

Foam-mat drying technique and some initial research results on local foods

Nguyen Tan Hung^{1*}, Phan Thi Ngoc Hanh¹, Pham Huynh Thuy An²

¹Tien Giang University

²Nam Can Tho University

* Corresponding author: Nguyen Tan Hung (email: nguyentanhung@tgu.edu.vn)

DOI: 10.64632/jsde.37.2025.607

ABSTRACT

Received: 31/5/2025

Revised: 10/6/2025

Accepted: 15/7/2025

Keywords: foaming agents, foam-mat drying, foam stabilizers, fruits and vegetable

Dehydration of foods is not simply a preservation technique in the present era, rather an important food processing operation which has many benefits in addition to enhancement of shelf life of foods. There are various methods of drying foods and most of them are unique in their own way. Present review is about Foam-mat drying technique for fruits and vegetables to develop good quality powders. Foam-mat drying is a new drying technique for foods which are highly heat sensitive and very sticky to dry. By using this drying technique product is dried in a very short time with minimum quality changes. Fruits and vegetables pastes were mixed with different foaming agents (egg albumin, soy protein, GMS etc.) and foam stabilizers (carboxymethyl cellulose etc.) in different concentration to introduce stable foams. Foams were dried in trays by application of hot air, microwave, freeze-drying and milled to develop free flowing powders. This is a simple technique and initially showed good results in drying liquid foods obtained from various local fruit and vegetable materials (jackfruit, red-fleshed dragon fruit, melon, etc.).

1. INTRODUCTION

Fruits and vegetables are a major commodity in the agricultural sector, especially in the Mekong Delta. They are rich in carbohydrates, vitamins, minerals, and a large number of antioxidants that are beneficial to humans. However, a large percentage of fruits and vegetables are currently wasted due to improper processing and preservation. A common

characteristic is that fruits and vegetables are highly perishable because of their high water content. Water is the main cause of microbial growth. It also participates in various chemical reactions, such as oxidation and non-enzymatic browning (Karim & Wai, 1999). Therefore, different processing techniques have long been used to extend shelf life and create new products

from fruits and vegetables. Many products made from fruits and vegetables, such as canned goods, concentrated juices, purees, ice cream, yogurt, candies, and sauces, have been the subject of previous research. The method of removing moisture and preserving food through drying is one of the earliest techniques. This can significantly extend the product's shelf life. The removal or reduction of water content in food, especially fruits and vegetables, affects various microorganisms that cause food spoilage. Traditionally, drying is considered a process that converts food in all forms (solid, liquid, semi-liquid) into a final solid product with low, stable moisture. Furthermore, drying reduces the product's weight, thereby lowering the cost of packaging, transportation, and storage. When fruits and vegetables are dried, they are exposed to heat, which reduces their water content, inhibits the growth of various enzymes and bacteria, and increases product stability (Izli et al., 2017).

The water activity of food significantly decreases during drying, making it stable against microbial spoilage. Moisture removal from food is a simultaneous heat and mass transfer operation. Heat provides enough energy to the water to cause evaporation. Vapor moves from the inside of the product to the surface due to a moisture diffusion gradient that develops between different layers of the product. Heat and mass transfer occur at a molecular level. The diffusion of water molecules from the product

into the surrounding atmosphere is driven by the vapor pressure difference. A large amount of energy is required to reduce the moisture content of food, which makes drying an energy-intensive process. The development and application of new drying techniques have been very helpful in creating new dehydrated products and convenient foods that easily meet quality, stability, and cost-effectiveness requirements (Qadri et al., 2020).

Drying techniques also affect other food characteristics such as palatability, flavor, aroma, viscosity, hardness, microbial spoilage, and enzyme activity. Various drying methods have been applied, including direct sun drying, solar drying, freeze-drying, microwave drying, vacuum drying, and infrared drying. Selecting the appropriate drying method is crucial for the final cost and quality of the dried product. Some drying methods like freeze-drying and vacuum drying require high investment and energy costs, making them unsuitable. Furthermore, many beneficial compounds in fruits and vegetables are highly sensitive to temperature (Qadri et al., 2020). Therefore, choosing an appropriate drying method is necessary to balance the requirements for nutritional and sensory quality with cost considerations.

