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Fortification of refractance window-dried *Curcuma longa* powder and its associated characterization

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Curcuma longa powder was prepared by refractance window (RW) drying and was fortified. Dried turmeric powder was fortified with folic acid and NaFeEDTA. The fortified turmeric powder was studied for its physical characteristics, such as bulk density, swelling power, solubility, dispersion time, hygroscopicity, water binding capacity, and color. The study revealed novel physical characteristics for dried turmeric powder, folic acid-, and NaFeEDTA-fortified with low hygroscopicity (8 - 9%), good solubility (28 - 30%), and good swelling power (1.8 - 2.0). The findings confirmed the insignificant influence of fortification on the desired properties of the folic acid- and NaFeEDTA-fortified RW dried turmeric powder product. Thus, it can be concluded that the fortified turmeric powder had good stability. This stable fortified turmeric powder can be effectively incorporated into various food systems, such as milk, instant turmeric latte powder, and health drinks, to enhance their nutritional profiles.

Keywords: refractance window drying, turmeric, fortification, folic acid, NaFeEDTA

INTRODUCTION

Vitamin and mineral deficiencies cause learning disabilities, mental retardation, low work capacity, blindness and even premature death. To overcome these issues, food fortification has been the best choice in comparison with pharmaceutical supplements. Fortification of food products involves enhancing essential micronutrients such as vitamins, minerals, and trace elements in foods. Thereby, multiple mineral deficiencies can be addressed to enhance health benefits without potential health risks. Cereals, flour, rice, and milk are often fortified to reduce deficiencies. Fortification also has potential challenges in terms of bioavailability of added nutrients, unacceptable organoleptic changes, and subsequent rejection of a developed product by the consumers and targeted population [1].

Three most common micronutrient malnutritions have been identified for human beings. These are iron, iodine, and vitamin A [2]. The micronutrient folate received significant global attention [3] due to its critical ability to address and mitigate issues associated with early embryonic brain development, malformation of the embryonic brain and spinal cord or neural tube diseases [4]. With 79 % of children between 6 – 35 months and women between 15 – 49 years of age being anaemic in India [5], iron deficiency has been opined due to the consumption of foods with lower bio-availability of iron. Thus, iron-fortified product research needs greater emphasis [6].

The influence of fortificants on mineral-fortified dried products is often targeted through associated studies. In a related prior art, the authors fortified Nepalese curry powder with alternate iron compounds [7]. Also, whole wheat flour fortified with a premix of ferrous sulfate, ethylenediamine tetra-acetic acid (EDTA) and folic acid was reported [8, 9].

Previous studies reported the fortification of salt with folic acid, iron, and iodine [5, 10] and the fortification of chickpea seeds and flour using ferrous sulfate heptahydrate, ferrous sulfate mono-hydrate and NaFeEDTA fortificants [11]. Similarly, researchers deployed finger millet and sorghum flours as double fortification vehicles with ferrous fumarate, zinc stearate and EDTA [12].

Till date, the parametric optimality of refractance window drying (RWD) process was targeted for vegetables such as carrots, onions, etc. [13, 14]. These vegetable powders were not studied for fortification and for a comparison of associated characteristics. In such investigations, physical characteristics (solubility, swelling time, hygroscopicity, dispersion time, water binding capacity, bulk density and color) are often targeted for the fortified and unfortified dried powder products. To date, no study has been devoted to the turmeric powder product system.

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Such investigations can provide useful insights into the role of fortification in altering these properties.

Considering the above-cited lacunae, the current research addresses the fortification of RW-dried turmeric powder with folic acid and NaFeEDTA and its characterization studies.

