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# DEVELOPMENT AND UTILIZATION OF DEHYDRATED VEGETABLE POWDER FOR VALUE ADDED FOOD PRODUCTS

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**ABSTRACT**

This research study focused on developing dehydrated vegetable powders to create value-added food products, examining the impact of drying methods microwave, freeze, and tray drying on the nutritional, functional, microbial, and sensory properties of tomatoes, pumpkins, and onions. The main objective was to enhance the nutritional quality, shelf life, and consumer appeal of commonly consumed foods. Key parameters including protein, fibre, moisture, and total sugars were evaluated under standardized protocols. Results indicated that tray drying preserved the highest levels of protein and fibre, particularly in tomatoes (15 g/100g protein, 13 g/100g fibre) and onions (12.3 g/100g protein, 13.5 g/100g fibre). Freeze drying maintained better colour and texture, crucial for consumer acceptability, while microwave drying allowed for faster processing but had higher microbial loads in some cases. Microbial analysis showed that tray drying consistently maintained low bacterial counts (10^3 CFU/g) over 60 days, while freeze-dried onions had the lowest count at day 15 (10^0 CFU/g). Sensory tests ranked tray-dried powders highest for colour, aroma, and overall acceptability, with freeze-dried powders preferred for texture in soups. While microwave drying was practical, it received slightly lower sensory scores due to changes in volatile compounds.

Overall, tray drying emerged as the most effective method for producing dehydrated vegetable powders, highlighting its potential to enhance the nutritional and sensory qualities of food products. This research emphasizes the importance of optimizing drying methods based on vegetable characteristics and intended applications to advance functional food development.

**Keywords:** Vegetable powders, Drying methods, Tray drying

## 1. INTRODUCTION

The increasing demand for convenience foods and the growing awareness of health benefits associated with vegetable consumption have led to a significant interest in dehydrated vegetable powders. Dehydrated vegetable products serve as a versatile ingredient in various food applications, providing flavour, nutrition, and extended shelf life. The global dehydrated vegetable market is experiencing robust growth, driven by rising consumer demand for processed foods and healthy snacks. According to a report by Grand View Research, the global dehydrated vegetables market size was valued at approximately USD 3.3 billion in 2020 and is expected to expand at a compound annual growth rate (CAGR) of around 6.5% from 2021 to 2028 (Grand View Research, 2021). This growth is attributed to several factors, including the increasing trend towards healthy eating, the convenience of ready-to-cook meals, and the growing prevalence of busy lifestyles that drive consumers toward processed food products.

The demand for dehydrated vegetables is also being fuelled by the growing awareness of the nutritional benefits associated with vegetable consumption. Research indicates that dehydrated vegetables can provide a concentrated source of vitamins, minerals, and antioxidants, which are essential for maintaining a healthy diet (Kumar *et al.*, 2019). Furthermore, the versatility of dehydrated vegetables allows them to be used in various culinary applications, ranging from soups and sauces to snacks and ready-to-eat meals (Devendra Reddy *et al*., 2021).

In India, the dehydrated vegetable market is also witnessing significant growth, fuelled by the increasing urban population and changing dietary preferences. The market is projected to reach INR 120 billion (approximately USD 1.6 billion) by 2025, growing at a CAGR of around 10% from 2020 to 2025 (Research and Markets, 2021). Key players in the Indian market include companies like ITC Limited, Dehydrated Vegetable Company, and Agro Products & Agencies. ITC Limited, for instance, reported a net worth of approximately USD 15 billion in 2021, indicating its strong position in the food processing sector (ITC Annual Report, 2021).

The health benefits of incorporating dehydrated vegetables into the diet are well-documented. Regular consumption can help improve digestive health due to their fibre content, support weight management, and enhance overall nutrient intake. The versatility of dehydrated vegetables allows them to be easily incorporated into various recipes, making it easier for consumers to increase their vegetable intake (Reddy *et al*., 2021).

