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Standardization of different drying methods and packaging materials for processing of onion (*Allium cepa* L.) into powder

Shahista Parveen, Jameel Jhalegar, Deepa Terdal, Noorulla Haveri and Ambresh

Abstract
Onion is a commercial crop of our country, belongs to the family Alliaceae. It is used for both internal consumption and foreign exchange. The more pungent varieties of onion appear to possess the greatest concentration of health promoting phytochemicals *i.e.* phenolics and flavonoids that have potential anti-inflammatory, anti-cholesterol, anti-cancer and antioxidant properties which protect against stomach and different types of cancers, improve lung function, especially in asthmatics. Besides this, it is a delicate commodity to store because of higher water content and serious losses occurring due to rotting, sprouting, physiological loss in weight and moisture evaporation. So an experiment was conducted entitled with studies on "standardization of different drying methods and packaging materials for processing of onion (*Allium cepa* L.) into powder" was conducted in the Department of Post Harvest Technology, COH, Bagalkote, Karnataka during the year 2020-21. In the experiment, onion powder showed significantly minimum moisture percentage (4.92 %), water activity (0.21), bulk density (0.36 g/cm^3), tapped density (0.47 g/mL), hygroscopicity (25.04 %), hausner ratio (0.86) and particle size (417.5 µm) also the maximum rehydration ratio (5.05), water soluble index (80.79), powder recovery (11.30%), and particle density (2.45 g/mL) were found in freeze drying (T_4) respectively. Besides it also retained maximum content of minerals (Ca, Mg, S, K, Fe, Mn, Cu and Zn) was seen in freeze drying (SCANVAC®).

Keywords: Onion, drying methods, Physico-chemical, solar tunnel, freeze drying

Introduction
Onion (*Allium cepa* L. 2n = 2x = 16) powder is an important value-added product. Hence it is widely used in traditional cooking and culinary preparations. The dehydrated onion powder is commonly used as ingredient or as a flavor additive in several food products such as soups, snacks, sauces, frozen foods, retorted products, salad dressings, meat products, pickles, pickles relishes (Arslan and Ozcan, 2010) [6]. In addition, it also offers great convenience for storage as it is characterized by reduced volume which in turn offers ease for preservation, handling, transportation and storage (Majid and Nanda, 2017) [31].

Different drying methods were used for onion drying to affect the final quality of the product. In onion drying, major quality problems are the loss of characteristic color and flavor. Drying also causes undesirable browning reactions that are responsible for decreasing nutrient value, degrading color, and flavor. In this regard, different drying methods such as Solar tunnel dryer, Fruit and vegetable dryer (CAZRI, Jodhpur), Tray dryer (EZIDRI®), Freeze dryer (SCANVAC®) and sun drying were examined in the present investigation for producing quality onion powder.

The present study was conducted to find out the best drying method for processing of onion powder and on the other hand, the demand for processed products increased owing to the popularization and other promotional activities by academic and research institutes, creating interest among the people across the country. Because of this, there is an need for technological intervention for developing a suitable technology that would meet the needs of the consumers to make product available to people in the off season as well as when the prices have raised and to generate higher returns for growers.

Material and Methods
The present investigation entitled "Standardization of different drying methods and packaging

materials for processing of onion (*Allium cepa* L.) into powder" was carried out during December 2020 to august 2021 in the Department of Post Harvest Technology, College of Horticulture, Bagalkote, Karnataka. The experiment was conducted in Completely Randomized design with five treatments and four replications.

Materials used in the experiment

Raw material: Onion Red colored onion (Variety Sitara Gaurav) of medium sized (50-100g weight) was purchased from farmer field and the experiment was carried out in the Department of Post Harvest Technology, College of Horticulture, Bagalkote.

Preparation of onion

The fresh onions of uniform color, shape and medium size were selected, root and stem ends were removed and then the skin was peeled manually using a sharp knife. Peeled onions were further cut into slices (6 mm × 6 mm) by using an onion slicer. Prepared onions (slices) were pretreated in solutions of sodium bisulfite ($NaHSO_3$) (1%) for 10 minutes as prescribed for a specified period. Then they were drained and taken for dehydration in a solar tunnel dryer, fruit and vegetable dryer (CAZRI, Jodhpur), tray dryer (EZIDRI®), freeze dryer (SCANVAC®) and also in sun drying with four replications the design followed is Completely Randomized Design each of sample of size 2 Kg/ treatment.

Quality analysis of the material

The onion powder was analyzed for the Moisture (%), Water activity (a_w), Rehydration ratio (RR), Water soluble index, Powder recovery (%), Time taken for drying (h), Bulk density (g/cm^3), Tapped density (g/mL), Hygroscopicity (%), Hausner ratio (HR), Particle density (g/mL), Particle size (μm), and minerals like Ca, Mg, S, K, Fe, Mn, Cu, and Zn (mg/kg).

Moisture content (%)

The moisture content of dehydrated onion was estimated using a Radwag moisture analyzer (Model: MAC 50, Make Poland). Two grams of dried sample was placed in the sample dish. The moisture analyzer indicated the endpoint of measurement by a beep sound and the resultant constant value for moisture was recorded.

Water activity (a_w)

The water activity of dried onion was determined by a water activity meter (Labswift-a_w Novasina). Small pieces of the sample was filled into sample holder up to the mark indicated and then placed inside the water activity meter, so that the sample wouldn't touch the sensor present in the lid. The endpoint was indicated by three beep sounds and the instrument gives constant value for water activity.