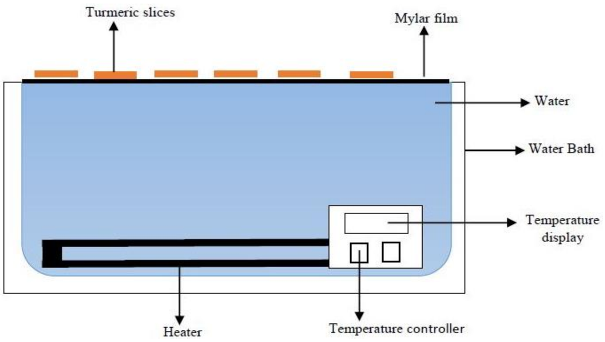

Fig.1. Schematic representation of refractance window drying process of turmeric

MATERIALS AND METHODS

Raw materials, chemicals and sample preparation

Turmeric was procured from the market complex, Indian Institute of Technology Guwahati, Kamrup, Assam, India and was packed in a polythene pouch to prevent contamination during its transportation. Sodium ferric ethylenediamine tetraacetate (NaFeEDTA), folic acid, potassium bromide, enzymes and other chemicals were obtained from Sigma Aldrich India. Subsequently, the procured raw turmeric was washed with tap water to remove surface contaminants and dirt. The sample was then wiped with tissue paper to remove excess water. Thereafter, the wiped turmeric was peeled. Eventually, using an adjustable slicer, the peeled turmeric was sliced to achieve sample pieces with 1 mm thickness.

Refractance window drying

The refractance window drying (RWD) experiments were conducted with optimal combinations of sample thickness, mylar film thickness, temperature, air velocity and drying time that were achieved with prior experimental investigations [15]. RSM was carried out to determine the drying parameters. From the modeling it was obtained that the optimal data set for RSM was found to be 95°C drying temperature, 75 min drying time and 0.76 m/s air velocity for optimal response characteristics of 90.52 % (AA), 188.22 mg GAE/g dry sample (TPC), 158.65 mg quercetin/g dry sample (TFC), 4.80 % w/w (CC), 3.67 % (MC) and 54.87 L values (color indices). In summary, RWD turmeric samples can be characterized with better retention of nutritional characteristics within these drying parameters. Thereafter, the dried samples were powdered using a dry portable electric grinder. Eventually, samples sieved through an 80-mesh sieve were obtained that possessed an average particle size of 0.177 mm [16].

Fortification with sodium ferric ethylenediamine tetraacetate and folic acid

The process for fortification of RW-dried turmeric powder was developed with slight modifications from the previous studies [5, 7, 9, 12]. The RDA for folic the acid is 400 µg/day for both men and women but 600 µg /day for pregnant women [9]. The RDA of iron varies with age of the person and is 15 - 18 mg/day for women, 27 mg/day for pregnant women, 11 – 8 mg/day for men and 8 mg/day for senior citizen [5, 9]. It was difficult to conclude upon a precise amount of NaFeEDTA and folic acid from literature review, leading to selection of a higher amount (20 g). The same amounts of NaFeEDTA and folic acid were taken for fortification to assist the effective comparison of the influence of NaFeEDTA and folic acid on the fortification characteristics of the turmeric powder. Therefore, 100 g of RW-dried turmeric powder was mixed with 20 mg of NaFeEDTA or 20 mg of folic acid to eventually achieve iron and folic acid-fortified turmeric powder samples. For both cases, dry mixing using a spatula was performed.

Characterization of refractance window-dried Curcuma longa powder products

For RW-dried turmeric powder, folic acid-fortified and NaFeEDTA-fortified turmeric powder samples, characterization was addressed in terms of associated parameters such as bulk density, solubility, swelling power, water binding capacity, dispersion time, hygroscopicity and color. A brief account of adopted procedures is as follows.

- *Bulk density.* To measure the bulk density of RW dried turmeric powder, folic acid fortified and NaFeEDTA fortified turmeric powder samples bulk density, 5 g of turmeric powder was placed into a measuring cylinder of 10 mL. The volume occupied by the turmeric powder in the cylinder was recorded, and the bulk density was calculated using the ratio of the weight to the volume of the turmeric powder sample [17].
- *Solubility & swelling power.* The solubility of the RW dried turmeric powder, folic acid fortified and NaFeEDTA fortified turmeric powder samples was determined by mixing 1 g of turmeric powder sample with 100 mL of distilled water at ambient temperature and mixing using Tarsons magnetic stirrer operated at 600 rpm for 5 min. Thereafter, the mixture was centrifuged at 3000 G for 5 min.