Foam-mat drying is a new and suitable drying technique that offers a high drying rate with minimal quality changes in the final product. Foam-mat drying has emerged as an important method for drying. This is the most suitable

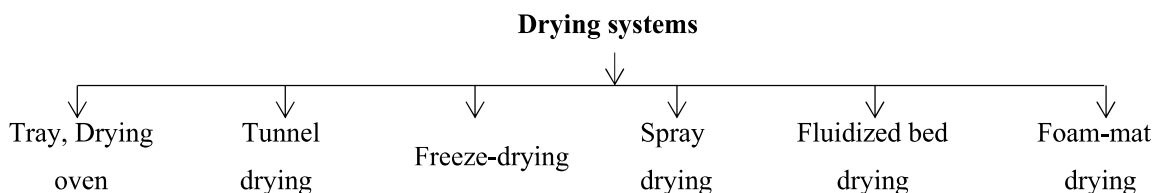
drying technique for fruit and vegetable extracts that are very heat-sensitive and those that have high viscosity, are sticky, and are difficult to dry. With this technique, various food materials such as milk, vegetable purees, fruit and vegetable juices, and instant coffee can be dried with minimal quality changes. In foam-mat drying, the fruit juice is dried with air at a lower temperature to reduce the moisture in the food and form a stable porous capillary system (honeycomb-like structure). With this technique, the surface area of the product to be dried increases due to foam formation, and the time required to dry the foamed product is reduced compared to drying non-foamed products. The product obtained from the foam-mat drying process has better quality, is more porous, and retains its original characteristics upon rehydration. This drying technique is very effective and suitable for heat-sensitive food components due to its relatively fast drying time, high quality, and easy rehydration. In this technique, the foamed raw material is dried using hot air at atmospheric pressure, which has shown to be more effective than vacuum, spray, and freeze-drying methods

(Javed et al., 2018). Furthermore, it is an economically feasible alternative to many other drying methods for producing food powders. The highlight is the foam-mat drying technology itself, as its combination with other methods has shown results that make this technology even more promising than conventional technologies (Qadri et al., 2020). This report provides an overview of food foam-mat drying and aims to summarize its recent developments and applications.

2. RESEARCH METHODS

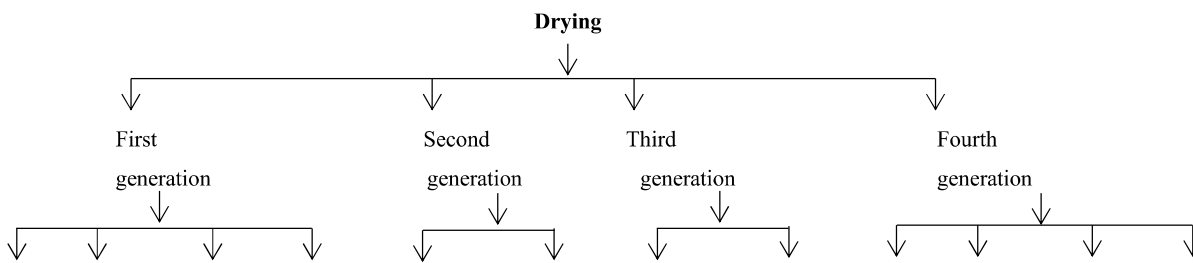
2.1 Introduction to foam-mat drying

Drying is one of the best preservation techniques that has been applied for a long time. Sun drying is the simplest and least efficient among drying methods but is still widely used due to its convenience and ease. Drying methods have evolved throughout the history of scientific research, and most of the reported methods are currently in use. There can be many ways to classify drying methods, and one such classification is based on different drying systems as shown in the table below:



Source: Qadri et al., 2020

Another classification distinguishes drying methods based on generations, as described in the following diagram:



Sun Tray Conveyor Tunnel Spray Drum Osmotic Freeze- Vacuum Microwave Fluidized
drying drying drying rying drying drying drying drying drying bed drying

Source: Izli et al., 2017

Each technique has its own advantages and disadvantages. The dried products of these techniques are distinguished by their physicochemical, nutritional, and microstructural properties. Among them, hot air drying is the most frequently used technique for producing dehydrated fruits and vegetables. In this technique, the need for high temperatures or long drying times can severely damage the product's flavor, color, and nutrients, and can reduce the rehydration capacity of the dried fruit. Microwave drying focuses on water molecules, which convert electromagnetic energy into kinetic energy. Consequently, heat is generated inside the product. This results in energy savings and an increased drying speed. However, this technique also has some drawbacks, such as surface overheating and damage to the product's texture. Freeze-drying produces high-quality output products. The chemical, biological, and physical properties of the product show only minor changes. On the other hand, it is time-consuming and expensive. In this technique, the raw material in the drying chamber must undergo a pre-freezing stage; however, the high temperature of the heating plate accelerates the sublimation period (Qadri et al., 2020).