Rehydration ratio (RR)

Five grams of the dehydrated onion powder is placed in a beaker and 50 ml distilled water was added to the beaker at room temperature (Sacilik *et al.*, 2006) [41]. The weight of the rehydrating sample was measured at 0.5, 1, 2, 3, 4 and 5 hours until the sample attain a constant weight. Then, rehydrated material was drained, blotted with filter paper and weighed. If the weight of the rehydrated sample was 'a' and the dehydrated sample was 'b' then, the rehydration ratio was calculated as below

$$\text{Rehydration ratio} = \frac{A}{B}$$

Water soluble index

Two and a half grams of powder and 30 ml distilled water were vigorously mixed in a 50 ml centrifuge tube. The mixture was incubated in a water bath at 30 °C for 30 min and centrifuged at 3000x for 15 min. The supernatant was collected in a pre-weighed petri dish and the residue was weighed after oven drying at 105 °C overnight (Cano-Chauca *et al.*, 2005)[10]. The number of solids in the dried supernatant as a percentage of the total dry solid pellet remaining after centrifugation was divided by the amount of dry sample.

$$\text{WSI} = \frac{(\text{Weight of the container} + \text{Dried supernatant}) - (\text{Weight of the container})}{\text{Sample dry weight}}$$

Powder recovery (%)

Calculated using a weight of onion powder before subjecting to driers and weight of final powder and multiply it by hundred to get a percentage value Tonon *et al*. (2008) [50].

$$\text{Recovery (\%)} = \frac{\text{Weight of powder}}{\text{Weight of initial powder}} \times 100$$

Time taken for drying (h)

The time required for drying onion to the safe moisture level of 4-7 per cent moisture was obtained by recording the time at which samples were kept for drying and the time at which they were taken out (Pooja, 2018) [37].

Bulk density (g/cm^3)

Bulk density of the sample was measured by using a 100 ml graduated cylinder was weighed and recorded as W_1, 2 g of sample was put into cylinder tapped hermetically to eliminate air space between the flour, the volume was noted and new mass was recorded as W_2. Bulk density was computed as follows method by Seifu *et al.* (2018) [44].

$$\text{Bulk density (g/cm}^3) = \frac{\text{Mass of the sample } (W_2\text{-}W_1)}{\text{Volume of the cylinder}} \times 100$$

Tapped density (g/mL)

Two grams of onion powder into an empty 10 mL graduated cylinder was tapped by hand on a bench 100 times from a height of 10 cm and calculated by dividing the mass of the powder by volume occupied by the sample Tonon *et al.* (2008) [50].

Hygroscopicity (%)

Hygroscopicity was determined based on the method described by Cai and Corke (2000) with modifications. A total of 1 g of sample was placed in a container at 25 °C with saturated NaCl solution (75.29% relative humidity). Samples were weighed after one week and hygroscopicity was expressed as a gram of adsorbed moisture per 100 grams of dry matter.

Hausner ratio (HR): The flow rate of the powder indicated by hausner ratio expressed as the tap density divided by the bulk density is used to indicate the flowability of granular powder in a wide variety of industries (Shi *et al*., 2013) [46].

$$HR = \frac{\rho\ tap}{\rho\ b} \times 100$$

Particle density (g/mL)
The particle density was measured using the method suggested by Jinapong *et al.* (2008) [24]. One gram of dried powder sample was transferred into a 10 ml measuring cylinder with a glass stopper. A total of 5 ml of petroleum ether was then added to this sample and shaken for some time so that all the particles are suspended. Finally, the wall of the cylinder is rinsed with 1 ml of petroleum ether and the total volume of petroleum ether and suspended particles value was recorded. The particle density was calculated as follows

$$\text{Particle density (g/mL)} = \frac{\text{Weight of the powder}}{\text{Total volume of petroleum ether and suspended particles (ml) - 6}}$$

Particle size (µm)
The particle sizes were determined according to the sieving method described by Waiss *et al.* (2020) [55] with some modifications. In brief, 10 g onion powders were poured onto the upper sieve of a series mounted vertically in decreasing order of meshes (1,200, 800, 400, 200 µm. Standard sieves set is selected (sieve no: 10, 22, 36, 44, 65, 80, 100,120) arrange them in such manner that the coarsest remains at the top and finest at the bottom of the mesh.

Calcium and Magnesium (mg/kg)
The calcium and magnesium content in dried onion powder was estimated by complexometric titration method. Calcium plus magnesium (Ca + Mg) was determined by EDTA titration at pH 10.00 using buffer complex in presence of Patons and Reader indicator (Jakson, 1973) [21].

Sulphur (mg/kg)
The sulphur content in dried onion powder was estimated by a turbidometric method. The di-acid digested sample of onion powder was fed to the spectrophotometer by adding 1 ml acid seed solution and barium chloride powder and making up the volume to 50 ml by using distilled water. The absorbance of the sample was measured at 420 nm. The reading was used along with the standard curve to estimate sulphur content (Piper, 1996) [36].

Potassium (mg/kg)
The di-acid digested samples of dried onion were fed to a flame photometer directly with proper dilution if it is required. The reading was used along with the standard curve to estimate potassium content (Piper, 1996) [36].

Micro nutrients (mg/kg): (Cu, Fe, Zn and Mn)
The digested samples were directly fed into MP-AES (Microwave Plasma Atomic Emission Spectrophotometer) and the intensity of emission for a particular nutrient was measured by referring to a respective standard curve of micronutrients (Lindsay and Norvell, 1978) [29].

Results and Discussion
Moisture (%)
There was a significant difference found among the treatments with respect to moisture percentage of processed onion powder was presented in table1. The mean moisture per cent was found to be 5.57%. A significantly lower moisture per cent was recorded in T_4 (4.92%), followed by T_3 (5.20%) and T_1 (5.29%) whereas, higher moisture per cent was recorded in T_5 (6.32%) which was on par with T_2 (6.11%).

Water activity (a_w)
Table 1 depicts the data pertaining to the water activity of processed onion powder. There was a significant difference was found among the treatments with respect to water activity. The mean water activity was found to be 0.28. A significantly minimum water activity was observed in T_4 (0.21) (FD SCANVAC®) followed by T_3 (0.25) and T_1 (0.29), whereas maximum water activity was observed in T_2 (0.32) followed by T_5 (0.34) (SD).

Rehydration ratio (RR)
The data pertaining to the rehydration ratio was found significant difference among the treatments was depicted in table 1. The mean rehydration ratio was found to be 3.83. Significantly maximum rehydration ratio was observed in T_4 (5.05) followed by T_3 (4.36) and T_2 (3.36), on the other hand, the lowest rehydration ratio was observed in T_1 (3.16) followed by T_5 (3.23).