Thereby, 20 mL of the obtained supernatant was decanted to a pre-weighed petri dish and dried at 70°C until constant weight of the system was achieved. Subsequently, percent solubility was determined in terms of the weight difference between the processed petri dish sample and the empty petri dish system. Solubility was evaluated using the expression:

$$\text{Solubility (\%)} = \frac{W_d}{W_s} \times 100 \quad (1)$$

The swelling power was calculated using the following expression:

$$\text{Swelling power (g/g)} = \frac{W_{sd}}{W_s} \quad (2)$$

In the above expressions, W_s, W_d and W_{sd} are the weights of original sample, dried residue and dried sediment mass, respectively [17].

- *Water binding capacity.* Using the following method, the water binding capacity (WBC) of RW dried turmeric powder, folic acid fortified and NaFeEDTA fortified turmeric powder samples were measured. Firstly, 5 g of turmeric powder was mixed with 75 mL of distilled water. Thereby, the system was agitated at 860 rpm and 20 °C for one h. Thereafter, the sample was centrifuged at 3000 G for 10 min. Subsequently, the supernatant was removed, drained for 10 min and weighed. WBC was evaluated using the expression:

$$\text{WBC (\%)} = \frac{M_w - M_d}{M_d} \times 100 \quad (3)$$

where, M_w and M_d are the wet weight (g) and dry weight basis of the powder (g), respectively [18].

- *Dispersion time.* The dispersion time was determined through the following procedure. Firstly, 80 mL of distilled water was transferred into a 100 mL beaker and was kept in an ambient environment (27°C). Thereby, 1 g of the powder sample was placed in a slider that separated the powder and liquid surface. The dispersion time measurement started at the very instance that corresponds to the powder sample and liquid being brought into contact through the quick removal of the slider that separated the powder and liquid. Thereby, the time was measured for the complete spontaneous wetting and immersion of the 1 g powder [19].

- *Hygroscopicity.* The hygroscopicity of the sample was determined by following the procedure summarized in [17]. According to the authors, hygroscopicity can be expressed in terms of the moisture mass (g) being absorbed by 100 g of sample during 7 days of storage at 25°C and 92 % relative humidity. To achieve these conditions, a desiccator with a saturated Na_2SO_4 solution was arranged. Thereby, 1 g of the sample was weighed in a petri dish and was transferred into a desiccator for mentioned time period (7 days). Subsequently, hygroscopicity was determined using the expression:

$$Hygroscopicity(\%) = \frac{\frac{x}{a_h + W_i}}{1 + \frac{x}{a_h}} \times 100 \quad (4)$$

where x corresponds to the enhancement in powder sample (g), a_h corresponds to the powder sample amount used for the measurement (g), and W_i refers to the water content of the powder exposed to the humid environment [20].

- *Color indices.* The color indices of both fresh and dried samples were determined using a colorimeter (Data color, Model: 250) set up (*L, a, b*) [20]. For each case, measurements of *L*, *a* and *b* were conducted at three different sample spots. Thereby, the data were reported as the mean of these three measurements.

RESULTS AND DISCUSSION

Bulk density

Bulk density is an important characteristic of the storage, transportation and packaging of powder products. Hence, it was assessed for various dried samples. The bulk density of the RWD-processed turmeric powder was obtained as 0.62 g/mL. Incidentally, the turmeric powder fortified with folic acid and NaFeEDTA possessed bulk density in the range of 0.64 – 0.65 g/mL (Table 1). Thus, it can be stated that the density did not vary with the addition of fortificants, and the trends were comparable to those reported in the relevant prior art.

Table 1. Bulk density data of unfortified and fortified turmeric powder products.

S. No.	Samples	Bulk density (g/ml)
1.	Unfortified	0.62
2.	Folic acid fortified	0.65
3.	NaFeEDTA fortified	0.64

Note: All standard deviations were in the range of 0.05 – 0.1.

Constant and falling rate drying mechanisms occur sequentially during the drying of food samples. Thus, during constant drying phase, higher drying temperatures translate into higher initial drying rates. Thereafter, the drying rate gets controlled due to moisture diffusion from the internal portion of the sample to its surface. Deploying higher temperatures during drying can form a hard and moisture-resistant crust at the surface that eventually prevents further loss of moisture. The formation of such a crust generally results in higher bulk density. In summary, the higher bulk density of the RW-dried samples is possibly due to the formation of moisture-resistant crust [17].