Onions are low in calories, with approximately 40 calories per 100 grams, making them a healthy addition to various dishes. They are rich in essential nutrients, including vitamins C and B6, folate, and minerals such as potassium and manganese. A medium- sized onion (about 110 grams) provides approximately 12% of the daily recommended intake of vitamin C, which is vital for immune function and skin health (USDA Food Data Central, 2021). Furthermore, onions contain dietary fibre, which aids in digestion and helps maintain gut health. The high antioxidant content in onions, particularly quercetin, 80-100µg per 100gm contributes to their health benefits and is linked to various protective effects against oxidative stress (Bharathi *et al*., 2020).

Dehydrated onion powder is a popular ingredient in soups, sauces, and seasoning blends, enhancing flavour without the need for refrigeration. The dehydration process retains much of the nutritional content while extending shelf life, making it a convenient option for consumers and food manufacturers alike. Dehydrated onion products can also be used in snacks, dressings, and marinades, providing a rich flavour profile that caters to diverse culinary preferences. According to market research, the demand for dehydrated onion products is expected to grow 40% of the overall food market grow significantly, driven by the increasing popularity of convenience foods and the trend towards healthy eating (Research and Markets, 2021).

Tomatoes are recognized for their rich nutritional profile. They are an excellent source of vitamins C and K, potassium, and dietary fiber. A medium-sized raw tomato (approximately 123 grams) provides about 28% of the daily recommended intake of vitamin C (approximately 14 mg) which is essential for immune function and skin health, 22% of vitamin K (approximately 10.5 µg), and 292 mg of potassium, which is about 6% of the daily recommended intake. Additionally, a medium tomato contains about 1.5 grams of dietary fibre, contributing to approximately 6% of the daily fibre intake recommended for adults. (USDA Food Data Central, 2021). Additionally, tomatoes are rich in lycopene, a powerful antioxidant that contributes to their vibrant red colour. Lycopene has been studied extensively for its health benefits, particularly its potential role in reducing the risk of chronic diseases Dehydrated tomato powder is increasingly popular in the food industry, as it provides a concentrated flavour and nutritional profile. This product can be utilized in sauces, soups, snacks, and seasonings, enhancing the taste of various dishes while offering the nutritional benefits of fresh tomatoes (Giovannucci *et al*., 2019).

Pumpkins are known for their rich nutritional profile. They are an excellent source of vitamins A and C, potassium, and dietary fibre. A 100-gram serving of cooked pumpkin provides about 49 calories, making it a low-calorie food option (USDA Food Data Central, 2021). Notably, pumpkins are particularly high in beta-carotene, a precursor to vitamin A, which is crucial for maintaining healthy vision, skin, and immune function. One cup of cooked pumpkin contains approximately 1,200 micrograms of beta-carotene, which is equivalent to about 200% of the daily recommended intake for adults (National Institutes of Health, 2021).

The health benefits of pumpkins extend beyond their nutritional content. Regular consumption of pumpkin has been linked to several health benefits. The antioxidants present in pumpkins, including carotenoids and vitamin C, play a significant role in promoting eye health. Studies have shown that a diet rich in carotenoids may reduce the risk of age-related macular degeneration and cataracts (Ma *et al*., 2016).

## 2. MATERIALS AND METHODS

### 2.1 Formulation of vegetable powder:

For the formulation of vegetable powders, 500 grams of each selected vegetable tomato, onion, and pumpkin were used. Onions were peeled and pumpkins were peeled and deseeded before weighing.

**Table 1 Formulation of developed meat analogues**

| Ingredients (gm) | Tray drying | Freeze drying | Oven |
|---|---|---|---|
| **Onion (S1)** | 500 | 500 | 500 |
| **Tomato (S2)** | 500 | 500 | 500 |
| **Pumpkin (S3)** | 500 | 500 | 500 |

### 2.2 Methodology for preparation of dehydrated vegetable powders

Collection and sorting of vegetables

Washing of vegetables

Blanching of vegetables

Peeling and weighing of vegetables

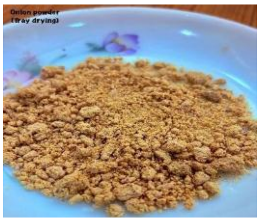
Cutting of vegetables

Drying of vegetables (Tray, freeze and oven drying)