Water soluble index
The data illustrate that there was a significant difference among the treatments was presented in table 1 as influenced by different drying methods. The mean water soluble index was found to be 60.54. A significantly maximum water solubility index was observed in T_4 (80.79) (FD SCANVAC®) which was on par with T_3 (74.75) and T_1 (70.59) on the contrary minimum water solubility index was observed in T_5 (25.95) followed by T_2 (50.48).

Powder recovery (%)
The results showed there was significant difference among the drying methods concerning powder recovery percentage of processed onion powder was presented in table 1. Significantly highest recovery percentage was recorded in T_4 (11.30%) followed by T_3 (8.14%) and T_1 (7.35%), while minimum recovery percentage was recorded in T_2 (7.15%) followed by T_5 (7.31%).

Time taken for drying (h)
Table 1 depicts the time taken for drying of processed onion powder. There was a significant difference was found among the different treatments. The mean time taken for drying of processed onion powder found to be 55.20 h. Significantly lowest drying time was recorded in T_1 (10.87 h) followed by T_3 (32.57 h) and T_2 (36.68 h) and significantly highest drying time was recorded in T_5 (122.99 h) followed by T_4 (72.88 h).

Table 1: Effect of different drying methods on moisture percentage, water activity, rehydration ratio, water soluble index, powder recovery and drying time of onion powder under ambient conditions (28±1°C and 43±1% RH)

Treatment details	Moisture (%)	Water activity (a_w)	Rehydration ratio (RR)	Water soluble index	Powder recovery (%)	Drying time (h)
T_1	5.29	0.29	3.16	70.59	7.35	10.87
T_2	6.11	0.32	3.36	50.48	7.15	36.68
T_3	5.20	0.25	4.36	74.75	8.14	32.57
T_4	4.92	0.21	5.05	80.79	11.3	72.88
T_5	6.32	0.34	3.23	25.95	7.31	122.99
Mean	5.57	0.28	3.83	60.54	8.26	55.20
S.Em ±	0.16	0.01	0.02	1.48	0.22	0.79
CD at 1%	0.67	0.04	0.11	6.20	0.95	3.29

Bulk density (g/cm^3)

The bulk density of processed onion powder showed a significant difference between the independent drying methods was presented in table 2. The mean bulk density was 0.56 g/cm^3. Significantly higher bulk density was recorded in T_5 (0.76 g/cm^3) which was on par with T_2 (0.66 g/cm^3) and T_1 (0.56 g/cm^3). On the contrary statistically minimal lower bulk density was perceived in T_4 (0.36 g/cm^3) (FD) followed by T_3 (0.47 g/cm^3).

Tapped density (g/mL)

Table 2 depicts the tapped density of processed onion powder as influenced by different drying methods of processed onion powder. The mean tapped density was found to be 0.66 g/mL. Significantly minimum tapped density value was observed in T_4 (0.47 g/mL) followed by T_3 (0.58 g/mL) and T_1 (0.62 g/mL), whereas as maximum tapped density was observed in T_5 (0.86 g/mL) followed by T_2 (0.77 g/mL) treatment.

Hygroscopicity (%): The data with respect tohygroscopicity per cent of processed onion powder as influenced by distinct drying methods are presented in table 2. The mean hygroscopicity per cent of processed onion powder was 42.83%. Statistically, the maximum hygroscopicity per cent was noticed in T_5 (65.15%) (SD) followed by T_2 (52.49%) on the other hand, minimum hygroscopicity per cent was in T_4 (25.04%) (FD SCANVAC®) followed by T_3 (32.18%) and T_1 (40.71%).

Hausner ratio (HR): The data in table 2 illustrates that hausner ratio in processed onion powder was influenced by discrete drying methods. The mean hausner ratio was found to be 1.22. The minimum hausner ratio was identified in T_4 (0.86) which was on par with T_3 (1.05) followed by T_1 (1.09), the other hand statistically maximum hausner ratio was identified in T_5 (1.66) (SD) followed by T_2 (1.45).

Particle density (g/mL): The data showed that with respect to particle density of powder in prepared dehydrated onion powder was significantly influenced by different drying methods presented in table 2. Statistically maximum PD was observed in T_4 (2.45 g/mL) (FD) followed by T_3 (1.50 g/mL) and T_1 (1.27 g/mL), while on the contrary minimum PD was observed in T_5 (0.90 g/mL) followed by T_2 (0.95 g/mL).

Particle size (µm): The results indicate that particle size of processed onion powder showed significantly different as influenced by discrete drying methods in table 2. The maximum significantly difference was observed in T_5 (1209 µm) followed by T_2 (1006 µm) and T_1 (793 µm). However, statistically, minimum difference was identified in T_4 (417 µm) followed by T_3 (624 µm) method.

Table 2: Influence of different drying methods on bulk density, tapped density hygroscopicity, hausner ratio, particle density and particle size of onion powder under ambient conditions (28±1°C and 43±1% RH)

Treatment details	Bulk density (g/cm^3)	Tapped density (g/mL)	Hygroscopicity (%)	Hausner ratio (HR)	Particle density (g/mL)	Particle size (µm)
T_1	0.56	0.62	40.71	1.09	1.27	793
T_2	0.66	0.77	52.49	1.45	0.95	1006
T_3	0.47	0.58	32.18	1.05	1.50	624
T_4	0.36	0.47	25.04	0.86	2.45	417
T_5	0.76	0.86	65.15	1.66	0.90	1209
Mean	0.56	0.66	42.83	1.22	1.41	810.05
S.Em ±	0.03	0.01	0.94	0.03	0.04	10.28
CD at 1%	0.01	0.04	3.91	0.14	0.17	42.84

Minerals (Ca, Mg, S, K, Fe, Mn, Cu and Zn)

Calcium (mg/kg)

The observations concerning the calcium content of prepared dehydrated onion powder were significantly influenced by different drying methods in table 3. Analytically maximum content of calcium was present in treatment T_4 (1138.70 mg/kg) (FD) followed by T_3 (944.20 mg/kg), however minimum content of calcium was present in treatment T_5 (642.70 mg/kg) followed by T_1 (784.70 mg/kg) and T_2 (822.70 mg/kg).

