Phytochemicals and Antioxidant Properties of Mao (*Antidesma thwaitesianum* Muell. Arg.) Fruit Juice Powders Prepared using Spray Drying and Foam Mat Drying Techniques

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ABSTRACT

Background: The limitations of Mao (*Antidesma thwaiteaianum*) fruit juice are the short period of production and the weight of juice products with containers. Thus, the fruit powder is the most form of juice that is solved this problem, enhancing shelf life and convenience to drink.

Methods: Our study was conducted on the processing of Mao fruit powders prepared from spray and foam mat drying with their sensory evaluations; and comparison of their water activity, anthocyanin and tannin contents and antioxidant properties.

Result: The foam mat drying powder had more preferable physical appearance including regularly fine granules with rose colors. While spray drying powder was irregularly coarse granules with pale rose-colored. This sensory evaluation was associated with the appearance and color of fruit powders and foam mat powder had more likeness scores on appearance, color and overall, rather than spray drying powder. Therefore, the solubility, flavor, texture and taste of foam mat powder had slightly lower likeness scores. Only anthocyanin content of spray drying powder (118.92 mg/kg) was significantly higher than foam mat powder (75.03 mg/kg). Whereas, water activity (aw), tannin content (TC) and DPPH scavenging activity (DPPH) of spray and foam mat drying powders were not statistically different at $p<0.05$ (aw = 0.41 and 0.44; TC = 0.66 and 0.65 mg/kg; DPPH = 395.69 and 335.82 mg tannin equivalent/100 g and 355.33 and 299.05 mg ascorbic acid equivalent/100 g, respectively).

Key words: *Antidesma thwaiteaianum*, Foam mat drying, Juice powder, Mao fruit, Spray drying.

INTRODUCTION

The fruit juice industry in Thailand is experiencing rapid growth and increasing competition, with a variety of products becoming available as more companies enter the market. Research has shown that developing healthy fruit and vegetable juice products can not only enhance people's quality of life but also increase household income significantly (Visuthranukul *et al.,* 2022). Tannins and anthocyanins, the common antioxidants, are applied to determine the quality of fruit juice, which is affected by the color, taste and health benefits of juice products. Studies on black chokeberries and apples had shown that the addition of black chokeberry juice to apple juice is enhances its antioxidant properties, total phenolic content and total anthocyanin levels, which had improved the overall quality of the mixed juice (Nour, 2022). Similarly, bignay fruit juice is supplemented with anthocyanin content contained aloe vera gel had impacted on antioxidant activity of the juice, which is shown the importance of bioactive compounds in fruit juice quality (Suriati *et al*., 2023). Furthermore, investigations on pomegranate cultivars have demonstrated the significant variations of tannin, anthocyanin and antioxidant levels contained in the skin and in juice. There had revealed the importance of phytochemical profiles, which have contributed to fruit juice quality (Mottaghipisheh *et al*., 2018; Untari and Satria, 2022).

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Spray drying of fruit juice is a conventional method, which is used to convert liquid juice into powder form to improve its shelf life and convenience for various applications. The optimization of this drying method significantly impacted the yield, acerbic acid, phenolic content, solubility and moisture content of the product. In addition, the use of structuring additives like milk proteins can improve the drying process and retain valuable bioactive components in the fruit powder. Additionally, the appropriate concentration of carrier agent and processing temperature provide desirable characteristics such as good rehydration times and antioxidant activity in the spray-dried fruit powders (Huynh *et al.,* 2023; Gani *et al.,* 2022; Pui and

Lejaniya, 2022; Jasiński, 2012; Illya Szilak., 2024). Foam mat drying is also a technique used to convert fruit juices into stable powders with enhanced shelf life and convenience. Various fruits including papaya, blueberry and pomelo have been studied for their potential in foam mat drying, which results in powders rich in nutrients such as vitamins, minerals and bioactive compounds. This process involves the creation of foam from the fruit juice mixed with suitable agents *i.e.,* glycerol monostearate or egg albumen and followed by drying in a powdered form with desirable physicochemical properties. These foam-mated fruit juice powders can be utilized in the production of ready-to-drink beverages, bakery products, ice cream and yogurt, offering a convenient way to incorporate the nutritional benefits of fruits into various food products. Recently, a study on optimization of the foam composition and drying parameters of different fruits has been conducted to maximize the retention of bioactive compounds and preferable sensory evaluation (Vani *et al.,* 2019; Noordia *et al.,* 2020; Sangamithra *et al*., 2014; Na and Na, 2024) .

