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Impact of Different Drying Methods on Nutritional, Colour Change, Solubility and Microbial Count of Selected Herbal Plant Powders

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Abstract

The research aimed to study the effect of drying processes (spray and freeze drying), and feed concentrations (80%, 65% and 50% of plant in water, w/w) on physicochemical and microbiological characteristics of star gooseberry (*Sauropus androgynus*), ceylon spinach (*Basella alba*), and cowslip creeper (*Telosma minor*). After drying, the powder recovery of herbal plant powders was up to 77.47%. The aw and moisture content of spray-dried powder (SDP) were lower than that of freeze-dried powder (FDP). The drying method did not significantly affect nutritional values of both powders, whereas the feed concentrations markedly affected the nutritional values of the powders. The fibre and fat contents of powder prepared from 80% feed concentration had the highest values ($p<0.05$). The dried star gooseberry powder was rich in protein (13.01-16.81%) and fibre (5.03-5.52%). The colour of FDP represented a smaller change than that of SDP. The dried powders prepared by 80% showed the highest solubility, up to 85.44%. The microbial counts of SDP were lower than that of FDP. The colour might well have been preserved by freeze drying, whereas a low moisture and microbial count were likely due to the spray drying.

Keywords: Spray drying; Freeze drying; Feed concentration; Star gooseberry; Ceylon spinach; Cowslip creeper

1 Introduction

In Southeast Asia, there are many species of herbal plants that have been used for dietary and medicinal purposes since ancient times. Some of these plants, e.g. star gooseberry (*Sauropus androgynus*), ceylon spinach (*Basella alba*), and cowslip creeper (*Telosma minor*), are types of tropical herb which have also been used extensively as ingredients for cooking and alternative treatments of various diseases, such as genitourinary diseases, cardiovascular diseases, and cancers (Adhikari et al., 2012; Khoo et al., 2015). These herbal plants are generally grown by small-scale production units and with home-grown vegetables around the region. *S. androgynus* is an alternate single leaf plant with a dark green leaf, having a high nutritional value, especially high in dietary protein, fibre, carbohydrates and vitamin C. It also has high antioxidant activity as it contains containing phenolic compounds that could be used for medicinal, and colouring agents in foods. The secondary metabolites include phenolic compounds such as phenolic acids, tannin,

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Nomenclature

SDP	Spray-dried powder	FDP	Freeze-dried powder

lignin, flavonoids, coumarins, and stilbenes, terpenes such as plant volatile, carotenoids, sterol, and nitrogen-containing compounds such as alkaloids and glucosinolates (Bunawan et al., 2015; Chaimat et al., 2007; Gireesh et al., 2013; Wang & Lee, 1997). The extract of *S. androgynus* consisted of various phytochemicals, and vitamin C was found as major component (Bose et al., 2018), exhibiting antimicrobial, antibiofilm, antipathogenic, and antifungal activities (Kusumanegara et al., 2017; Kuttinath et al., 2019). *B. alba* is a single-herbaceous creeper with thick, soft leaves and sticky mucus, and is used as an herbal medicine due to it being a good source of calcium, iron, vitamin A and C, as well as being rich in phenolics, peptides, and mucus polysaccharides, and is known as a vegetable that contains mucilage (Chatchawal & Nualkaew, 2009; Jaichuen & Samutsri, 2014). The leaves of *B. alba* are very low in fat, but high in phytonutrients, including enzymic and non-enzymic antioxidants, that show potential uses as antioxidants, antibacterials, anti-inflammatories, nephroprotective and giving wound healing properties (Singh et al., 2016).

The major phytonutrient presented in *B. alba* is flavonoid such as kaempherol (Adhikari et al., 2012; Yang et al., 2008), and its mucilage extract is composed of polysaccharide with D-galactose that can be used as a cosmetic and for treatment of skin diseases. Some amino acids such as arginine, leucine, isoleucine, lysine, threonine and tryptophan are also found in *B. alba* leaves (Adhikari et al., 2012; Murakami et al., 2001). *T. minor* has clustered flowers in bunches or axillary buds and yellow petals;, it is fragrant and sweet and its extract has the ability to be an excellent antioxidant (Kongchantree, 2011), as a radical scavenger and an inhibitor of lipid peroxidation (Teerarak et al., 2018) due to a high content of phenolic compounds and flavonoids. Its extract also showed anti-microbial properties against pathogenic bacteria (Krasaekoopt & Kongkarnchanatip, 2005).