Magnesium (mg/kg)

The considerations with respect to magnesium content of processed onion powder were significantly different by separate drying methods in table 3. Markedly highest content of magnesium was obtained in T_4 (1352.00 mg/kg) treatment followed by T_3 (1114.00 mg/kg) on the other side, lowest content of magnesium was obtained in T_5 (764.50 mg/kg) treatment succeed by T_1 (852.75 mg/kg) and T_2 (970.00 mg/kg).

Sulphur (mg/kg)

The data in table 3 reproduces the content of processed onion powder as influenced by individual drying methods. The observation in the sulphur content of prepared onion powder was significantly different with individual treatments. The maximum content was observed in T_4 (317.60 mg/kg) and T_3 (304.90 mg/kg) whereas, minimum content was obtained in T_5 (137.10 mg/kg) (SD) followed by T_1 (155.50 mg/kg) and T_2 (175.30 mg/kg).

Potassium (mg/kg)

The statement regarding the potassium content of processed onion powder was declared as significantly different from each other treatments is presented in table 3. Statistically, the maximum potassium was reported in T_4 (2729.50 mg/kg) followed by T_3 (2680.70 mg/kg) in contrast, a minimum total was found in T_5 (2491.20 mg/kg) followed by T_1 (2581.20 mg/kg) and T_2 (2639.70 mg/kg).

Iron (mg/kg)

The data illustrates in table 3 that the iron content of processed onion powder as influenced by different drying methods. The data regarding iron content present in the freshly processed onion powder significantly varied with all the treatments. The highest iron content was found in T_4 (83.50 mg/kg) pursued by T_3 (77.50 mg/kg), contrarily on the flip side showed lowest content in T_5 (65.70 mg/kg) and T_1 (68.70 mg/kg) followed by T_2 (76.20 mg/kg).

Manganese (mg/kg)

The result of manganese content in prepared onion powder by using different drying methods was significantly different of each other is presented in table 3. The maximum content was identified in dryer T_4 (14.85mg/kg**)** followed by different treatment T_3 (13.02 mg/kg) and T_2 (10.87 mg/kg), on the contrary minimum content was observed in T_5 (5.75 mg/kg) which was partly different from treatment T_1 (8.30 mg/kg).

Copper (mg/kg)

The copper content of processed onion powder as affected by different drying methods is presented in table 3. The result obtained in an amount of copper content present in dehydrated onion powder showed a significant difference with isolated drying treatments. But the maximal share was distinguished between the T_3 (10.00 mg/kg) technique which was on par with the T_4 (9.25 mg/kg) (FD SCANVAC®) technique and T_2 (7.52 mg/kg), on the other hand, the minimal share was in T_5 (5.25 mg/kg) which was on par with T_1 (6.00 mg/kg).

Zinc (mg/kg)

The zinc content of processed onion powder as affected by different drying methods is presented in Table 3. The data showed that zinc content in processed onion powder as governed by different drying methods significantly different from all other methods. The highest content was found in a method like T_4 (21.12 mg/kg), T_3 (20.75 mg/kg) and T_2 (14.50 mg/kg), on the other side lowest content was present in T_5 (7.62 mg/kg) followed by T_1 (13.00 mg/kg).

Table 3: Effect of different drying methods on mineral analysis of calcium, magnesium, sulphur, potassium, iron,manganese, copper and zinc in onion powder

Treatment Details	Calcium (mg/kg)	Magnesium (mg/kg)	Sulphur (mg/kg)	Potassium (mg/kg)	Iron(mg/kg)	Manganese (mg/kg)	Copper(mg/kg)	Zinc (mg/kg)
T_1	784.70	852.70	155.50	2581.20	68.70	8.30	6.00	13.00
T_2	822.70	970.00	175.30	2639.70	76.20	10.87	7.52	14.50
T_3	944.20	1114.00	304.90	2680.70	77.50	13.02	9.25	20.75
T_4	1138.70	1352.00	317.60	2729.50	83.50	14.85	10.00	21.12
T_5	642.70	764.50	137.10	2491.20	65.70	5.75	5.25	7.62
Mean	866.60	1010.60	218.10	2624.50	74.35	10.56	7.60	15.35
S.Em ±	2.16	2.61	1.91	2.76	1.12	0.32	0.25	0.44
CD at 1%	9.03	10.9	7.96	11.51	4.69	1.34	1.05	1.87

Physico-chemical parameters

Moisture (%)

Water has several effects on food stability, palatability and overall quality. Moisture can affect the physical properties such as hardening or caking in powder or powder product. Water as a plasticizer has an additional effect on the shelf life of low and intermediate-moisture food stuffs (Roos, 1997; Chirife, *et al*., 1996) [40, 11]. Table 1 represents the moisture content (%) and a_w of the dried onion powders with different drying methods, the moisture content of the dried onion powders varied as seen in this table. As expected, the lowest and highest drying temperature (-109 to 55 °C) resulted in the lowest moisture content. During the experiment significantly minimum moisture content of processed onion powder was recorded in freeze dried onion powder (T_4: 4.92), among five different drying methods used in the experiment. This might be due to lower the temperature of the product to below freezing temperature (lyophilization). Where, the moisture of the sample is converted into ice crystals. Whereas higher moisture percentage of onion powder was observed in sun drying method (T_5: 6.32%) which was on par with fruit and vegetable dryer (CAZRI, Jodhpur) (T_2: 6.11%). This is because decreased heat penetration through the product retards the drying process. The results were in close conformity with Arslan and Ozcan, 2010[6]; Agarry *et al.*, 2013[2]; Umar *et al.*, 2016[53]; Jiapeng and Zhang, 2016[23]. Moisture content of dehydrated food is below 8%, microorganisms do not grow while, when moisture content is above 18% some microorganisms may be reproduce gradually (Luh and Woodroof, 1975) [30]. In addition, El Wakeel, 2007 showed that when the moisture content of the dried materials was > 10% such materials are considered as more proper for keeping quality of powdered food products.