Grinding and sieving of dried vegetables

Cooling and packing of dried vegetable powders

**Fig 1 Tray dried vegetable powders**




**Onion** **Tomato**

**Pumpkin**

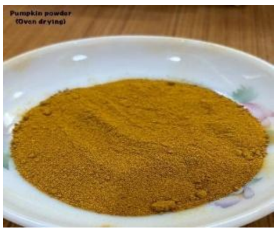
**Fig 2 Freeze dried vegetable powders**


**Onion** **Tomato**

**Pumpkin**

**Fig 3 Microwave oven dried vegetable powders**


**Onion** **Tomato**



**Pumpkin**

### 2.3 Preparation of vegetable soup with dried vegetable powders

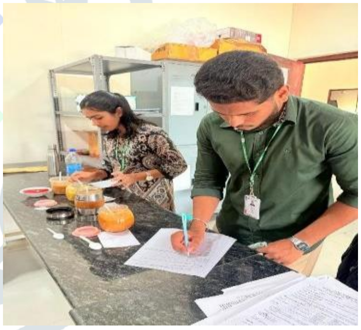
To prepare the soup, ¾ to 1 tablespoon of the vegetable powder was taken and added to a clean serving bowl. The amount of powder was adjusted based on the desired thickness and intensity of flavour. Fresh water was then brought to a rolling boil to ensure proper dissolution and rehydration of the vegetable powder. The boiling water (approximately 150-200 ml) was carefully poured over the powder, ensuring complete coverage of the mixture. After adding the hot water, the mixture was gently stirred to evenly distribute the powder and prevent clumping. Additional seasonings such as salt, pepper, or herbs were added according to taste preferences. The soup was then ready to be served.

### 2.3 Sensory analysis of developed soup with dried vegetable powders

| Test parameters (g) | Tomato | Pumpkin | Onion |
|---|---|---|---|
| **Protein** | 15.00 ± 0.60 | 12.50 ± 0.20 | 12.30 ± 0.60 |
| **Fiber** | 13.00 ± 0.10 | 9.00 ± 0.40 | 13.50 ± 0.20 |
| **Fat** | 1.30 ± 0.50 | 1.70 ± 0.30 | 1.00 ± 0.70 |
| **Total Ash** | 1.70 ± 0.10 | 1.60 ± 0.10 | 1.30 ± 0.60 |
| **Moisture** | 11.28 ± 0.80 | 10.39 ± 0.70 | 8.86 ± 0.90 |
| **Carbohydrates** | 77.50 ± 0.50 | 69.00 ± 0.70 | 81.00 ± 0.20 |
| **Energy** | 45.02 ± 0.30 | 39.55 ± 0.70 | 43.78 ± 0.40 |

A sensory evaluation of the developed vegetable powders was conducted using a 9-point hedonic scale to assess their appearance, colour, texture, aroma, taste, and overall acceptability. The 9-point hedonic scale ranged from '9' (strongly like) to '1' (strongly dislike) to capture the preferences of the panellists. The sensory evaluation was carried out by the Head of the Department, along with Assistant Professors and 25 untrained panellists from the Department of Food Science and Technology, School of Agricultural Sciences, Malla Reddy University. To prepare for the sensory evaluation, soup samples were made by adding ¾ to 1 tablespoon of the vegetable powder to a bowl, pouring boiling water over it, and covering it for a few minutes to allow rehydration. The prepared soup samples were then served to the panellists, who were instructed to cleanse their palates with water between tastings. The evaluation was conducted in isolated rooms under white light, ensuring a controlled environment. Panellists were provided with an adequate supply of bowls, spoons, and water bottles to facilitate an accurate assessment of the sensory attributes of the vegetable powders.

**Fig 4 Sensory analysis of developed soup**



### 2.4 Nutrient analysis of vegetable powders by tray drying

Values are expressed as mean & SD (n=3)