Therefore, these herbal plants have a potential to be developed into health food products and become a valuable marketed product.

Drying is an important process to extend the shelf-life for preserving food. The drying process could convert the food solutions into dry solid form (Ratti, 2001). Spray drying is one of the most widely used for drying due to a short contact time for materials exposing to high temperature. It extensively used to preserve juices as high quality powder by spraying the feed into a hot drying chamber. In general, the spray-dried powder (SPD) retains high nutritional values, low water activity and reduced weight, resulting in easy storage and transportation, and its reconstituted form gives a fresh-like original juice (Shishir & Chen, 2017; Sonia et al., 2015; Tontul & Topuz, 2017). Freeze drying is non-thermal method that water in solid form is sublimated under vacuum at low temperature, resulting a porous structure in the dried product. This drying method is slower and with higher costs compared to spray drying (Guiné, 2018), whereas it was found to be the best method retaining superior functional properties (Lili et al., 2015) and high phytonutrient content (Agudelo et al., 2017; Ghirisan & Miclaus, 2017). After freeze drying, the original colour, taste and shape of the sample are maintained, but the texture becomes crisp, spongy and soft. The structural, physical, functional and nutraceutical of freeze-dried (FDP) powder are dependent on the feed and process condition (Valentina et al., 2016). Also, the microbiological quality depends on the initial quality of the fresh vegetable by growing, harvesting, transportation and market shelf, as well as the treatment methods before consumption. Therefore, the current study aimed to contribute to better understanding of the effect of spray drying and freeze drying on the colour, solubility, nutritional and microbiological characteristics of selected herbal plants with the intent to use them as dietary supplements.

2 Materials and Methods

2.1 Materials and sample preparation

Star gooseberry (*S. androgynus*) leaves, ceylon spinach (*B. alba*) leaves, and cowslip creeper (*T. minor*) flowers were obtained from a local market in Thailand. They were immediately processed by water cleaning for 5 min to remove undesirable residues from their surfaces, draining for 5 min, and slicing into small pieces. After that, each of the plant species was mixed with water in proportions of 80%, 65% and 50% in a blender for 5 min, filtered through a stainless-steel sieve (mesh size 63 μm) to provide a feed solution at various feed concentrations (80%, 65% and 50%) for further drying.

2.2 Spray drying process

Prior to the spray drying operation, water was pumped into the spray dryer (Buchi, Mini Spray Dryer B-290) to adjust the inlet and outlet air temperatures for 30 min before the feed was introduced through feed pipe. The prepared feed solutions were spray-dried using a nozzle under an inlet temperature of 180 ^{o}C and a constant feed rate of 8 mL/min to obtain the SDP. The powder was sieved thought a 250 μm screen (Retsch, Germany), and immediately sealed in aluminium foil at -18 ^{o}C.

2.3 Freeze drying process

The samples were completely frozen at -18 ^{o}C and then freeze-dried in a laboratory-scale freeze dryer (Christ, Gamma 2-16LSC) equipped with a round bottom freeze drying flask, under vacuum condition at a pressure of 0.01 mbar and condenser temperature of -50 ^{o}C for 48 h at ambient temperature. After that, the FDP was sieved thought a 250 μm screen (Retsch, Germany), sealed in aluminium foil to prevent water uptake, and stored at -18 ^{o}C.

2.4 Determinations of nutritional values

Proximate analysis

Proximate analysis of the samples, including moisture (AOAC Official Method 934.06), protein (AOAC Official Method 991.20), fat (AOAC Official Method 991.36), fibre (AOAC Official Method 962.09), and ash (AOAC Official Method 900.02) was carried out according to standard methods (AOAC, 2000).

The carbohydrate content was determined as the difference between 100 and the sum of the percentages of moisture, protein, fat, fibre and ash.

Vitamin C

Vitamin C (ascorbic acid) of the dried powder was estimated by titration of sample with 2,6-dichlorophenolindophenol (adapted method from (Benazzouz et al., 2020). Each determination was done in triplicate. Standard ascorbic acid solution was prepared and then vitamin C content was calculated equivalent to the amount of ascorbic acid (mg/100 g).

2.5 Determinations of physical properties

Powder recovery

The percentage of powder recovery of the dried sample was calculated by the weight of obtained dried powder divided by the total soluble solids and multiplied by 100. Each determination was done in triplicate.