Water activity (a_w)

The amount of water and degree of binding are affected by factors such as protein type, concentration, polar group, pH, salts and temperature (Hall, 1997) [19]. The physico-chemical state of water is related to water activity, which is a measure of water availability for the growth of various microorganisms. Water activity (a_w) is a major issue in relation to chemical stability of dry food products and has already been identified as intrinsic factors in determining shelf life (Chirife *et al*., 1996; Sunyoto and Futiawati, 2012) [11, 49] in milk powders. From the same table, all the given values of a_w was measured at ambient condition and data proved that drying methods significantly affected a_w values of the onion powder. Significantly minimum water activity was recorded in (T_4: 0.21) which is (FD SCANVAC®) onion powder compared to in all investigated samples followed by TD (EZIDRI®), fruit and vegetable dryer (CAZRI, Jodhpur), STD and SD. This might be due to the free water is frozen and the water activity is decreased to almost zero under low pressure and low drying temperatures which prevented thermal and enzymatic degradation of the final product. Similar trend was observed in moringa (Alicia *et al*., 2019; Silva *et al*., 2019) [4, 47] seeds. However maximum water activity was observed in T_5 (0.34) sun dried method (Table 1). But some of the literature reviewed showed that average water activity of powders ranged from 0.18 to 0.25; thus, they can be considered biochemically or microbiologically quite stable. Similar findings were also recorded by Quek *et al*., 2007; Tonon *et al*., 2010[38, 51] while studying with watermelon and acai powders, respectively.

Rehydration ratio (RR)
The rehydration properties, rehydration rate and rehydration capacity are prominent characteristics of many food products, related to their later preparation for consumption (Jokic *et al*., 2009) [25]. The rehydration capacity was used as a quality characteristic of the dried product (Velic *et al*., 2004) [54]expressed in the rehydration ratio (Lewicki *et al*., 1998) [28]. When the dried foods reconstituted, it must show acceptable textural, visual and sensory characteristics while, the rehydration time is minimized. Fig 1 represents the rehydration ratio (RR) of the dried onion powder. Data in Fig 1 proved that different drying methods used for dried onion powder had significantly affected the RR. The RR of onion powder ranges from 5.05 to 3.23 in different drying methods (Table 1). It was found that the RR was more in the case of T_4 (5.05) samples that represent rehydration efficiency of freeze dried onion slices was more than other treated onion powders. Variation in rehydration ratio might be due to the drying process increasing ruptured and shrunken cells that cause solute migration and loss of osmotic pressure, and changes in the cell walls permeability (Aparna *et al*., 2021) [5]. From the above mentioned data it could be stated that the best RR was achieved in FD (SCANVAC®) compared to TD (EZIDRI®), fruit and vegetable dryer (CAZRI, Jodhpur), STD and SD, this is may be due to the lower a_w and low water content of FD. The result found in the experiment was nearly similar to the one reported previously with drying, the rehydration ratio of onion was reported 6.87 (Lewicki, 1998) [28] in onion.

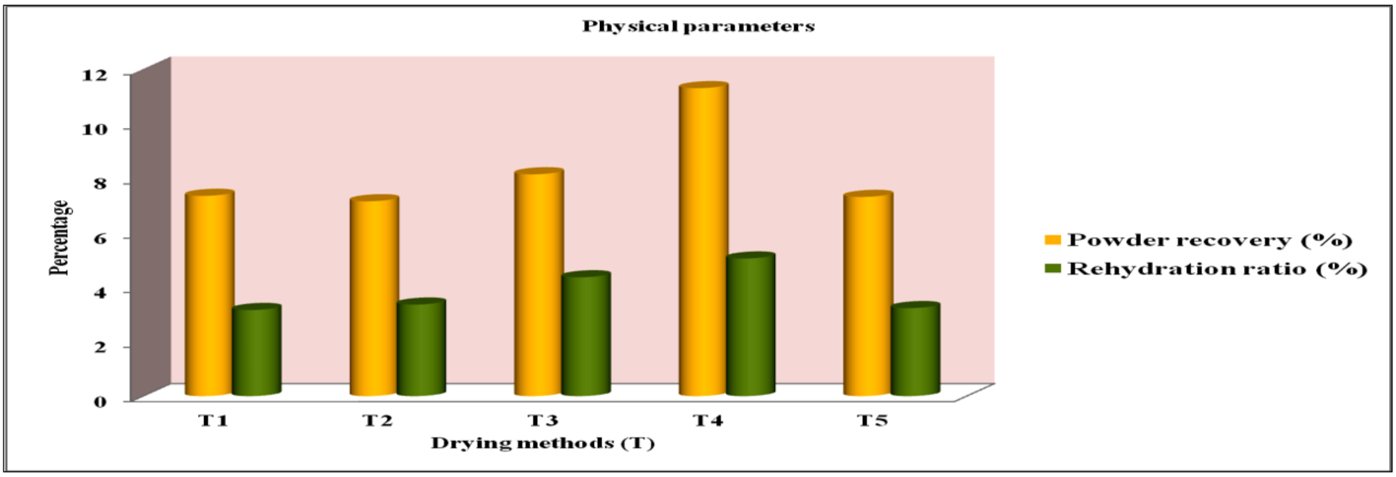

Fig 1: Effect of different drying methods on powder recovery and rehydration ratio in onion powder under ambient conditions (28±1°C and 43±1% RH)

Water soluble index
The water solubility index increased significantly indicating the ability of the powder to absorb water and an increase in the number of soluble materials, which can be easily digested. Water solubility index of different drying methods ranged from 25.95-80.79 (Table 1). It is evident that WSI increased quadratically with different drying methods. From the results obtained, a significantly maximum water solubility index was observed in T_4 (80.79) which was in freeze dried onion powder than those of other drying methods. Drying involves the use of heat to vaporize the water present in the food and also the removal of the water vapor from the food surface. Hence, it combines heat and mass transfer for which energy must be supplied. To use hot air flowing over the food is the most common way of transferring heat to a drying material being this process mainly by convection (Cruz *et al*., 2015). The water solubility index of the onion powders was increased with decreasing the particle size. As the particle size is small, the surface area is large and the water is easy to transfer (Lee *et al*., 2012) [26]. Consequently, a minimum water solubility index was observed in T_5 (25.95) SD this is due to the large particle size which results in lower WSI. Similar findings were observed in Murugkar *et al*. (2013) [34].