Antidesma thwaitesianum, known as Mao in Thailand, is a tropical fruit with various applications. The fruit juice of *A. thwaitesianum* has shown significant antimicrobial properties against food-borne pathogens and spoilage, making it a potential natural food preservative. Additionally, Mao fruits are a source of anthocyanins, with studies indicating that storage at lower temperatures enhances the stability of anthocyanins in Mao juice and concentrate (Tinchan *et al.,* 2022; Min *et al.,* 2024). Furthermore, extracts from *A. thwaitesianum* have demonstrated antioxidant and antimicrobial activities of the water extract from the decocting residue, which shows strong antioxidative power and high total phenolic content (Prommakool and Phattayakorn, 2016) . Therefore, Mao fruit is cultivated in North-Eastern of Thailand and the harvesting time is limited to about three months of the winter season. The limitation of juice is manufactured in a short time and the weight of products (with containers), they are difficulted to transport between regions. Thus, fruit powder is the most common form of juice that has solved this problem. In addition, fruit powder products are enhancing shelf life and convenience to drink. The spray drying of fruit juice is an expensive drying method that is unsuitable for small manufacturer entrepreneurs (SMEs) who cultivate and process Mao juice in small-scale production. Hence, the foam mat drying method is lesser invested and more appropriate to SMEs, therefore the phytochemicals and antioxidants of Mao juice powder from different drying methods are concerned with its quality. Our study was conducted on the processing of Mao fruit powders prepared from spray and foam mat drying with their sensory evaluations; and a comparison of their water activity, anthocyanin and tannin contents and antioxidant properties.

This study examines the quality and sensory characteristics of Mao fruit powders produced via spray drying and foam mat drying. It assesses the powders' water activity, anthocyanin, tannin concentration and antioxidant activity. It also evaluates the advantages of each drying process in terms of product appearance, shelf life and ease of possible food industry uses. The research also looks at the antioxidant capabilities of each drying method.

MATERIALS AND METHODS

Fruit collection and juice preparation

The Mao fruits (10 kg) were purchased from local markets, Sakon Nakhon, North-Eastern of Thailand from December 2023 to February 2024. The fruits were small-rounded in bushy. The purplish-black colored ripe fruits (~4.5 kg) were selected, pooled together, cleaned and squeezed. After the juicing process, the marc and seed were removed and the rose-color juice was stored at 4°C before drying process.

Drying process of fruit juice powder

Before drying processes, concentrated juice was diluted with distilled water (1:1), added with 4% (w/v) sucrose and boiled for 10 min.

Spray drying

The 300 ml of prepared juice was added with 45 g of maltodextrin and homogeneously mixed. The mixture was loaded into a spray dryer (Mini Spray Dryer B-290, Büchi Germany) and the drying conditions included water evaporation rate (~1 ml/sec), drying temperature (~150°C) and pump pressure (40%).

Foam mat drying

The 300 ml of prepared juice was added with 15 g of maltodextrin and 45 g of egg albumin. The mixture was thoroughly mixed for 20 min by a Food mixer (Cucira Hr 1539 Terbaru, Philips, Thailand) until the foaming occurred. The foaming juice was spread on the waxed sheet and dried with a dryer machine (Skyline Pro Electric Combi Oven 10GN1/1, Electrolux, Thailand) until the surface of the spread powder was completely dried. The fruit powder was ground with a food blender (HR2221/00, Philips, Thailand) until it was finely powdered form.

After the drying processes, each fruit juice powder was collected in an opaque container and kept at 25°C in at drying environment.

Quality of Mao juice powder

Sensory evaluation

Three juice powders from spray and foam mat drying methods were evaluated for physical properties, which included appearance, color, solubility, flavor, texture and taste. The forms of sensory tests were used on a 9-point hedonic scale (Lawless and Heymann, 1999; Meilgaard *et al*., 1999) and panelists (n = 30) filled out the forms. Panelists were evaluated on the appearance and color of juice powder and the solubility, flavor, texture, taste and overall likeness of brewed juice were evaluated after drinking.

Water activity

The water activity (a_w) revealed the moisture content in juice powders, which was determined according to AOAC (AOAC International, 2019). The aw meter was used to measure the moisture content of juice powders and the variation of values was acceptable within ±0.02. Actually, the a_w value of dried food as juice powder should be lower than 0.6, which can inhibit the growth of food borne pathogens and spoilage microbials.