2.2 Foam-mat drying

Heat-sensitive, difficult-to-dry, and sticky fruit and vegetable juices have been successfully dried using the foam-mat drying method. This gives the method a wide range of applications in the dehydration sector. Foaming a liquid significantly increases the surface area, which

enhances mass transfer and thus shortens the drying time. Foam-mat drying has gained attention for its ability to process difficult-to-dry materials and obtain products with desired properties. Materials dried by the foam-mat technique have been reported to have better retention of volatile compounds compared to non-foamed dried materials (Kadam et al. 2012).

2.2.1 Foam structure

A foam is a dispersion of gas in a liquid, and if the liquid forms a gel or hardens after gas dispersion, it is called a solid foam. After the dispersed system is formed, the foam undergoes several changes. The diffusion of gas through the continuous phase into larger bubbles causes them to increase in size. Bubbles tend to rise, forming a separation at the top. The deformation between the bubbles leads to a polyhedral foam structure. The drainage of liquid from the bulk continues to break the film between the bubbles, eventually leading to their coalescence. The different types of foams commonly found in food can be desirable (egg whites in baked goods) or undesirable (formation during fermentation). To effectively control foams, it is crucial to understand their nature and physical properties (Foegeding, 2006).

2.2.2 Foam stability

Foam stability is of paramount importance for the success of the foam-mat drying process. The foam must remain intact throughout the drying process. Most importantly, the foam must be thermally stable and maintain its structure, at least during the constant-rate drying period.

Initial stability is crucial because any collapse in the structure can lead to the complete failure of the foam-mat drying concept. If the foam survives the initial drying stage, as drying continues with the removal of moisture, the structure becomes harder and eventually a dry sheet with a honeycomb structure is obtained (Javed et al., 2018).

2.2.3 Foaming

Liquids can be foamed by one of two methods : (1) A gas is saturated in the liquid by forced dissolution at high pressure, such as in soft drinks. When the pressure is released, the liquid begins to foam. (2) The second method involves a mechanical approach. The liquid can be foamed by vigorous shaking or whipping. Foaming food for foam-mat drying is primarily done using the mechanical method. The liquid solution can be shaken or stirred in the presence of gas with the help of various devices that create vigorous agitation in the liquid. The foam created by whipping is thoroughly mixed, resulting in an even dispersion of gas. Many foods do not have foaming properties and therefore, may not form a stable foam even with the application of any foaming method. Such foods can be transformed into a stable foam with the help of certain additives. Additives that help form stable foams are divided into foaming agents and foam stabilizers. Foaming agents reduce the surface tension between surfaces and help foam the liquid. A good foaming agent helps form a durable, elastic, and cohesive film with good thermal and mechanical stability. Therefore, the foam formed will be stable, which is a prerequisite for the foam-mat drying process. For the group of foaming agents, proteins often act as good surfactants and provide kinetic stability,

minimizing thermodynamic instability in foams (Qadri et al., 2020). According to Zayas (1997), proteins used as foaming agents in food must be effective at low concentrations, work well over a wide pH range, and be effective in the presence of other components that may have foam-inhibiting properties. Commonly used foaming agents in various studies include fresh and dried egg albumin, whey protein, and soy protein.

2.2.4 Foam stabilizers

These are additives that help the foam retain its structure for a longer time and delay coalescence. Polymers are preferred additives for stabilizing foams due to their ability to increase the viscosity of the solution, which reduces the rate of liquid drainage and the gas permeability of the lamella (Klitzing và Muller, 2002), including gelatin, starch, pectin, and various gums. Common stabilizers used in foam-mat drying research are mainly polysaccharides such as various gums (xanthan gum, guar gum, gum Arabic, gum karaya, and locust bean gum). Although the roles of foaming agents and foam stabilizers are different, there are many studies where researchers have used these terms interchangeably and classified various additives under either category, such as carboxymethyl cellulose, which acts as both a foaming agent and a stabilizer (Qadri et al., 2020).

2.3 Foam-mat drying process

The foam-mat drying process can be conveniently divided into four essential steps, as summarized in the following diagram:

Raw material (fruits and vegetables)

↓

Juice extraction (processing, pressing, grinding, etc.)