Powder recovery (%)
Table 1 depicted the percentage of powder recovery in processed onion powder. A significantly maximum recovery percentage was observed in T_4 (11.30%) in FD (SCANVAC®) followed by TD (EZIDRI®), fruit and vegetable dryer (CAZRI, Jodhpur), STD and SD, this might be due to presence of lowest moisture per cent in freeze drying process could be attributed to higher recovery percentage (Fig 1). However significantly minimum powder recovery percentage of processed onion powder was observed in T_2 (7.15%) in CAZRI dryer this is mainly due to irregular moisture variation in onion powder during mechanical processes. The present investigation are correlated with the findings of (Muzaffar and Kumar, 2015; Suhag *et al*., 2016 in honey powders; Tonon *et al*., 2008 and Du *et al*., 2014) [35, 48, 50, 14].

Time taken for drying (h)

Present investigation showed significant difference among different drying methods in (Table 1). Alam *et al*., 2014[3] evaluated in his study that as the drying time of the sample increases, the moisture per cent decreases and time taken for drying also reduces. Observation recorded in STD T_1 (10.87 h) showed significant lower drying time since the quick removal of moisture from the surface of the product with higher temperature in the drying chamber. Results also showed that maximum drying time was recorded in T_5 (122.99 h) *i.e.* sun drying as it is a weather dependent and also low temperature during drying so that it takes longer days for removal of moisture content as attributed to attaining fine powder properties.

Bulk density (g/cm^3)

Untapped density is a significant parameter for the powder because it indicates the area covered by the powder which is vital for packing industry. Bulk density results of processed onion are presented in (Table 2)(Fig 2). Drying at high temperature makes sample denser hence stronger packing material is required. More over lower bulk density of a powder is preferred because it improves dispensability when reconstituted in water (Udensi and Okoronkwo, 2006; Abdullah and Geldart, 1999) [52, 1]. The bulk density values decreases from 0.76 - 0.36 with the shift from sun to freeze drying. The researchers reported that the remaining solids after removal of moisture have higher densities than water and the overall solid density increases as moisture is removed. The study results are in the line with those reported for tomato (Goula and Adamopoulos, 2005; Manickavasagan *et al*., 2015 in date; Santhalakshmy *et al*., 2015) [18, 32, 42] in jamun powder.

Tapped density (g/mL)

In this study, the tapped density of processed onion powders was significantly affected by the different drying temperatures**.** The tapped density was higher than bulk density because tapping enabled the smaller particles to occupy the voids between larger particulates and attain a dense packing condition (Mitra *et al*., 2015) [33]. With respect to tapped density significantly higher TD (EZIDRI®) was observed in T_5 (0.86 g/mL) (Table 2)(Fig 2), in which the particles of SD onion powder were relatively larger (heavier) hence during tapping smaller particles can easily accommodate voids between larger particles. On the other hand, significantly lower tapped density was observed in T_4 (0.47g/mL) *i.e.* freeze dried method due to lower moisture contents, onion powder become more compact, so that smaller particles can easily occupy space between particles during tapping, hence results in low tapped density. Similar findings were observed in apple (Jakubczyka *et al*., 2011) [22] and muskmelon powder (Asokapandian *et al*., 2016) [7].

Hygroscopicity (%)

Hygroscopicity is one of the most quality indexes of powder products for the reason that it would affect the stability of the physico-chemical properties of powder during storage and later preparation processes (Ran *et al*., 2019). The present findings of processed onion powder showed significant difference for hygroscopicity. It was noted that freeze dried powder showed the lowest hygroscopicity value in T_4 (25.04%) which followed by T_3 (32.18%) (Table 2) TD (EZIDRI®). The reason for the lowest hygroscopicity in FD powder might be due to less level of free water existing in the powder. However, in T_5 (65.15%) (SD) onion powder noticed higher level of hygroscopicity. This result is supported by the scientist (Lee *et al*., 2012 in mashroom; Cynthia *et al*., 2014) [27, 13]. Also reporters said that hygroscopicity increased with the decreasing particle size because of the absorbing surface area/unit weight was large as the particle size decrease.

Hausner ratio (HR)

The hausner ratio is defined as the ratio of a powder's tapped bulk density to its poured (loose) bulk density. This ratio can be applied to provide an index of the flow character of a powder (Table 2). The hausner ratio has been reported that it is a measure of inter-particulate friction (Shah *et al*., 2008) [45]. The results with respect to hausner ratio properties in processed onion powder showed significantly different as influenced by different drying methods. The HR is classified and presented in Appendix V (Hausner, 1967) [20]. In this experiment, HR had a very narrow range of between 0.86 – 1.66. Lower (0.86) HR values generally indicate better powder flowability which was found excellent in T_4 (0.86) freeze dried powder sample, on the other hand statistically maximum HR ratio was identified in T_5 (1.66) (Table 5) SD which was poor observed due to moisture content present in the powdered sample (Shi *et al*., 2013) [46].

Particle density (g/mL)

The particle density corresponds to the real solid density and does not consider the space between particles (Tonon *et al.,* 2008) [50]. Results showed that particle density was significantly influenced by different drying methods. The particle density of processed onion powder is presented in (Table 2). The freeze dried *i.e.* T_4 (2.45 g/mL) powder had a significantly higher particle density than other dried powders this might be due to as particle size decreases the density of particle increases. Similar results of higher particle density were observed by Bhusari *et al*., 2014[8]; Tonon *et al*., 2010[10] for spray dried tamarind and acai powders, respectively at various processing conditions. Statistically lower particle density was observed in treatment T_5 (0.90 g/mL) control/SD method, as a trend similar to soya milk powders (Seerangurayar *et al*., 2017; Jinapong *et al*., 2008) [43, 24].