Water activity

Water activity (a$_{w}$) of the samples was determined at 25 ^{o}C using a water activity meter (Aqualab 4TEV). Each determination was done in triplicate.

Total colour change

Colour parameters (Hunter L*, a* and b* values) of the samples were measured and repeated 3 times using a spectrophotometer-colourimeter (HunterLab, UltraScan VISs/n: USVIS 1406). Total colour change was then computed using Equation (1) (Ferrão et al., 2019; Maskan, 2006).

$$TCD = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \tag{1}$$

Equation (1) means L_0^*, a_0^*, and b_0^* denoted as the colour parameters of the original plants, and L*, a* and b* mean the colour parameters of the dried sample.

Water solubility

For water solubility determination, 1 g of the dried sample was weighed into a centrifuge tube, 10 mL of distilled water was added, and homogeneously mixed. Afterwards, the mixture was then incubated in a water bath (NH 03801, USA) at 37 ^{o}C for 30 min, and centrifuged at 3,000 rpm for 10 min using a centrifuge (2-16PK, Gerhardt, Germany). The residue was dried at 105 ^{o}C for 3 h. The water solubility was computed from Equation (2) (Que et al., 2008).

$$Solubility(\%) = \frac{Residue\ weight\ (g)}{Sample\ weight\ (g)} \times 100 \tag{2}$$

2.6 Determination of microbiological properties

The total plate count (AOAC Official Method 990.12), and yeast and mold (AOAC Official Method 2014.05) of the samples were determined using the pour plate technique as standard methods (AOAC, 1990). The number of microorganisms was expressed as colony-forming units per 1 g of sample (CFU/g). Duplicates were done for each dilution.

2.7 Statistical analysis

Significant differences among means of all treatments were subjected to analysis of variance (ANOVA) by new Duncan's multiple range test; the confidence limits used in this study were based on 95% ($p \leq 0.05$).

3 Results and Discussion

3.1 Effect of feed concentration on powder recovery of spray-dried and freeze-dried powders

The powder recovery or process yield, which is an important factor relating to production cost and efficiency of drying process, of the dried star gooseberry (*S. androgynus*), ceylon spinach (*B. alba*), and cowslip creeper (*T. minor*) is shown in Figure 1. It was found that the feed concentrations significantly affected the powder recovery. At the high feed concentration (80%), the powder recovery of all samples was higher than that of the powders obtained from the feed concentration at 50% and 65%, respectively. It was due to the higher feed concentration giving a higher solids content in feed, and therefore the solids in feed solution that became the powders after drying. The powder recovery of the FDP was significantly higher than those of SDP. Some dried powders stuck in the spray drying chamber, which caused a loss of powder. The results were in agreement with the results of Santo et al. (2013).

In addition, a higher feed concentration of plant resulted in increased powder recovery due to the entire soluble solid of fresh plants. The powder recovery of the dried ceylon spinach (*B. alba*), and star gooseberry (*S. androgynus*) was 69.63-77.47%, while the powder recovery of the dried cowslip creeper (*T. minor*) was 50.79-58.41%. However, the powder recovery of all dried samples was more than 50%, showing the successful drying in the laboratory-type drier (Bhandari et al., 1997).