↓
Foaming (stabilizers, foaming agents, mixing)

↓
Drying (pouring on trays, hot air, sublimation, microwave)

↓
Product (collection, milling, packaging)

Juice extraction: Fruits and vegetables can be peeled, cored, blanched, and ground into a puree. The resulting puree or juice can be concentrated for subsequent operations. Liquid foods like milk can be used directly for foaming.

Foaming: This step involves adding foaming agents and stabilizers, and foaming is mainly done by shaking or whipping with the help of a high-speed mixer. Some raw materials have high viscosity and can be converted into highly stable foams. These materials can be appropriately diluted and foamed to form the desired foam.

Batch hot air (convection) drying in a drying oven is the most commonly used method. Besides hot air drying, other drying techniques have also been used by many researchers, such as microwave drying. During foam-mat drying, liquid drainage by capillary diffusion through the liquid film is the primary cause of water movement.

Collection and milling: The dried material is removed from the surface after drying and milled. The honeycomb structure of the dried material makes it easy to remove, and the resulting pieces can be ground into a powder that is easy to rehydrate.

2.4 Combined drying

Foam-mat drying is a simple process with significant advantages, but products dried by foam-mat drying are not always of superior

quality when compared to other drying techniques, especially spray drying. There have been reports of an 80% reduction in vitamin content in mango puree and lower consumer acceptability compared to spray-dried products. Another comparative study showed that although the physical and rehydration properties of foam-dried soy milk were better than non-foamed soy milk, spray-dried material exhibited superior properties. Flavor retention has been shown to be impaired by foam-mat drying in some foods, such as foam-mat dried tomato powder. Despite good solubility, the poor flavor retention of this product and accelerated oxidation reactions due to a sharply increased liquid-gas contact surface are among the main reasons for product quality degradation, including flavor loss, in addition to other causes. A study on tamarind powder reported that product acceptability in terms of flavor was significantly affected by the type of foaming agent used. To mitigate these adverse effects on drying characteristics and quality properties, some studies have been conducted where foam-mat drying has been combined by replacing the conventional hot air drying method with advanced techniques, even though foam-mat drying is still faster than non-foaming drying (Qadri et al., 2020).

Foam-mat vacuum drying: Initial studies have concluded that concentrated whole milk dried by vacuum foam-mat drying has superior dispersion quality.

Foam-mat freeze-drying: Freeze-drying is an advanced dehydration process that produces high-quality dried products. All studies on foam-mat freeze-drying have concluded that the products obtained have better quality properties. Freeze-drying is a widely studied dehydration

method, but its use is still limited due to high costs and long processing times, and foam-mat drying is an unconventional drying method. Therefore, this combination is rare and needs thorough research to be feasible and successful.

Foam-mat microwave drying: Microwave drying is a new and potential method for dehydrating food materials due to its ability to rapidly generate heat within the food material. Some studies have reported the advantages of microwaves over conventional drying methods, such as reduced drying time, better color, and rehydration properties. Microwave heating can be a feasible solution to this problem. Experiments have demonstrated a 4-8 times increase in drying speed with microwave drying compared to convection drying with no fundamental change in quality. Even the high temperatures ranging from 93 to 110°C achieved during microwave drying, compared to 76.7°C in convection drying, did not cause adverse changes in color. This could be due to the very short microwave drying processing time (5–15 minutes) compared to convection drying (55–65 minutes), depending on the thickness. The quality of microwave-dried powder is better in terms of ascorbic acid retention, while other properties such as pH, acidity, and color are within the normal range. The destruction of heat-labile components is due to temperature and exposure time. Because the processing time is significantly reduced, the destruction of these components is well compensated, even when the product temperature reaches higher values (Qadri et al., 2020).

3. RESULTS AND DISCUSSION

In the study on the processing and quality evaluation of instant acerola powder using the

foam-mat drying method (Nguyen Tan Hung, 2023), the research was conducted based on the following surveys: (i) the effect of the foaming agent ratio: 2-10% glycerol monostearate-GMS (w/v) + 2% carboxymethyl cellulose and (ii) drying conditions: temperature 50-70°C and foam thickness 3-7 mm on product quality. The results showed that foaming capacity and foam stability increased with the increasing GMS ratio. A mixture of acerola juice and 8% GMS + 2% CMC was most suitable, yielding a foam expansion of 101% and stability of 98% after 3 hours. The powder obtained at different drying temperatures and thicknesses had low moisture content and water activity. The color of the powder (L^* , a^* , b^* , and color difference ΔE) changed mainly with drying temperature. Increasing the temperature reduced moisture, water activity, and solubility, while increasing the thickness increased moisture and water activity. In addition, the powder obtained when dried at 60°C and 70°C had higher contents of vitamin C, polyphenols, and carotenoids compared to the powder dried at 50°C. The drying conditions of 70°C (higher drying temperature) and 3 mm (lower thickness) led to a shorter drying time, helping to create acerola powder with high stability (low moisture and water activity), increasing convenience and shelf life.