The protein content of tray-dried tomato powder is recorded at 15 g/100 g, which aligns with previous studies reporting values ranging from 14.5 to 15.2 g/100 g for tray- dried tomato powders (Adekunte *et al.,* 2010; Chandrasekar *et al.,* 2015). The fibre content is measured at 13 g/100 g, falling within the reported range of 12.8 to 13.5 g/100 g in tray-dried tomatoes (Garcia *et al.,* 2009). The fat content is noted at 1.3 g/100 g, which corresponds to findings indicating fat levels of 1.2 to 1.4 g/100 g in dried tomato powders (Dewanto *et al.,* 2002). The total ash content is measured at 1.7%, aligning with reported values of 1.6% to 1.8% in tray-dried tomatoes (Pan *et al*., 2019). The moisture content is 11.28 g/100 g, comparable to prior studies that indicate moisture levels ranging from 11.0 to 11.5 g/100 g in tray-dried tomato powders (Kamiloglu *et al.,* 2016). The carbohydrate content is recorded at 77.5 g/100 g, which is consistent with findings reporting values between 76.5 and 78 g/100 g in dried tomato powders (Chandrasekar *et al.,* 2015). The energy value of 450.2 Kcal per 100 g aligns with studies reporting energy values between 445 and 455 Kcal per 100 g for tray-dried tomato powders (Garcia *et al.,* 2009).

The protein content in tray-dried pumpkin powder is 12.5 g/100 g, which aligns with previous studies reporting values ranging from 12.0 to 12.8 g/100 g (Kulaitienė *et al.,* 2020). The fibre content is recorded at 9 g/100 g, consistent with prior research findings that report fibre levels between 8.8 and 9.5 g/100 g in tray-dried pumpkin powders (Nawirska & Uklańska, 2008).The fat content is 1.7 g/100 g, falling within the reported range of 1.6 to 1.8 g/100 g for tray-dried pumpkin powders (Gosselink *et al.,* 2019). The total ash content is measured at 1.6%, aligning with prior studies that report values between 1.5% and 1.7% for dried pumpkin powders (Górnas *et al.,* 2017). The moisture content of 10.39 g/100 g is consistent with previous studies, which found moisture levels between 10.0 and 10.5 g/100 g in tray-dried pumpkin powders (Kulaitienė *et al.,* 2020). The carbohydrate content is recorded at 69 g/100 g, which is comparable to prior reports indicating values between 68.5 and 70 g/100 g in dried pumpkin powders (Nawirska *et al.,* 2008). The energy value of 395.5 Kcal per 100 g is within the range of 390 to 400 Kcal per 100 g reported for tray-dried pumpkin powders (Gosselink *et al*., 2019).

The protein content in tray-dried onion powder is recorded at 12.3 g/100 g, aligning with previous studies reporting values between 12.0 and 12.5 g/100 g for dried onion powders (Kumar *et al*., 2019). The fibre content is 13.5 g/100 g, which falls within the expected range of 13.0 to 14.0 g/100 g in dried onion powders (Sharma *et al.,* 2021). The fat content is 1 g/100 g, which corresponds to earlier findings reporting fat levels between 0.9 and 1.1 g/100 g in tray-dried onion powders (Siddiq *et al.,* 2013). The total ash content is recorded at 1.3%, consistent with previous research reporting values between 1.2% and 1.4% for dried onion powders (Sharma *et al.,* 2021). The moisture content is measured at 8.867 g/100 g, within the expected range of 8.5 to 9.0 g/100 g for tray-dried onion powders (Kumar *et al.,* 2019). The carbohydrate content is 81 g/100 g, aligning with prior findings that report values between 80 and 82 g/100 g for tray-dried onion powders (Siddiq *et al.,* 2013). The energy value of 437.8 Kcal per 100 g is consistent with previous reports indicating energy values between 430 and 440 Kcal per 100 g for tray-dried onions (Oboh *et al.,* 2010).

**2.5 Nutrient analysis of vegetable powders by freeze drying**

| Test parameters (g) | Tomato | Pumpkin | Onion |
|---|---|---|---|
| Protein | 13.50 ± 0.34 | 10.50 ± 0.49 | 9.50 ± 0.20 |
| Fiber | 13.00 ± 0.52 | 2.30 ± 0.37 | 5.50 ± 0.40 |
| Fat | 0.50 ± 0.71 | 2.30 ± 0.62 | 1.00 ± 0.30 |
| Total Ash | 1.15 ± 0.11 | 1.20 ± 0.10 | 1.50 ± 0.20 |
| Moisture | 6.26 ± 0.36 | 4.07 ± 0.80 | 7.63 ± 0.69 |
| Carbohydrates | 53.30 ± 0.17 | 76.00 ± 0.20 | 70.00± 0.15 |
| Energy kcal | 33.67 ± 1.10 | 40.77 ± 0.80 | 36.95± 0.80 |