Particle size (µm)

Particle size plays a key role in food transportation, handling, and storage at industrial-scale production (Waiss *et al*., 2020) [55]. The results constituted with respect to particle size of processed onion powder showed significant differences as influenced by different drying methods. It can be observed that the longer the drying time the higher the percentage of particles on the smallest mesh size. The maximum particle size was observed in T_5 (1209 µm) (Table 2) which was attributed due to lower drying temperature and irregular drying periods, recorded that onion slices were still very moist (around 25% moisture content) therefore, it was difficult to grind them to obtain a real onion powder, an agglomerate which accumulated on the upper meshes (1,200 µm). Studies showed that by comparing the drying kinetics and the particle size distribution, it can be seen that particle size distribution was affected by moisture content. At a longer drying period, lower moisture content of (-109 °C) was identified in T_4 (417 µm) *i.e.* FD and (624 µm) *i.e.* TD (EZIDRI®) allowed the onion slices to be easily ground resulting in a smaller particle size. This was attributed that small particles are undesirable in powder products because of their reduced ability of flowability (Majid and Nanda, 2017) [31]. Similar records were reported in these experiments in powders (Geldart *et al.*, 2009) [16].

Minerals (mg/kg)

The mineral composition of onion powder prepared from five different drying methods was determined. Macro-minerals such as Ca, Mg, K and S were recorded as abundant in the bulb than micro-minerals like Fe, Zn, Mn and Cu. Both intrinsic and extrinsic factors showed the influence of drying on the level of retention or loss of minerals during processing. The observations with respect to macro-minerals and micro-minerals per cent in prepared dehydrated onion powder were significantly influenced by different drying methods.

Analytically highest content of macro-minerals like calcium, magnesium, sulphur and potassium was present in freeze dried *i.e.* T_4 (1138.70 mg/kg), (1352.00 mg/kg), (317.60 mg/kg) and (2729.50 mg/kg) in (Table 3)(Fig 3). The highest micro-minerals like iron, manganese, copper and zinc were also found in freeze drier (T_4) (83.50 mg/kg), (14.85 mg/kg), (10.00 mg/kg) and (21.12 mg/kg) in (Table 3)(Fig 4), which might be due to low temperatures and low vacuum pressure, employed during freeze drying resulting in a reduction in moisture content leading to better retention of minerals. Thus the absence of liquid water during the dehydration process means that undesirable chemical reactions will not occur and due to low temperature nutrient losses will not occur. Similar trend was noticed by (Gnana Deepika *et al.*, 2021) [17] in moringa leaf powder.

Considerably, lowest macro-minerals calcium, magnesium, sulphur and potassium were present in T_5 (642.70 mg/kg), (764.50 mg/kg), (137.10 mg/kg) and (2491.20 mg/kg) (SD) in (Table 3)(Fig 3) respectively. On the flip side lowest micro-minerals like iron, manganese, copper and zinc showed in between sun-dried T_5 (65.70 mg/kg), (5.75 mg/kg), T_2 (5.25 mg/kg) fruit and vegetable dryer (CAZRI, Jodhpur) which was on par with T_1 (6.00 mg/kg) STD and zinc content in T_5 (7.62 mg/kg) in (Table 3)(Fig 4) this might be due to physico-chemical changes occurred because of variation in drying temperature, drying time and mechanism of drying on the produce.

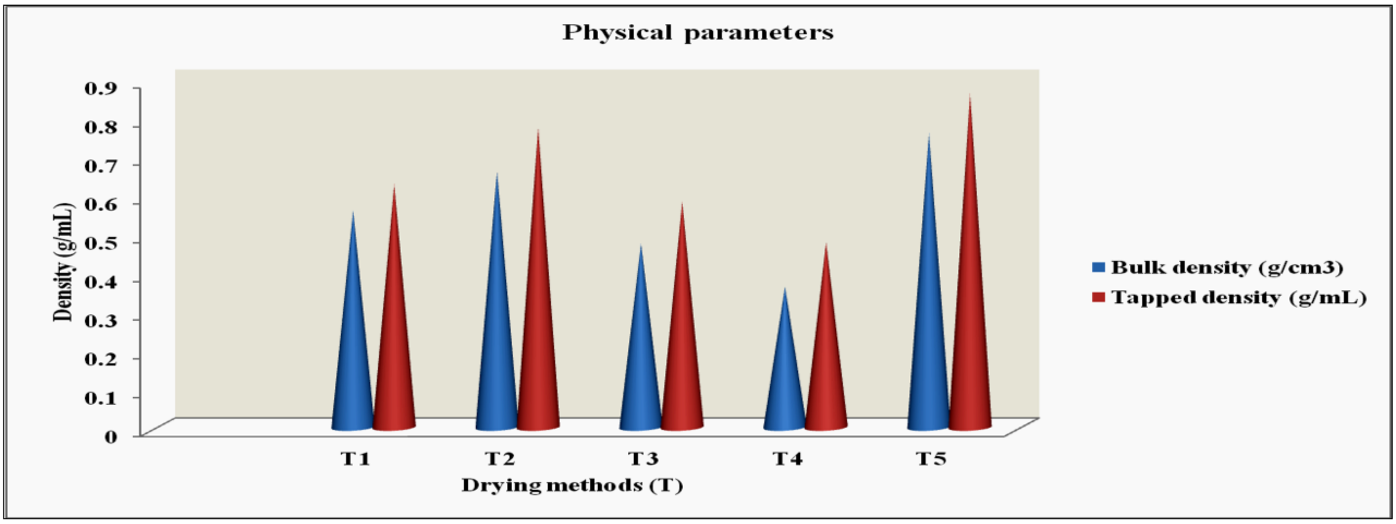

Fig 2: Influence of different drying methods on bulk density and tapped density in onion powder under ambient conditions (28±1°C and 43±1% RH)