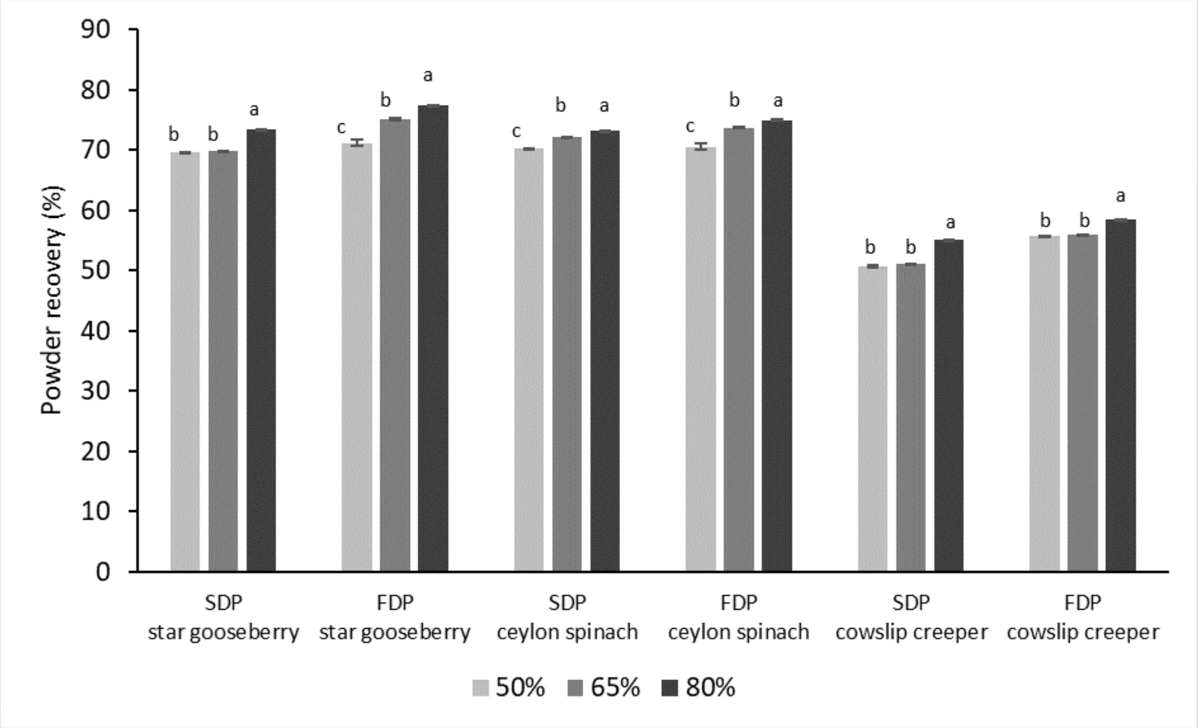

Figure 1: Percentage of powder recovery of selected herbal plants after spray and freeze drying at various plant feed concentrations of 50%, 65% and 80%. The bars with the same letter for each group were not statistically different (p>0.05)

3.2 Effect of feed concentration on nutritional values of spray-dried and freeze-dried powders

After drying, the moisture of some selected plant powders was much less compared to the fresh plants from 77.56-92.34% down to 3.17-5.85% (Table 1). The moisture content of FDP was higher than that of SDP ($p \leq 0.05$) because of a high temperature during spray drying. Santo et al. (2013) also concluded that higher moisture contents were achieved with freeze drying comparative to spray drying. However, the moisture of the powder might have increased during storage due to hygroscopicity, which is the ability of materials to absorb moisture when exposed to the environment. The lower hygroscopicity, with the addition of maltodextrin into the feed, caused the stickiness and coagulation of the powders (Chen et al., 2014).

The nutritional values of dried star gooseberry (*S. androgynus*), ceylon spinach (*B. alba*), and cowslip creeper (*T. minor*) powders are shown in Table 1. The feed concentrations affected the contents of ash and carbohydrate of *B. alba* and *T. minor* dried samples. An increased of feed concentration led to an increase of ash content and a decreased of carbohydrate of the samples. Moreover, the feed concentration also had an effect on protein and fibre contents of *S. androgynus* dried sample. The dried star gooseberry (*S. androgynus*) contained high protein (13.01-18.61%) and fibre (5.03-5.52%) due to its original source, suggesting a potential protein and fibre source of plant-based powder. The vitamin C contents of SDP were higher than that of FDP because of a short processing time of spray drying compared to freeze drying (including freezing