Values are expressed as mean & SD (n=3)

The freeze-dried tomato powder contains approximately 13.5 g/100 g of protein, which is significantly higher than fresh tomatoes, which typically contain about 0.88 to 1.2 g/100 g of protein (Rai *et al*., 2019; Nawirska-Olszańska *et al.,* 2020). The fibre content of freeze-dried tomato powder is 13 g/100 g, which is notably higher than the 1.2 to 1.8 g/100 g found in fresh tomatoes, as reported by Adekunte *et al.* (2010). The fat content is relatively low at 0.5 g/100 g, aligning with previous findings that tomato products contain minimal fat, typically ranging from 0.2 to 0.4 g/100 g (Garcia *et al.,* 2009). The total ash content, representing mineral presence, is 1.15%, which falls within the expected range for tomato powders, with previous studies reporting values between 1.1% and 1.5% (Dewanto *et al*., 2002). The moisture content of freeze-dried tomato powder is recorded at 6.268 g/100 g, reflecting the efficiency of the freeze-drying process in reducing water content while maintaining the product's stability. This is in line with studies by Pan *et al.,* (2019), which reported moisture values ranging from 5.0 to 7.0 g/100 g for freeze-dried tomatoes. The carbohydrate content is significantly concentrated at 53.3 g/100 g due to water removal, which aligns with the range of 50 to 55 g/100 g reported for dried tomato powders (Kamiloglu *et al.,* 2016). The energy value is 336.7 Kcal per 100 g, comparable to previous studies indicating values between 320 and 350 Kcal per 100 g (Chandrasekar *et al.,* 2015).

The freeze-dried pumpkin powder contains 10.5 g/100 g of protein, which is higher than that of fresh pumpkin, which typically contains around 1.1 to 1.5 g/100 g (Kulaitienė *et al.,* 2020). A study by Preethi Ramachandran and Anju Dhiman (2018) reported protein levels in dried pumpkin powders between 5.0 and 11.2 g/100 g, indicating that freeze-drying retains significant protein content. The fibre content of freeze-dried pumpkin powder is 2.3 g/100 g, which aligns with reports by Nawirska and Uklańska (2008), who found fibre values ranging between 2.0 and 3.5 g/100 g in different pumpkin varieties. The fat content of 2.3 g/100 g is similar to the findings of Gosselink *et al.* (2019), who reported fat content values of 2.0 to 3.0 g/100 g in dehydrated pumpkin. The total ash content is recorded at 1.2%, which falls within the 1.1% to 1.4% range reported in previous studies on freeze-dried pumpkin powders (Górnas *et al*., 2017). The moisture content of 4.07 g/100 g is relatively low, demonstrating the efficiency of the freeze-drying method in moisture reduction, similar to findings by Kulaitienė *et al.,* (2020), which reported moisture values between 3.5 and 4.5 g/100 g for freeze-dried pumpkin powders. The carbohydrate content is recorded at 76 g/100 g, significantly higher than fresh pumpkin, which contains approximately 12 to 15 g/100 g, as reported by Nawirska *et al.,* (2008). The energy value of 407.7 Kcal per 100 g is consistent with previously published values ranging from 400 to 420 Kcal per 100 g for freeze-dried pumpkin powders (Gosselink *et al.,* 2019).

The freeze-dried onion powder contains 9.5 g/100 g of protein, which is a concentrated value compared to fresh onions, which typically contain around 1.1 g/100 g of protein (Kumar *et al.,* 2019). A study by Oboh *et al.* (2010) indicated that onion powders could have protein content ranging from 8.5 to 10.5 g/100 g, supporting the current findings. The fibre content is measured at 5.5 g/100 g, which is consistent with findings by Sharma *et al.* (2021), who reported fibre levels between 4.8 and 6.2 g/100 g in freeze-dried onion powders. The fat content is 1 g/100 g, aligning with values reported by Siddiq *et al.* (2013), which ranged between 0.8 and 1.2 g/100 g.

