Chapter 4

Results and discussion

The physicochemical properties of spray-dried lime powder were analyzed for color, moisture, solubility, hygroscopicity, particle size, morphology, vitamin C, total phenolic, total flavonoid compounds, and antioxidant activity. The production of the powder was optimized to reach the highest quality of lime juice powder.

4.1 Lime juice composition

The average amount of lime juice per kg of lime was 621.8 mL or 0.59 kg. Nutritional value of lime juice per 100 g was carbohydrate 10.5 g (sugar 1.7 g + dietary fiber 2.8 g), fat 0.2 g, protein 0.7 g, vitamins (Thiamine, B1 0.03 mg (3%), Riboflavin, B2 0.02 mg (2%), Niacin, B3 0.2 mg (1%), Pantothenic acid, B5 0.217 mg (4%), vitamin B6 0.046 mg (4%), folate, B9 8 mg (2%), and vitamin C 29.1 mg (35%)), minerals and water (88.3 g). The total soluble solids (TSS) of lime juice measured using a digital Refractometer (AR 200, Reichert, USA) was 8% Brix (100-88.3=11.7). A low pH of lime juice was 2.1, which referred to low acid juice inhibiting microbial growth.

4.2 Morphology and particle size analyses of lime powder

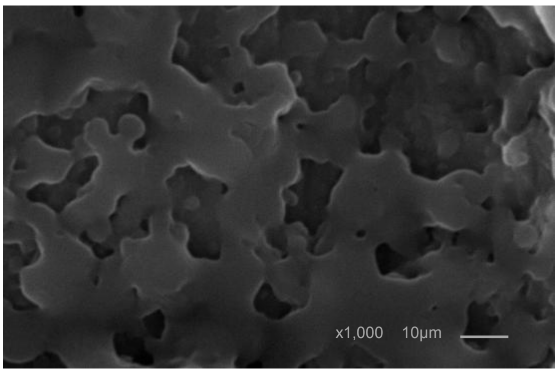
The average particle size (Table 4.1) for spray-dried lime powder produced with homogenization ranged from 0.1 to 4 μm was smaller than that of non-homogenized powder from 18 to 26 μm. It can be assumed that the homogenization of lime juice feed applied before spray-drying had lead to formation of smaller droplets. When the droplet is contacted to high drying air, the evaporation of moisture is more rapid compared with a bigger droplet.

Table 4.1 Particle size of lime powder with and without homogenization

Samples	Average diameter (μm)
Lime powder	18-26
Homogenized lime powder	0.1-4

The morphological characteristics of spray-dried lime powder with and without high shear homogenization are shown in Figure 4.1. The surface morphology study showed differed shapes and size between the spray-dried powder materials. In non-homogenized powder, the particles were clumped together and no individual particle was formed. On the other hand, both small and large spherical particles were observed in homogenized lime powder at 1,000x magnification. Its smooth surface, small size, and spherical shape differed from the non-homogenized powder resulted from high shear homogenization because the spray drying condition were kept constant for both samples.

(A)



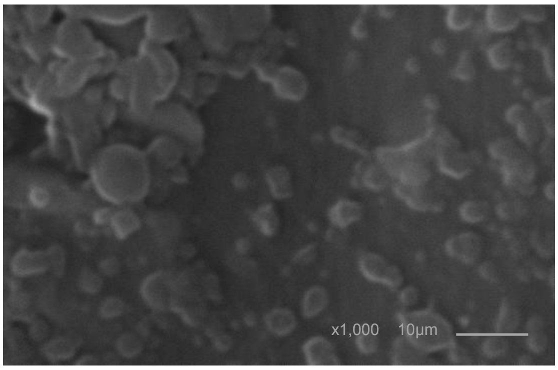
(B) 

Figure 4.1 SEM images of spray-dried lime powders (A) without homogenization (B) with homogenization

4.3 Lime powder analyses

In this study, we used the same spray drying conditions for all treatments. The spray-dried powders, which a smaller particle size showed the higher yield compared with untreated powder. Moisture contents regardless of drying agent (Table 4.2) affected by the air flow rate, drying air temperature of the spray dryer (Goula & Adamopoulos, 2005), and evaporation rate droplet size (Chranioti, Chanioti, & Tzia, 2016; Noshad, Mohebbi, Koocheki, & Shahidi, 2015). A reduced size of particles results in lower residual moisture content due to faster diffusion rates (Bhattarai et al., 2001).