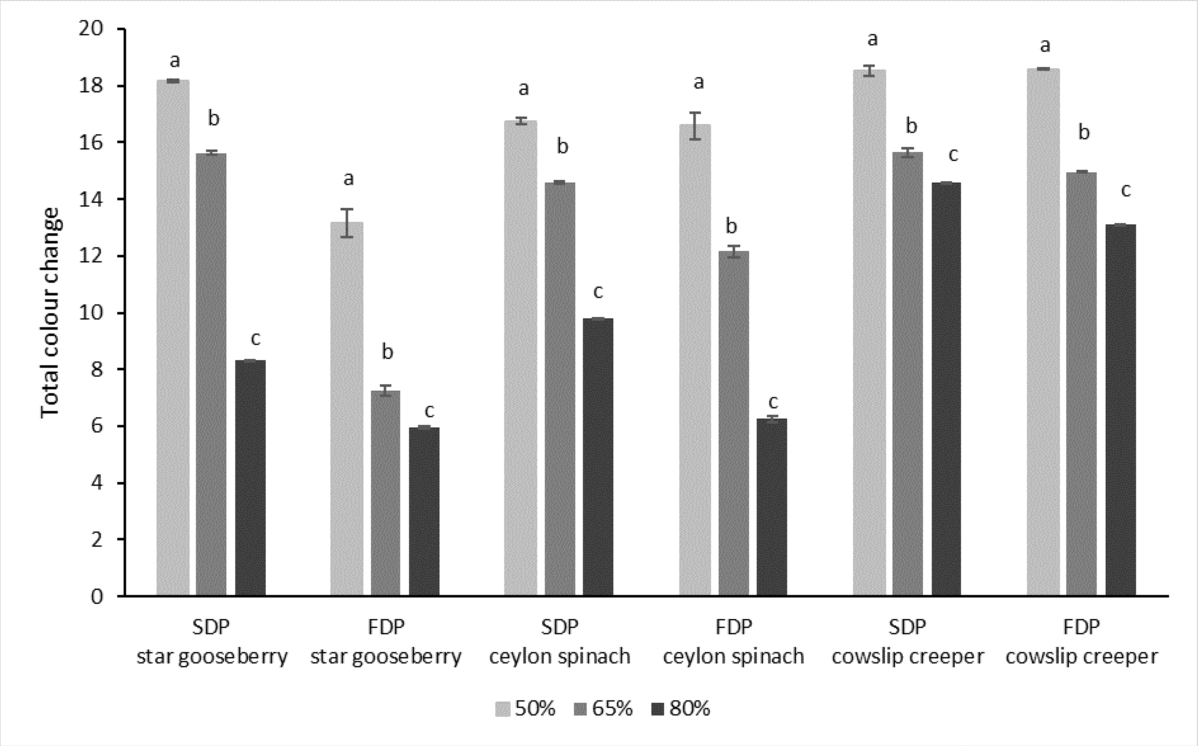

Figure 2: Total colour change of spray-dried and freeze-dried powders at various plant feed concentrations of 50%, 65% and 80%. The bars with the same letter for each group were not statistically different (p>0.05)

and drying process times). It has been reported that spray drying techniques could be used to preserve natural juice in a powder form as a potential source of nutritional values (Badmus et al., 2016), and freeze drying should also preserve the nutrients because of a short exposure of nutrients to oxygen, which resulted in fewer oxidation/degradation reactions (Silva-Espinoza et al., 2019).

3.3 Effect of feed concentration on physical properties of spray-dried and freeze-dried powders

Figure 2 illustrates the total colour change of SDP and FDP, showing the value in the range between 5.96 and 18.58 compared to the original samples, and showing a clear difference colour of the dried powder in comparison to the fresh plant. It has been reported that a larger value of total colour change denotes greater colour change from the reference material (fresh sample). A typical scale for evaluation of the colour difference is as follows: total colour change value in the range between 0.0 and 2.0 corresponds to unrecognizable differences, in the range between 2.0 and 3.5 corresponds to differences possible to recognize by an experienced observer, and over 3.5 corresponds to clear differences of colour (Ferrão et al., 2019). In the study, a high concentration of plant (80%) led to a small total colour change value, showing a fresh-colour similar to the original feed, followed by the 65% and 50% of plant, respectively. Moreover, the colour of FDP was greener than the SDP powder, showing lower total colour change value compared to SDP. Freeze

Table 1: Nutritional values (wet basis) of spray-dried and freeze-dried powders at various plant feed concentrations (50%, 65% and 80%) compared to the fresh plant