Phytochemical contents

Tannin content

Each juice powder was determined the tannin content by using a spectrophotometric-based method (λmax = 760 nm). This analytical approach involved the use of Folin-Denis reagent (Sigma Alrich, USA) in accordance with the established by the AOAC. A standard curve was performed by utilizing of known concentration of tannic acid (Sigma-Aldrich, USA) (AOAC, 2005).

Anthocyanin content

Each juice powder was determined anthocyanin content by using pH differential method (λmax = 520 and 700 nm, respectively), which was modified from AOAC. The content was calculated from both absorbance and dilution factors and reported as mg of cyanidin-3-glucoside equivalent (CE) per L (AOAC, 2005) .

Antioxidant assay

The Mao juice powder was determined for antioxidant activity by the monitoring of 2,2-diphenyl-1-picrylhydrazyl, DPPH (Sigma Alrich, USA) radicals. The reduction of DPPH radicals in the presence of juice was monitored microplate reader at 550 nm. The scavenging activity of DPPH radicals was expressed in mg of Trolox equivalent (TE) per 100 ml and in ascorbic equivalent (AE) per 100 ml (Katsube *et al.,* 2004).

Statistical analysis

Each likeness of factor from sensory evaluation was represented as the average of panelist scores. Water activity (a_w), tannin and anthocyanin content and DPPH scavenging activity of Mao juice powder from different drying methods were represented as average of parameters, which were calculated from triplicated measurements. The differences in water activity, phytochemical contents and antioxidant activity between drying methods were analyzed with an independent *t*-test and statistically significant was judged at $p<0.05$.

RESULTS AND DISCUSSION

The Mao fruit powders from spray and foam mat drying methods are depicted in Fig 1. The foam mat drying powder is characterized by its more attractive physical appearance, including uniformly fine granules with a rose color. In contrast, the spray drying powder has irregularly coarse granules and a pale rose color. These observations align with the sensory evaluation results shown in Table 1, where foam mat drying received higher scores for appearance, color and overall acceptability compared to spray drying. However, spray drying was rated slightly higher for solubility, flavor, texture and taste. The reduced scores for these attributes in the foam mat powder may be attributed to the use of a foaming agent. Table 1 presents the sensory evaluation scores of Mao fruit juice powders prepared using spray drying and foam mat drying. A panel of 30 participants rated various sensory characteristics on a scale from 1 (extreme dislike) to 9 (extreme like). The evaluated aspects include appearance, color, solubility, flavor, texture, taste and overall acceptability.

The results indicate that foam mat drying received higher ratings for appearance (6.7 vs. 4.5), color (8.1 vs. 5.8) and overall acceptability (7.4 vs. 6.9) compared to spray drying. This suggests that the foam mat drying process produced a more visually appealing and acceptable product. On the other hand, spray drying was rated slightly better for solubility (7.8 vs. 7.2), flavor (7.5 vs. 7.1), texture (7.3 vs. 7.0) and taste (8.4 vs. 8.2), indicating that it maintained better functional properties despite its less favorable appearance. Additionally, the yield of foam mat drying powder was higher than that of spray drying powder. However, the spray drying process had a shorter turnaround



Fig 1: The physical appearance and color of Mao fruit powders from spray drying and foam mat drying methods.

Table 1: Sensory evaluation of Mao juice powders from different drying methods (n = 30)[a].

Method/Parameter	Appearance	Color	Solubility	Flavor	Texture	Taste	Overall
Spray drying	4.5	5.8	7.8	7.5	7.3	8.4	6.9
Foam mat drying	6.7	8.1	7.2	7.1	7.0	8.2	7.4

[a] Score of likeness: 1 = Dislike extremely, 2 = Dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like nor dislike, 6 = Like slight, 7 = Like moderately, 8 = Like very much, 9 = Like extremely.

Table 2: Phytochemical contents and antioxidant properties of Mao juice powders from different drying methods[a].

Method/Parameter	Water activity	Tannin[b] (mg/kg)	Anthocyanin[c] *(mg/kg)	DPPH radical scavenging activity mg TE/100 g	mg AE/100 g
Spray drying powder	0.41	0.66	118.92	395.69	355.33
Foam mat drying powder	0.44	0.65	75.03	335.82	299.05

AE = Ascorbic acid equivalent; TE = Trolox equivalent; [a]Data of all assay were calculated from triplicate experiments; [b]Tannic acid and [c]Cyanidin-3-glucoside were used as standard curve; *Statistically significant at $p<0.05$.

time due to its use of higher temperatures for a brief period. Notably, the anthocyanin content was significantly higher in the foam mat drying powder compared to the spray drying powder.