Both lime powders had a whitish color, which homogenized lime power was significantly lighter compared to that of non-homogenized one (Table 4.2). Chroma measurement indicates the vividness of color and the value of homogenized lime power is lower. A hue angle indicates color based on a circle of 0°, 90°, 120°, and 240° represent a red, yellow, green, and blue color, respectively. The homogenized lime power had significantly ($p<0.05$) higher Hue angle values, which had stronger yellow color.

Table 4.2 Physical analyses of lime powder with and without homogenization

Powder Analyses	Lime powder	Homogenized lime powder
Yield (%)	72.82 ± 2.31^{a}	84.11 ± 0.29^{b}
Moisture content (g/100 g powder)	5.42 ± 0.61^{a}	3.91 ± 0.14^{b}
Color variables		
*L**	79.5 ± 0.01^{a}	84.1 ± 0.01^{a}
Chroma	12.55 ± 0.014^{a}	8.91 ± 0.008^{a}
Hue angle	74.5 ± 0.01^{a}	78.8 ± 0.07^{b}
Solubility (%)	59.54 ± 0.24^{a}	76.84 ± 0.32^{b}
Hygroscopicity (g/100g)	12.99 ± 0.11^{a}	11.68 ± 0.27^{a}

Mean ± standard deviation of triplicate analysis. $^{a,\,b}$ means with same letters in each row are not significant ($p<0.05$).

4.4 Solubility and Hygroscopicity

The size of particles affects not only its physical properties, but might have contributed to solubility and hygroscopicity properties of the spray-dried powder. The solubility percentage of the samples ranged between 59.54 and 76.84% (Table 4.2). The smaller particles resulting in lower moisture content in homogenized powder compared with non-homogenized one might have contributed to increased solubility. Less hygroscopicity was observed in homogenized powder.

4.5 Phytochemical and antioxidant activity analyses

Fresh lime juice contained 7.74 mg gallic acid/g solid, 2.67 mg quercetin acid/g solid and 19.85 μmol Trolox /g solid. The antioxidant activity derived from total phytochemical compounds in the powders was reported in Table 4.3.

Table 4.3 Ascorbic acid, gallic acid and trolox equivalents of lime powder with and without homogenization

Analyses	Lime powder	Homogenized lime powder
Ascorbic acid (mg/g solid)	0.19 ± 0.01^{a}	0.41 ± 0.02^{b}
Gallic acid equivalents (mg/g solid)	1.49 ± 0.12^{a}	2.51 ± 0.34^{b}
Quercetin equivalents (mg/g solid)	0.32 ± 0.01^{a}	0.37 ± 0.02^{a}
Trolox equivalents (μmol/g solid)	7.93 ± 0.12^{a}	13.48 ± 0.22^{b}

Mean ± standard deviation of triplicate analysis. $^{a, b}$ means with same letters in each row are not significant ($p<0.05$).

Phytochemical contents and antioxidant activity of lime powders were decreased from the fresh form when operated by hot-air spray dryer. The initial ascorbic acid contained in fresh lime juice was degraded approximately 93% and 86% in lime powder with and without homogenization, respectively. The result showed that entrapment process by homogenization before spray drying could protect some ascorbic acid loss. The same results were observed in total phenolic content, which showed the higher amounts in homogenized powder, but total flavonoid content showed no significant difference on drying for both powders. However, significantly increased antioxidant activity measured by DPPH assay was observed in the homogenized lime powder when compared with untreated powder.

This result could be due to individual phenolic compounds have different degree of tolerance to heat and the structural degradation affects its content and activity of lime powder during the hot drying process. Thus, the change in phenolic and flavonoid contents and antioxidant activity depends upon individual phenolic acid constituents and their susceptibility to heat and conformational changes. Thus, this study indicated that applying drying agents and the high shear homogenization could protect phytochemical compounds from heat during spray drying.