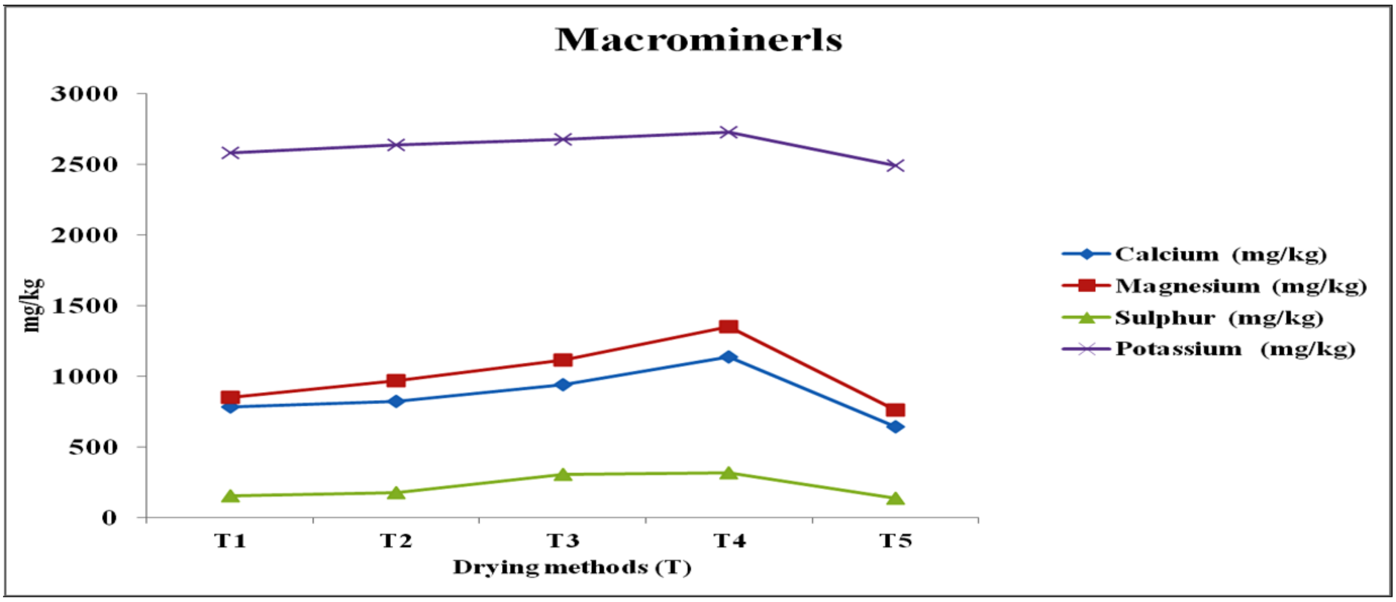

Fig 3: Impact of different drying methods on mineral analysis of calcium, magnesium, sulphur and potassium in onion powder

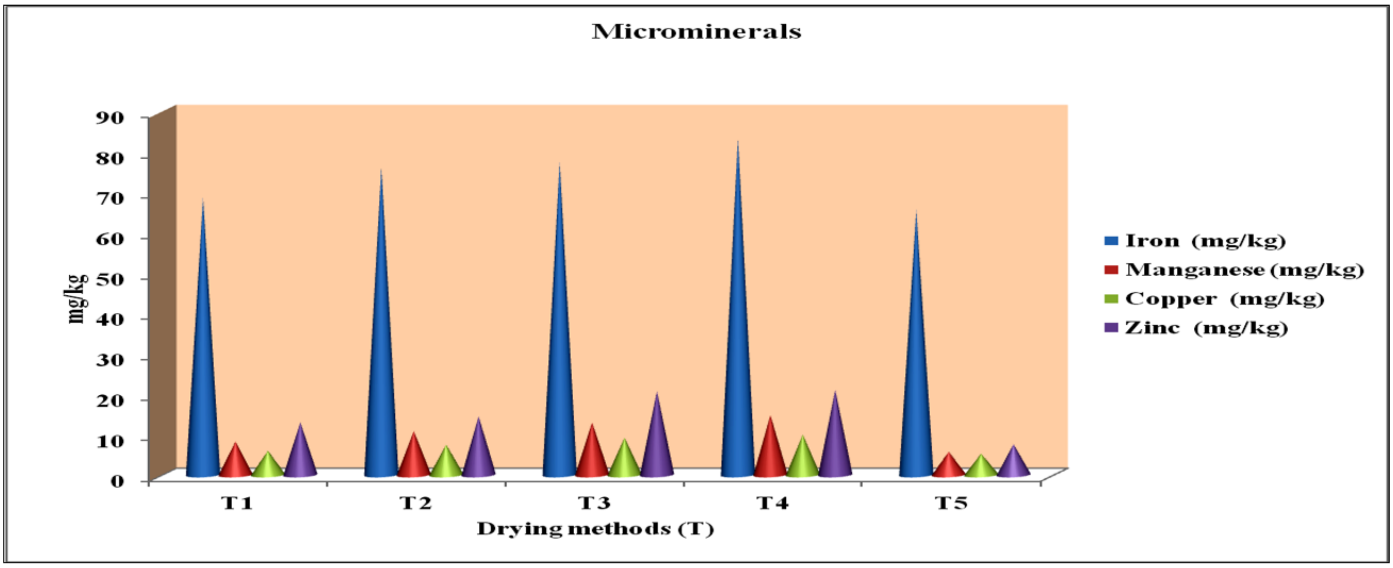

Fig 4: Effect of different drying methods on nutrient analysis of iron, manganese, copper and zinc in onion powder

Conclusion

From this study, results revealed that, moisture (%), water activity (a_w), rehydration ratio (RR), water soluble index, powder recovery (%), time taken for drying (h), bulk density (g/cm^3), tapped density (g/mL), hygroscopicity (%), hausner ratio (HR), particle density (g/mL), particle size (µm), and minerals like Ca, Mg, S, K, Fe, Mn, Cu, and Zn (mg/kg) were seen highest in freeze dried (T_4) onion powder. From this, it may be concluded that freeze drying was superior in retaining most of the physico-chemical quality parameters in onion powder at ambient conditions (28±1°C and 43±1% RH).

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