Table 2 details the phytochemical contents and antioxidant properties of the Mao juice powders produced by the two drying methods. The table includes measurements of water activity, tannin content, anthocyanin content and antioxidant activities as assessed by DPPH radical scavenging activity, reported in Trolox equivalent (TE) and ascorbic acid equivalent (AE). The data indicate that both drying methods resulted in powders with similar water activity and tannin content, but differed significantly in other phytochemical parameters. Spray drying powder exhibited higher anthocyanin content (118.92 mg/kg vs. 75.03 mg/kg) and greater antioxidant activity (395.69 mg TE/100 g and 355.33 mg AE/100 g) compared to foam mat drying powder (335.82 mg TE/100 g and 299.05 mg AE/100 g). These findings suggest that while both methods are effective, spray drying may better preserve certain phytochemicals and antioxidant properties of Mao fruit juice powder.

Spray drying and foam-mat drying are both popular techniques for juice production, each with its advantages and applications. Foam-mat drying involves the conversion of juice products into stable foam before drying, which increases surface area and reduces drying time with cost-effectiveness. This method is particularly suitable for heat-sensitive products like fruit juices. Foam-mat drying showed significant effects on yield, bulk density and color. On the other hand, spray drying is a common method that is widely used in industrial applications. This technique involves atomizing the juice into droplets and drying them quickly. The foam-mat drying is simplicity, faster drying and improved product quality, while spray drying is favored for its efficiency in large-scale production and versatility in handling various types of juices. Both techniques have their strengths, foam-mat drying excelling in quality retention and spray drying being more suitable for mass production and versatility (Roy and Alam, 2023; Koç *et al.,* 2022; Hossain *et al.,* 2021). Since Mao fruit products are majority manufactured by SMEs who apply in small-scale industries and lower investment, foam mat drying is more suitable rather than spray drying. Our results revealed that the qualities of Mao fruit powder from the foam mat drying method were more preferable due to good physical characteristics and color; acceptable solubility, flavor, texture and taste and similarly providing on-shelf life, phytochemical contents and health benefits.

Practical implications

The drying process used has a significant impact on the manufacturing of Mao fruit powder, notably in terms of quality and cost. Foam mat drying produces a more visually attractive product with superior physical qualities and color, making it an excellent alternative for applications requiring appearance and color, such as consumer items and natural food colorants. Its adaptability for heat-sensitive materials increases its value, particularly for SMEs with limited resources that must optimize both product quality and manufacturing efficiency. Spray drying, on the other hand, remains favorable for larger-scale operations owing to its efficiency and capacity to keep greater quantities of particular phytochemicals, making it ideal for applications that prioritize the preservation of certain bioactive components and antioxidant capabilities.

Limitations and Future Directions

Foam mat drying resulted in powders with better appearance and color compared to spray drying but had slightly lower ratings for solubility, flavor, texture and taste, which may be attributed to the foaming agent used. On the other hand, spray drying preserved higher levels of anthocyanins and antioxidant activity but produced a less visually appealing product. Therefore, foam mat drying is more suitable for small-scale production, whereas spray drying is favored for large-scale operations due to its efficiency. To expand on the existing results, future research might look at a variety of topics. Investigating the effect of other drying factors, such as temperatures and drying durations, may give further insights into optimizing the drying process for various quality metrics. Furthermore, research might look at the long-term stability of the phytochemicals and antioxidant effects of Mao fruit powder prepared using these procedures under various storage settings. Future studies might concentrate on enhancing the quality characteristics of drying techniques and investigating the long-term stability of phytochemicals and antioxidant capabilities under varied storage settings.

Conclusion

Foam mat drying method was suitable drying process on the small-scale production of Mao fruit juice powder in SMEs, North-Eastern of Thailand. By sensory evaluation, appearance, color and overall likeness of foam mat powder were better than spray drying powder and other sensory parameters including solubility, flavor, texture and taste were

similar. This study ensured that the qualities of juice powder, including water activity, tannin content and DPPH scavenging activity from this method, similar to spray drying as a conventional method with more expensive. However, anthocyanin content of foam mat juice powder was significantly lower.

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Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all aspects of this work.

Availability of data and materials

Not applicable.

Use of artificial intelligence

Not applicable.

Declarations

Authors declare that all works are original and this manuscript has not been published in any other journal.

Conflict of interest

The authors have no conflicts of interest regarding this investigation.

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