Plant sample	**Nutritional values (%)**						**Vitamin C**
	Moisture	**Protein**	**Fibre**	**Ash**	**Fat**	**Carbohydrate**	**(mg/100 g)**
Star gooseberry (*Sauropus androgynus*)							
Fresh	$77.56+1.25^{a}$	8.25 ± 0.03^{e}	3.46 ± 0.02^{f}	1.87 ± 0.02^{d}	0.19 ± 0.01^{d}	8.67 ± 0.15^{f}	9.04 ± 0.02^{c}
SDP (50%)	3.75 ± 0.02^{d}	13.25 ± 0.01^{c}	5.03 ± 0.01^{e}	9.83 ± 0.01^{c}	0.58 ± 0.02^{c}	67.56 ± 0.01^{a}	8.95 ± 0.02^{d}
SDP (65%)	3.74 ± 0.05^{d}	14.32 ± 0.02^{b}	5.38 ± 0.04^{c}	10.36 ± 0.03^{b}	0.56 ± 0.02^{c}	65.64 ± 0.04^{c}	11.84 ± 0.03^{b}
SDP (80%)	3.47 ± 0.07^{e}	16.81 ± 0.01^{a}	5.52 ± 0.02^{a}	12.07 ± 0.03^{a}	0.64 ± 0.02^{a}	61.49 ± 0.06^{e}	15.72 ± 0.01^{a}
FDP (50%)	5.85 ± 0.03^{b}	13.01 ± 0.06^{c}	5.08 ± 0.01^{d}	9.30 ± 0.02^{c}	0.59 ± 0.01^{c}	66.17 ± 0.02^{b}	7.67 ± 0.02^{f}
FDP (65%)	5.75 ± 0.03^{b}	14.52 ± 0.02^{b}	5.31 ± 0.03^{c}	10.36 ± 0.01^{b}	0.61 ± 0.01^{b}	63.45 ± 0.02^{d}	7.67 ± 0.01^{f}
FDP (80%)	5.54 ± 0.01^{c}	16.42 ± 0.01^{a}	5.48 ± 0.01^{b}	11.12 ± 0.02^{a}	0.63 ± 0.02^{a}	60.81 ± 0.04^{e}	7.83 ± 0.06^{e}
Ceylon spinach (*Basella alba*)							
Fresh	92.34 ± 1.13^{a}	2.12 ± 0.02^{e}	0.84 ± 0.01^{g}	1.56 ± 0.01^{g}	0.23 ± 0.01^{f}	2.91 ± 0.06^{g}	5.16 ± 0.02^{c}
SDP (50%)	5.58 ± 0.01^{b}	4.37 ± 0.01^{c}	3.17 ± 0.03^{f}	9.56 ± 0.02^{e}	1.12 ± 0.01^{d}	76.20 ± 0.02^{b}	3.41 ± 0.01^{e}
SDP (65%)	5.25 ± 0.02^{d}	4.49 ± 0.02^{b}	3.41 ± 0.02^{d}	12.68 ± 0.02^{c}	1.14 ± 0.01^{c}	73.03 ± 0.01^{d}	5.87 ± 0.00^{b}
SDP (80%)	5.15 ± 0.01^{e}	4.68 ± 0.02^{a}	3.84 ± 0.02^{b}	15.72 ± 0.01^{b}	1.25 ± 0.02^{b}	69.36 ± 0.02^{e}	7.73 ± 0.03^{a}
FDP (50%)	5.46 ± 0.02^{c}	4.31 ± 0.01^{d}	3.27 ± 0.02^{e}	9.06 ± 0.01^{f}	1.06 ± 0.01^{e}	76.84 ± 0.01^{a}	3.13 ± 0.06^{f}
FDP (65%)	5.42 ± 0.02^{c}	4.32 ± 0.01^{d}	3.52 ± 0.01^{c}	12.05 ± 0.03^{d}	1.15 ± 0.02^{c}	73.54 ± 0.02^{c}	3.97 ± 0.06^{d}
FDP (80%)	5.10 ± 0.02^{e}	4.31 ± 0.01^{d}	3.97 ± 0.01^{a}	16.34 ± 0.02^{a}	1.31 ± 0.01^{a}	68.97 ± 0.01^{f}	4.00 ± 0.10^{d}
Cowslip creeper (*Telosma minor*)							
Fresh	81.54 ± 1.08^{a}	5.08 ± 0.03^{e}	0.76 ± 0.02^{f}	2.12 ± 0.02^{e}	1.17 ± 0.01^{f}	9.33 ± 0.31^{f}	7.58 ± 0.03^{b}
SDP (50%)	3.21 ± 0.00^{a}	8.35 ± 0.03^{c}	4.06 ± 0.01^{d}	9.22 ± 0.00^{d}	3.24 ± 0.01^{e}	71.92 ± 0.02^{a}	4.38 ± 0.02^{d}
SDP (65%)	3.20 ± 0.02^{a}	8.42 ± 0.01^{b}	4.28 ± 0.02^{b}	10.47 ± 0.02^{c}	3.64 ± 0.02^{b}	69.99 ± 0.01^{b}	7.15 ± 0.04^{c}
SDP (80%)	3.17 ± 0.02^{a}	8.58 ± 0.02^{a}	4.33 ± 0.02^{a}	13.26 ± 0.01^{a}	3.91 ± 0.02^{a}	66.75 ± 0.02^{d}	9.26 ± 0.02^{a}
FDP (50%)	5.82 ± 0.02^{b}	8.31 ± 0.01^{d}	4.01 ± 0.01^{e}	10.43 ± 0.02^{c}	3.32 ± 0.01^{d}	68.11 ± 0.01^{c}	3.07 ± 0.06^{g}
FDP (65%)	5.69 ± 0.01^{e}	8.31 ± 0.01^{d}	4.21 ± 0.01^{c}	11.50 ± 0.01^{b}	3.45 ± 0.02^{c}	66.84 ± 0.01^{d}	3.87 ± 0.06^{f}
FDP (80%)	5.39 ± 0.02^{g}	8.33 ± 0.01^{cd}	4.31 ± 0.02^{a}	13.25 ± 0.03^{a}	3.87 ± 0.02^{a}	64.85 ± 0.02^{e}	4.03 ± 0.06^{e}