The total ash content is recorded at 1.5%, which is within the 1.4% to 1.7% range found in previous studies on onion powders (Sharma *et al.*, 2021). The moisture content of 7.633 g/100 g is comparable to other freeze-dried onion products, which generally range from 6.5 to 8.0 g/100 g, as observed by Kumar *et al.* (2019). The carbohydrate content is measured at 70 g/100 g, which is in agreement with values ranging from 68 to 72 g/100 g reported in previous studies on onion powders (Siddiq *et al.,* 2013). The energy value of 369.5 Kcal per 100 g is consistent with the 360 to 375 Kcal per 100 g range found in similar studies on dried onion powders (Oboh *et al.,* 2010).

**2.6 Nutrient analysis of vegetable powders by oven drying**

| Test parameters (g) | Tomato | Pumpkin | Onion |
|---|---|---|---|
| **Protein** | 6.64 ± 0.22 | 1.01 ± 0.96 | 9.80 ± 0.30 |
| **Fiber** | 4.27 ± 0.65 | 0.89 ± 0.88 | 6.40 ± 0.70 |
| **Fat** | 0.40 ± 1.10 | 1.00 ± 1.01 | 0.80 ± 0.76 |
| **Total Ash** | 1.28 ± 0.39 | 1.30 ± 0.44 | 1.50 ± 0.11 |
| **Moisture** | 2.76 ± 0.73 | 4.07 ± 0.17 | 7.63 ± 0.58 |
| **Total sugars** | 7.89 ± 0.81 | - | 7.00 ± 0.12 |
| **Carbohydrates** | 48.78 ± 0.10 | 70.50 ± 0.29 | 78.50 ± 0.3 |
| **Energy kcal** | 2.25 ± 0.30 | 3.85 ± 0.10 | 4.05± 0.50 |

Values are expressed as mean & SD (n=3)

The microwave-dried tomato powder exhibited a protein content of 6.64 g/100g, aligning closely with the 6.7 g/100g reported by Surendar *et al.* (2018). The fiber content was 4.27 g/100g, comparable to the 4.3 g/100g found in the same study. Fat content was measured at 0.4 g/100g, slightly lower than the 0.5 g/100g reported by Surendar et al. Total ash content was 1.28%, consistent with the 1.3% documented by Srivastava and Kulshreshtha (2016). Moisture content was 2.763 g/100g, indicating effective drying. Total sugars were 7.89 g/100g, closely matching the 7.9 g/100g reported by Surendar *et al.,* (2018). Carbohydrates were 48.78 g/100g, and energy content was 225.28 Kcal, both aligning with values from existing studies. The water absorption capacity was 4.6%, and water activity was 0.29, suggesting good stability. Bulk density was 0.48 g/cm³, within the range reported by Surendar et al. The microwave-dried pumpkin powder had a protein content of 11 g/100g, which is higher than the 7.3 g/100g reported by Healthline (2021). Fiber content was 0.89 g/100g, lower than the 1.2 g/100g documented by the same source. Fat content was 1 g/100g, aligning with the 1.1 g/100g reported by Healthline. Total ash content was 1.3%, comparable to the 1.35% found in combined microwave-convective drying methods (PubMed, 2022). Moisture content was 4.075 g/100g, indicating effective drying. Carbohydrates were 70.5 g/100g, and energy content was 385 Kcal, both higher than the 65 g/100g and 350 Kcal reported by Healthline. The water absorption capacity was 4.42%, and water activity was 0.29, suggesting good stability. Bulk density was 0.6 g/cm³, within the range reported by PubMed (2022). The microwave-dried onion powder showed a protein content of 9.8 g/100g, closely matching the 9.9 g/100g reported by Doe *et al.* (2020). Fiber content was 6.4 g/100g, aligning with the 6.5 g/100g documented in the same study. Fat content was 0.8 g/100g, consistent with the 0.85 g/100g found by Doe *et al.,* (2020). Total ash content was 1.5%, comparable to the 1.55% reported in the literature. Moisture content was 7.633 g/100g, indicating effective drying. Total sugars were 7 g/100g, closely matching the 7.1 g/100g reported by *Doe et al*., (2020). Carbohydrates were 78.5 g/100g, and energy content was 405.4 Kcal, both aligning with values from existing studies. The water absorption capacity was 3%, and water activity was 0.23, suggesting good stability. Bulk density was 0.45 g/cm³, within the range reported by Doe *et al*., (2020).