Hygroscopicity

Hygroscopicity, like solubility, is a very important parameter of dehydrated products and has a definite role in influencing their shelf-life characteristics. Lower hygroscopicity is desired to achieve chemical and microbiological stability in due course of the long-term storage of a food sample. For RW-processed turmeric, NaFeEDTA and folic-fortified processed turmeric powder samples, lower hygroscopicity values have been obtained as 8.70 %, 8.80 % and 8.50 %, respectively (Table 2). Hence, the addition of fortificants did not significantly alter the hygroscopicity property of the turmeric powder sample.

Table 2. Hygroscopicity data of unfortified and fortified turmeric powder products.

S. No.	Sample	Hygroscopicity (%)
1.	Unfortified	8.70
2.	Folic acid fortified	8.80
3.	NaFeEDTA fortified	8.50

Note: All standard deviations were in the range of 0.1 – 0.3.

The low hygroscopicity could be due to the formation of dense structures that tend to reduce the intake of water into the cells. The formation of dense structures is due to the fast drying during RWD process [21]. Also, the lower hygroscopicity of turmeric is due to its lower sugar content. The fortificants, namely folic acid and NaFeEDTA, were also stable and had a lower affinity to water vapor. Thus, the fortified turmeric samples powder also possessed lower hygroscopicity. In the literature, similar results have been reported for RW and freeze-dried yoghurt samples. The reported values were lower than those obtained for the food powders and could be due to the lower sugar content in the yoghurt [17]. The hygroscopic properties of a powder play a vital role in determining its chemical stability and influence its flow characteristics. Hygroscopic substances typically exhibit poor flowability, leading to issues with weight variation. Moisture present in cohesive materials can create solid and liquid bridges between particles, ultimately resulting in hard cake formation. Additionally, the stickiness of hygroscopic compounds can complicate the compaction process, causing problems such as picking and sticking. Elevated moisture levels often lead to particle agglomeration. In contrast, powders with low hygroscopicity and anti-caking properties facilitate easier mixing, agglomeration, or tableting, which can contribute to reducing packaging costs [17].

Solubility and swelling power

This parameter is attained after the powder undergoes the sequential dissolution steps of sinkability, dispersibility and wettability [20]. For RW dried turmeric, folic acid fortified RW dried turmeric and NaFeEDTA fortified RW dried turmeric, the solubility was about 29, 30 and 28 %, respectively (Table 3). Thus, good solubility was achieved, and this is promising from a product acceptability perspective [18]. Corresponding swelling power values were 1.8, 2.0 and 1.9 g/g respectively (Table 3). The fortificants did not significantly alter the product solubility and swelling power. The literature confirmed that the solubility and swelling power of RW-dried powders were like freeze-dried powder samples and were lower than that of spray and drum-dried powders. This is due to the mild processing temperature for both RW and freeze-drying methods [20]. High solubility in powders is crucial for various commercial applications, particularly in the pharmaceutical, food, and agricultural industries. In pharmaceuticals, high solubility ensures that drugs can be effectively absorbed into the bloodstream, enhancing their bioavailability and therapeutic efficacy. Approximately 40% of new chemical entities developed are poorly soluble in water, which poses significant challenges for formulation scientists aiming to deliver effective treatments. Similarly, in the food industry, instant powders with high solubility dissolve quickly and uniformly, preventing clumping and ensuring consistent product quality during preparation and consumption [18].

Table 3. Solubility and swelling power data of unfortified and fortified turmeric powder products.

S. No.	Samples	Solubility (%)	Swelling power (g/g)
1.	Unfortified	29.00	1.80
2.	Folic acid fortified	30.00	2.00
3.	NaFeEDTA fortified	28.00	1.90

Note: All standard deviations for solubility and swelling power were in the range of 2 – 3 and 0.1 – 0.2, respectively.