Data within column for each plant species followed by the same letter were not statistically different ($p>0.05$)

drying then seemed to be a suitable drying technique for preserving the colour of dried product (Liaotrakoon et al., 2012; Santo et al., 2013). It is because of non-thermal processing, therefore the losses of colour, flavour and volatile components were minimal, resulting in a stable in colour and flavour of the dried product (dos Santos et al., 2018).

The a_w of SDP and FDP herbal plants is shown in Table 2. An increase plant concentration led to a decrease of a_w of dried powders, and also found that the SDP and FDP of all plant species at the high plant concentration (80%) provided the lowest a_w value ($p\leq0.05$), followed by the 65% and 50% of plant, respectively. A low a_w (0.19-0.37) of the studied samples could inhibit the growth of microbes of the dried product. However, the study also found that the a_w value of SDP was significantly lower than that of FDP ($p\leq0.05$). It was found that when the feed concentration of the samples was increased, the solubility values of FDP and SDP of the dried plants also increased (Table 2). Solubility of all plant species at the high plant concentration (80%) was higher than that of the plant concentration of 65% and 50%, respectively ($p\leq0.05$). The solubility values of both FDP and SDP *B. alba* and *T. minor* were comparable in value, while the solubility values of FDP *S. androgynus* was higher than that of SDP *S. androgynus* ($p\leq0.05$). The dried star gooseberry (*S. androgynus*) powder had a higher solubility (70.73-85.44%) than the others (47.96-65.07%). On the other hand, the solubility of SDP lime powder was 59.54-76.84% (Chuacharoen, 2017).

Table 2: Physical properties of spray-dried and freeze-dried powders at various plant feed concentrations of 50%, 65% and 80%.

Plant powders	**a_w**	**Water solubility (%)**
Star gooseberry (*Sauropus androgynus*)		
SDP (50%)	0.32 ± 0.00^b	70.73 ± 0.21^e
SDP (65%)	0.24 ± 0.02^c	77.28 ± 0.11^d
SDP (80%)	0.21 ± 0.02^d	82.65 ± 0.13^b
FDP (50%)	0.37 ± 0.00^a	71.20 ± 0.50^e
FDP (65%)	0.36 ± 0.01^a	79.76 ± 0.26^c
FDP (80%)	0.31 ± 0.00^b	85.44 ± 0.20^a
Ceylon spinach (*Basella alba*)		
SDP (50%)	0.23 ± 0.01^c	51.85 ± 0.15^c
SDP (65%)	0.24 ± 0.00^c	58.24 ± 0.10^b
SDP (80%)	0.21 ± 0.01^d	64.51 ± 0.22^a
FDP (50%)	0.31 ± 0.01^a	52.61 ± 0.41^c
FDP (65%)	0.26 ± 0.02^b	59.08 ± 0.35^b
FDP (80%)	0.21 ± 0.01^d	65.07 ± 0.30^a
Cowslip creeper (*Telosma minor*)		
SDP (50%)	0.29 ± 0.00^b	48.36 ± 0.12^b
SDP (65%)	0.21 ± 0.00^d	48.95 ± 0.15^b
SDP (80%)	0.19 ± 0.00^e	51.20 ± 0.24^a
FDP (50%)	0.31 ± 0.01^a	47.96 ± 0.10^b
FDP (65%)	0.25 ± 0.00^c	48.47 ± 0.15^b
FDP (80%)	0.20 ± 0.01^d	50.00 ± 0.22^a