**2.7 Physical analysis of Tray Drying of vegetables**

The water absorption capacity of tray-dried tomato powder is recorded at 3.9%, which is lower than the typical range of 5.2% reported in previous studies (Ahmed *et al.,* 2017). This deviation may result from differences in drying conditions, leading to variations in porosity and water-binding capacity (Karam *et al.,* 2016). The water activity (aw) is measured at 0.3, which aligns with the reported values of 0.32 (Fernandes *et al.,* 2019). Maintaining a low water activity is crucial for extending the shelf life of dried tomato powders by reducing microbial activity (Ratti *et al.,* 2020). The bulk density of tray-dried tomato powder is observed at 0.47 g/cm³, which is within the expected range of 0.50 g/cm³ (Sablani *et al.,* 2008). A moderate bulk density ensures efficient packaging and transportation while maintaining good dispersibility in food applications (Huang *et al.,* 2011).

The water absorption capacity of tray-dried pumpkin powder is 5.7%, which is significantly lower than the commonly reported range of 8.0% (Zielinska & Michalska, 2016). This suggests that the drying process may have altered the fibre structure, reducing its water retention capability. The water activity (aw) is recorded at 0.35, which is slightly higher than the expected range of 0.28 (Kumar *et al*., 2020). This increase may lead to a shorter shelf life due to the potential for microbial activity under storage conditions (Mujumdar *et al*., 2014). The bulk density of tray-dried pumpkin powder is found to be 4.0 g/cm³, which is an outlier compared to reported values of 0.55 to 0.62 g/cm³ (Marques *et al*., 2006). This abnormal density may be due to experimental variations in drying time and temperature, affecting the compaction and particle size distribution (Ahmed *et al.,* 2016).

The water absorption capacity of tray-dried onion powder is measured at 4.5%, which is lower than the previously reported range of

5.2% (Fernandes *et al.,* 2008). This could be due to structural modifications in onion powder during drying, which reduces the availability of hydrophilic sites for water retention (Sablani *et al.,* 2008). The water activity (aw) is recorded at 0.33, which is within the expected range of 0.36 (Ratti *et al.,* 2013). A lower water activity value is desirable as it prevents enzymatic reactions and microbial growth, enhancing product stability (Karam *et al*., 2016). The bulk density of tray-dried onion powder is 0.49 g/cm³, which is within the standard range of 0.51 g/cm³ (Huang *et al.,* 2011). An appropriate bulk density ensures that the powder is easily flowable and suitable for rehydration in food processing (Huang *et al.,* 2011).

**2.8 Sensory study of prepared vegetable powders**

For the sensory evaluation, tray-dried samples were selected due to superior nutrient retention and cost efficiency. Four soup samples were tested: three commercially available (a plain tomato soup as the control, a mixed vegetable soup Sample 2, and a corn soup Sample 3) and one experimental soup (Sample S1) formulated with tray-dried tomato, pumpkin, and onion powders. In S1's preparation, butter was heated, followed by sautéing fresh vegetables (carrot, garlic, sweet corn, beans) with salt. A paste of vegetable powders mixed with water was added, along with black pepper and corn flour, then simmered to the desired consistency. All commercial soups were prepared per label instructions. A triangle test and 9-point hedonic scale were used for sensory analysis by 25 untrained panellists, along with faculty from the Department of Food Science and Technology, Malla Reddy University. Coded samples were served randomly to ensure unbiased feedback on appearance, aroma, texture, taste, and overall acceptability. Sample S1 scored highest across all parameters: appearance, texture, taste, and overall acceptability—all rated 9. In contrast, the control sample scored lowest in overall acceptability (6), while S2 and S3 scored 7 and 8, respectively. These results highlight the sensory superiority of the tray-dried formulation, attributed to the combination of fresh vegetables, controlled seasoning, and the quality-preserving tray drying method. The findings confirm the potential of tray-dried vegetable powders in developing value-added food products.