In the publication by Ung Minh Anh Thu, Chau Thi Thuy Nguyen, Nguyen Tan Hung (2022) for the process of producing instant powder from secondary jackfruit (Changai) using the foam-mat drying technique, the research was carried out based on a survey of (i) factors affecting the foaming process (ratio of added egg albumin and Carboxymethyl Cellulose) and (ii) the effect of hot air drying conditions (drying

temperature and foam layer thickness) on the quality of instant jackfruit powder. Jackfruit juice was foamed with egg albumin (4%) and CMC (7.5%), which helped create a good and stable foam layer. On the other hand, the foamed layer was dried at 60°C and a thickness of 3 mm, which helped to obtain powder with good color and the best retention of nutrients, with vitamin C content of 3.96 mg%, carotenoid content of 5.34 g/g, total sugar content of 11.27%, reducing sugar content of 8.33 g/100g, total acid content of 0.077%, and low moisture content of 4.28%.

In the publication by Nguyen Tan Hung, Ung Minh Anh Thu (2022) for the process of producing instant powder from red-fleshed dragon fruit, this study aimed to determine the effect of soy protein concentration on the properties of foam-dried red dragon fruit powder. The effect of drying conditions on the physicochemical properties of the dried product was also studied. Red-fleshed dragon fruit juice combined with soy protein at concentrations of 2-12% by weight was whipped for 10 minutes. Foamed layers with thicknesses of 3 mm, 5 mm, and 7 mm were dried at temperatures of 50°C, 60°C, and 70°C. The results showed that differences in soy protein concentration and drying conditions affected the foam expansion and nutritional composition of the red dragon fruit powder. The optimal condition for foaming was 10% soy protein after 10 minutes of whipping, yielding the highest foam expansion (156.67%). A foam layer with a thickness of 3 mm dried at 60°C for 210 minutes showed the highest ascorbic acid content as well as the highest overall sensory quality. Therefore, this technique can be used for the commercial production of red dragon fruit powder for further

use in developing ready-to-mix beverages by rehydrating the powder.

In the study by Nguyen Thi Kim My and Nguyen Tan Hung (2023) for the process of processing instant lime-lemongrass powder using the foam-mat drying technique, the research was conducted based on (i) a survey of the effect of foaming agents (albumin: 8-12% and CMC: 6-10%); (ii) drying temperature (50-70°C) and foam layer thickness (3-5 mm); and (iii) the appropriate mixing ratio between lime powder and lemongrass powder. The research results showed that the appropriate concentrations of egg albumin and CMC were 10% and 8% respectively, helping the lemongrass juice to foam completely and maintain good foam stability for 4 hours, which supported the drying process well. In addition, the appropriate temperature and foam layer thickness for hot air drying of the foamed lemongrass juice were 60°C and 3 mm, which helped create a product with good color, low moisture, low water activity, and a high TPC content. The appropriate mixing ratio between lime powder and lemongrass powder was chosen as 30:70, which helped create an instant lime-lemongrass powder product with a uniformly light color, a fine powder that was not sticky to the touch, and good sensory quality.

In the study by Tran Xuan Hien, Le Thi Thuy Hang, Le Thi Thuy Loan, and Nguyen Tan Hung (2023) on the production of powder from secondary melon using the foam-mat drying technique, the research was conducted based on a survey of the effect of hot air drying temperature (50-70°C) with foam thickness (3-7 mm) and foam thickness (1-7 mm) on the production process and quality of melon powder. The research results showed that melon powder

obtained using the hot air drying technique (foamed with 6% glycerol monostearate-GMS and 8% carboxymethyl cellulose-CMC) with an appropriate drying temperature of 70°C and a foam layer thickness of 3 mm for 250 minutes produced a product with a moisture content of 4.21%, vitamin C of 11.44 mg%, water activity of 0.39, and a solubility of 15.33 seconds. In addition, melon powder obtained using the microwave drying technique (foamed with 1% Tween 80, 6% Gum Arabic, and 10% Maltodextrin), with a drying time of 1.5-2 minutes and a foam layer thickness of 3 mm, produced a product with a moisture content of 4.37%, vitamin C of 10.56 mg%, water activity of 0.41, and a solubility of 7 seconds.