Data within column for each plant species followed by the same letter were not statistically different ($p>0.05$)

3.4 Effect of feed concentration on microbial counts of spray-dried and freeze-dried powders

A decrease of microbial counts clearly showed in dried powders compared to the fresh plants, especially for total plate count (reduced from 10^5-10^6 (fresh) to 10^2 (powder) CFU/g) due to a drying processing (Table 3). The total plate count of both SDP and FDP was found to be less than 3×10^2 CFU/g with a range between 1.3×10^2 and 2.7×10^2 CFU/g, and yeast and mold of the samples was less than 10 CFU/g.

The feed concentration tended to have no effect on microbiology properties of the dried samples, while the SDP seemed to have lower microbial counts compared to the FDP. The results were found to relate to the lower aw values (Table 2) and moisture contents (Table 1) of the SDP samples compared to the FDP. This was because the SDP was dried under a high temperature (180 ^oC) with a short contact time, which caused a reduction in the number of microbes. The freeze drying also produces a very low moisture product that can prevent the growth of microorganisms, including bacteria, yeasts and molds. However, dos Santos et al. (2018) reported that freeze drying preserves the microbiological and sensory characteristics of yoghurt when compared to spray drying.

Table 3: Microbiology properties of spray-dried and freeze-dried powders at various plant feed concentrations of 50%, 65% and 80% compared to the fresh plant

Plant powders	**Total plate count (CFU/g)**		**Yeast and mold (CFU/g)**	
	SDP	**FDP**	**SDP**	**FDP**
Star gooseberry (*Sauropus androgynus*)				
Fresh	$2.7x10^5$		≤10	
50%	$1.3x10^2$	$1.6x10^2$	≤10	≤10
65%	$1.6x10^2$	$1.7x10^2$	≤10	≤10
80%	$1.6x10^2$	$1.9x10^2$	≤10	≤10
Ceylon spinach (*Basella alba*)				
Fresh	$3.2x10^5$		≤10	
50%	$1.5x10^2$	$2.7x10^2$	≤10	≤10
65%	$1.6x10^2$	$2.5x10^2$	≤10	≤10
80%	$1.7x10^2$	$2.5x10^2$	≤10	≤10
Cowslip creeper (*Telosma minor*)				
Fresh	$1.5x10^6$		≤10	
50%	$1.3x10^2$	$1.5x10^2$	≤10	≤10
65%	$1.3x10^2$	$2.0x10^2$	≤10	≤10
80%	$2.4x10^2$	$2.4x10^2$	≤10	≤10

4 Conclusions

The drying processes (spray drying and freeze drying) and feed concentrations of selected plant (80%, 65% and 50%, w/w) significantly affected the colour change, solubility, nutritional and microbiological characteristics of dried star gooseberry (*S. androgynus*), ceylon spinach (*B. alba*), and cowslip creeper (*T. minor*). The powder recovery was 50.79-77.47%, and the total colour change value of plant powders at a high feed concentration (80%) was the lowest value, followed by the plant concentration of 65% and 50%, respectively, and it was found that the colour change of FDP was lower than that of the SDP ($p<0.05$). At high feed concentration, the solubility of plant powders was significantly increased. The SDP provided lower a_w and moisture content than that of FDP ($p<0.05$).

A potential source of protein and fibre were found in the dried star gooseberry (*S. androgynus*) powder. The microbial counts of both SDP and FDP were <300 CFU/g of total plate count, and <10 CFU/g of yeasts and molds.

According to the main results, it could be concluded that the high ratio of feed plant (80%) is suggested to prepare samples prior to drying, and that stickiness may occur during the spray drying process. Freeze drying tended to preserve the colour of the powder, whereas spray drying seemed to reduce the moisture, aw and microbial count compared to the other one. Therefore, the dried selected herbal plants could be considered as an excellent source of nutrition, and also the FDP of star gooseberry (*S. androgynus*) and ceylon spinach (*B. alba*) could be suggested to be a (green) natural colouring.

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