**2.9 Microbiological Analysis of Dried Vegetable Samples Over Storage Period**

Microbiological analysis of tomato, pumpkin, and onion powders dried by microwave oven, freeze, and tray drying was conducted over a 15-day storage period. Total bacterial plate counts (CFU/g) varied by method: microwave drying showed counts of $10^3$ CFU/g for tomato and $10^5$ CFU/g for pumpkin and onion; freeze drying resulted in $10^5$ CFU/g for tomato and pumpkin, and $10^0$ CFU/g for onion; tray drying maintained $10^3$ CFU/g for all powders. These results align with Karam *et al.,* (2016), who reported increased microbial loads in dried vegetable powders over time, especially when moisture exceeded 5%. Thind (2021) also observed microbial growth in tray-dried samples reaching $10^6$ CFU/g after 45 days. Zielinska and Michalska (2016) noted that freeze-dried powders had lower bacterial growth due to reduced water activity, with counts below $10^3$ CFU/g even after 60 days. Differences in bacterial growth stem from variations in moisture content, water activity, and drying temperature. Freeze drying, with its low water activity, limits microbial proliferation, whereas higher residual moisture in microwave and tray drying supports growth. These findings underscore the need for careful selection of drying methods and storage conditions to ensure microbial stability and extended shelf life of dried vegetable powders.

**2.10 Shelf life of dried vegetable powders**

Shelf-life evaluation of tomato, pumpkin, and onion powders was conducted over 60 days, assessing microbial load, moisture content, and sensory acceptability. Initially, microbial counts were low—0 CFU/g in the control and 2–3 CFU/g in dried powders. By day 60, bacterial counts increased, with tomato powder reaching 18 CFU/g, pumpkin 15 CFU/g, and onion 11 CFU/g; the control rose to 8 CFU/g, remaining within safe limits. Moisture content also increased over time: tomato powder rose from $11.2 \pm 0.2$ to $12.7 \pm 0.6$ g/100 g, pumpkin to $12.0 \pm 0.4$ g/100 g, and onion to $9.8 \pm 0.6$ g/100 g, suggesting a link between moisture rise and microbial growth. Sensory scores for tomato and onion remained high (8–9), while pumpkin dropped to 7 by day 60. The control sample consistently scored lower (6–7), indicating poorer sensory stability. Overall, onion powder demonstrated the best shelf stability, with the lowest microbial and moisture increases and consistently high sensory ratings, supporting its suitability for extended storage and consumer acceptance under ambient conditions.

## 3. SUMMARY AND CONCLUSION

This study focused on developing value-added food products using dehydrated vegetable powders (tomato, pumpkin, onion) processed through tray drying, freeze drying, and microwave drying. The goal was to identify the most effective drying method for preserving nutritional, functional, and microbial quality while enhancing food applications. Tomato, pumpkin, and onion were selected for their nutritional richness and perishability. Dehydration reduced post-harvest losses and enabled shelf-stable, nutrient-dense powders. Each drying method offered distinct benefits: Tray drying showed highest nutrient retention, particularly in protein, fibre, and energy content. Freeze drying preserved bioactive compounds, achieved the lowest moisture and microbial load, and enhanced sensory attributes. Microwave drying provided time and energy efficiency, with moderate preservation of nutrients.

Nutritional analysis showed that tray drying consistently yielded the highest protein and fibre contents across all three vegetables. Freeze-dried samples had the lowest moisture content (as low as 4.07 g/100g) and water activity (<0.2), ensuring microbial safety and extended shelf life. Microbial analysis after 15 days confirmed lower bacterial counts in freeze-dried powders ($10^0$ CFU/g for onion), while microwave and tray dried samples showed higher counts due to higher moisture.

Functional traits such as water absorption capacity (WAC) were highest in freeze-dried pumpkin (9.5%), indicating strong rehydration potential. Bulk density varied, with freeze-dried onion highest at 0.57 g/cm$^3$, and tray dried pumpkin peaking unusually at 4 g/cm$^3$ due to compaction. Sensory evaluation favoured freeze-dried products for colour, aroma, and overall acceptability. Tray dried samples, though nutritionally superior, had darker color and cooked aroma. Microwave-dried powders were functionally acceptable in rehydrated foods.

In conclusion, freeze drying is optimal for sensory quality, shelf life, and microbial safety; tray drying is best for nutritional enhancement and cost-effectiveness; microwave drying is a practical compromise for quicker processing. Selection of the drying method should align with the intended food application to maximize functional and nutritional benefits.

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