4. CONCLUSION

Foam-mat drying is a new drying technique for foods that are very heat-sensitive and sticky. By using this drying technique, the product is dried in a very short time with minimal quality changes. Although foam-mat drying is not a new method and has been studied for a long time, there are very few studies and publications applying this technology to fruit and vegetable materials in Vietnam. The foam-mat drying technique offers many advantages over many conventional drying methods. Most studies report that foam-mat drying is a potential drying technology when the foam-mat technique is combined with other drying technologies such as microwave, freeze-drying, etc.. The powder produced by this drying technique has the ability to preserve heat-sensitive compounds to the maximum extent. However, further research is needed on the feasibility and commercial success of this technology in the future.

REFERENCES

- Dehghannya, J., Pourahmad, M., Ghanbarzadeh, B., & Ghaffari, H. (2018). Influence of foam thickness on production of lime juice powder during foam-mat drying: Experimental and numerical investigation. *Powder Technology*, 328, 470–484.
<https://doi.org/10.1016/j.powtec.2018.01.034>
- Foegeding, E. A. (2006). Food biophysics of protein gels: A challenge of nano and macroscopic proportions. *Food Biophysics* 1(1):41–50. doi: 10.1007/s11483-005-9003-y.
- Izli, N., Izli, G., & Taskin, O. (2017). Influence of different drying techniques on drying parameters of mango. *Food Science and Technology (Brazil)*, 37(4), 604–612.
<https://doi.org/10.1590/1678-457x.28316>
- Javed, I. M., Abbas, A., Rafique, H., Nawaz, M. F., & Rasool, A. (2018). A review paper on foam-mat drying of fruits and vegetables to develop powders. *MOJ food process technol*, 6(6), 465-467.
<https://doi.org/10.15406/mojfpt.2018.06.00207>
- Kadam, D. M., Wilson, R. A., Kaur, S., & Manisha. (2012). Influence of foam mat drying on quality of tomato powder. *International Journal of Food Properties* 15, 211–20
- Karim, A. A., & Wai, C. C. (1999). Foam-mat drying of starfruit (*Averrhoa carambola* L.) puree. Stability and air drying characteristics. *Food Chemistry*, 64(3), 337–343.
[https://doi.org/10.1016/S0308-8146\(98\)00119-8](https://doi.org/10.1016/S0308-8146(98)00119-8)
- Klitzing, R. V. & Müller, H-J. (2002). Film stability control. *Current opinion in Colloid & Interface Science*, 7(1-2), 42-49.

- [https://doi.org/10.1016/S1359-0294\(02\)00005-5](https://doi.org/10.1016/S1359-0294(02)00005-5)
- Nguyen, T. H., & Ung, M. A. T. (2022). Study on the production process of instant powder from red-fleshed dragon fruit. *Tien Giang University Science Journal*, 12(18), 183-192.
- Nguyen, T. H., Truong, T. T. T., Tran, T. N. T., & Phan, T. N. H. (2023). Effects of glycerol monostearate foaming agent and drying conditions on the quality of acerola powder (*Malpighia glabra* L.). *Journal of Agriculture & Rural Development*, 06/2023, 89-97.
- Nguyen, T. K. M., & Nguyen, T. H. (2023). Study on the processing of instant lime-lemongrass powder using the foam-mat drying method. *Tien Giang University Science Journal*, 13(1), 3-12.
- Qadri, O. S., Srivastava, A. K., & Yousuf, B. (2020). Trends in foam mat drying of foods: Special emphasis on hybrid foam mat drying technology. *Critical Reviews in Food Science and Nutrition*, 60(10), 1667–1676.
- <https://doi.org/10.1080/10408398.2019.1588221>
- Tran, X. H., Le, T. T. H., Le, T. T. L., & Nguyen, T. H. (2023). Research on the application of the foam-mat drying method to process powder products from melon (*Cucumis melo* L.). *Dong Thap University Science Journal*, 12(2).
- Ung, M. A. T., Châu, T. T. N., & Nguyen, T. H. (2022). Study on the production process of instant powder from Thai jackfruit using foam-mat drying technique. *Nutrition & Food Magazine*, 18(3+4), 26-36.
- Zayas, J. F. (1997). *Functionality of Proteins in Food*. Springer Berlin Heidelberg.
- <https://doi.org/10.1007/978-3-642-59116-7>