Dispersion time

For all evaluated powders namely, RW processed turmeric, folic acid fortified and NaFeEDTA fortified RW dried turmeric powders, the dispersion time was lower than 20 s (Table 4). The relatively short times of powder dispersion confirm good wettability characteristics of the tested samples. The literature hypothesized that larger particles possess higher wettability than finer particles and thereby translates into lower dispersion time [19]. Also, the addition of fortificants did not significantly alter the dispersion time of the samples.

The higher wettability of such samples could be also due to higher drying temperature. However, it can as well be inferred that the phenomenon of hard crust formation due to faster drying translate into the higher wettability of the samples [17].

Table 4. Dispersion time data of unfortified and fortified turmeric powder products.

S. No.	Sample	Dispersion time (s)
1.	Unfortified	20.00
2.	Folic acid fortified	17.00
3.	NaFeEDTA fortified	19.00

Note: All standard deviations were in the range of 2 – 3.

Water binding capacity

The water binding capacity is an important technical property and is related to the hydration capacity of the food samples that have rich constitution of protein and/or fiber content. The water binding capacity of RW dried turmeric, folic acid and NaFeEDTA fortified RW dried turmeric samples were high and were 66, 65 and 67 % respectively (Table 5). Thus, the fortificants did not critically alter the water binding capacity of the turmeric samples. According to a relevant literature [22], higher drying temperature ensured higher water binding capacity of the dried samples. Hence, the RW dried turmeric sample possessed higher water binding capacity due to the drying at high temperature that eventually fostered the onset of pasting or gelatinization.

Table 5. Water binding capacity data of unfortified and fortified turmeric powder products.

S. No.	Sample	Water binding capacity (%)
1.	Unfortified	66.00
2.	Folic acid fortified	65.00
3.	NaFeEDTA fortified	67.00

Note: All standard deviations were in the range of 2 – 3.

Color indices

The color parameters *L, a,* and *b* of turmeric powder, folic acid fortified and NaFeEDTA fortified RW dried turmeric have been summarized in Table 6. The *L* parameter decreased from 63.67 (fresh sample) to 56.67, 55.70 and 56.10 for turmeric powder, folic acid fortified and NaFeEDTA fortified RW dried turmeric samples. Such a reduction in lightness was attributed to the surface dryness or loss of moisture due to the drying at 95 °C. The measurement trends also confirmed upon the browning of the sample. Another reason is that the non-enzymatic browning (or Maillard reaction) occurs at relatively high drying temperatures. The reduction in *a* (redness) and *b* (yellowness) to 31.05 – 30.80 and 62.13 – 61.20 from 43.07 and 75.12, respectively, also corroborates the reasoning associated to heat treatment [23]. Also, it can be observed from the table that the addition of fortificants did not alter the color of the samples.

Table 6. *L*, *a*, and *b* values of unfortified and fortified RW dried turmeric powder samples.

S. No.	Samples	*L*	*a*	*b*
1.	Fresh	63.67	43.07	75.12
2.	Unfortified	56.67	31.05	62.13
3.	Folic acid fortified	55.70	30.10	61.80
4.	NaFeEDTA fortified	56.10	30.80	61.20

Note: All standard deviations for *L, a* and *b* were in the range of 1 – 2, 2 – 3 and 1 – 3, respectively.

CONCLUSIONS

The bulk density of RW-dried turmeric powder, folic acid-fortified turmeric powder and NaFeEDTA-fortified turmeric powder did not vary significantly. The hygroscopicity of fortified products was lower and like that of samples obtained by freeze drying process while the solubility and swelling power of the powders were good and matched the results obtained by freeze drying methods. In case of the dispersion time, it was less and hence the powders had better wettability. Meanwhile, the water-binding capacity of all three powders was high. The color indices were almost the same for all. From this work, it could be concluded that the addition of folic acid and NaFeEDTA to the RW-dried turmeric powder did not change the physical characteristics and constitution of the native RW-dried turmeric powder. This is due to the stability of folic acid and NaFeEDTA compounds added to the RW-dried turmeric. Thereby, they did not interact with the RW dried turmeric powder to cause physical changes to the powder.

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Pankaj Jyoti Barman. Ramagopal V.S. Uppaluri supervised the conducted research and improvised the manuscript.

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