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Foaming Agents Affect the Physicochemical and Antioxidants in Red Dragon Fruit Powder Drinks from Foam Mat Drying

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Abstract

This study investigated the effect of foaming agent type and concentration on foam characteristics during foam mat drying and the physicochemical and antioxidant properties of red dragon fruit powdered drink. Foaming agents, including soy lecithin, fresh egg whites, egg white powder, and whey protein concentrate, were tested at different concentrations (5%, 10%, and 20%). Results showed that soy lecithin produced the most stable foam, effectively preserving bioactive compounds such as phenolics and flavonoids, which contributed to higher antioxidant activity (measured by DPPH and FRAP methods). Whey protein concentrate and fresh egg whites enhanced foam overrun and moisture retention, leading to powders with lower moisture content and higher solubility. The optimal concentration of foaming agent was 10%, which resulted in the best foam stability, antioxidant preservation, and overall product quality. This study highlights the importance of selecting appropriate foaming agents and concentrations to improve the quality and antioxidant properties of red dragon fruit powdered drinks for food applications.

Keywords: antioxidant activity; foam mat drying; soy lecithin; whey protein concentrate; white egg

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1. Introduction

Functional beverages are functional food that provides health benefits to the human body. They are considered practical and contain more active food components than processed foods. One key advantage of functional beverages is their positive effects on health and fitness (Donno et al., 2018). These beverages can be made from various plant parts, including fruits, leaves, and stems. One such fruit with significant health benefits is red dragon fruit (*Hylocereus polyrhizus*), which contains bioactive compounds such as antioxidants (ascorbic acid, beta-carotene, and anthocyanins) and dietary fiber like pectin (Luu et al., 2021). Antioxidants are crucial in neutralizing free radicals, preventing cell oxidation, and reducing cellular damage (Chandrasekara & Shahidi, 2018). However, fresh red dragon fruit has a high water content (approximately 90%), resulting in a short shelf life of 7–10 days at 14°C (Luu et al., 2021; Pacheco et al., 2020). Processing the fruit into powder is a practical solution to extend its shelf life. Powdered products have multiple advantages, including durability, lighter weight, and smaller volume, making them easier to package and transport (Hamad et al., 2020).

Foam mat drying is an effective method for producing powdered beverages. This process involves converting liquid foods into foam using foaming agents and stabilizers, which enhance surface area, reduce surface tension, improve porosity, and accelerate water evaporation while maintaining product quality (Reis et al., 2021). Compared to other drying methods, foam mat drying is simple, cost-effective, and efficient, producing high-quality, water-soluble products with good taste and color (Adamade & Olaoye, 2021). A critical factor in foam mat drying is the choice of

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foaming agent. These food additives help form and maintain the uniform dispersion of gas phases in food systems. Effective foaming agents should easily absorb at the air-water interface, lower surface tension, and form strong cohesive films. Proteins, due to their hydrophobic properties, are especially effective, forming stable foams by rapidly adsorbing at the air-water interface and creating elastic, coherent layers(Maciel et al., 2022; Reis et al., 2021; Susanti, Sediawan, Fahrurrozi, Hidayat, et al., 2021). This study investigates the effects of different types and concentrations of foaming agents (fresh egg white, powdered egg white, whey protein concentrate, and soy lecithin) on red dragon fruit powder's physical, chemical, and antioxidant characteristics. By optimizing the foam mat drying process, the research aims to produce a functional beverage powder with superior quality and health benefits.

2. Materials and Methods

2.1. Materials

The materials used to produce the powder include red dragon fruit, distilled water, powdered egg white, fresh egg white, soy lecithin, whey protein concentrate (95%), maltodextrin, gum arabic, and CMC (carboxymethyl cellulose). Materials for analysis include distilled water, ethanol 98%, NaCl, $AlCl_3$, CH_3COONa buffer, 2,2-Diphenyl-1-picrylhydrazyl, CH_3COONa, 2,4,6-Tripyridyl-s-triazine, HCl, and $FeCl_3$.

2.2. Preparation of Red Dragon Fruit Powder

Red dragon fruit juice is made by blending red dragon fruit and water in a 1:1 ratio, then filtering to separate the pulp. The juice's Brix degree is measured. Fifty grams of red dragon fruit juice are mixed with 20% binder (a 1:1 mix of gum arabic and maltodextrin). A 5 g of gum arabic are added and stirred until homogeneous, followed by 5 g of maltodextrin and 0.25 grams of CMC, stirred until homogeneous. The density of the solution is measured.

A foaming agent is added (type and concentration based on experimental variables: powdered egg white, fresh egg white, soy lecithin, whey protein concentrates at 5%, 10%, and 20% (w/v)) and mixed using an Ultra-Turrax homogenizer at 20,000 rpm for 5 min, ensuring uniform foam. The final foam volume is measured and then left for 60 minutes at room temperature to record foam stability. The foam is spread evenly in a pan and dried in an automatic dryer at 60°C for 10 hours. The dried solid is ground into powder, packed in airtight plastic, and ready for analysis (Susanti, Sediawan, Fahrurrozi, Hidayat, et al., 2021).

2.3. Foam Physical Characterization

Foam parameters include Foam Expansion (FE), Air Fraction (AF), Foam Overrun (FO), and Foam Stability (FS), and Foam Stability (FS) according to the method followed by Susanti et al., 2021 (Susanti, Sediawan, Fahrurrozi, & Hidayat, 2021). FS is the percentage ratio of the initial foam volume to the foam volume after one hour.

2.4. Physical Characteristics of Red Dragon Fruit Powder Drink

Physical analysis includes moisture content, water solubility index, hygroscopicity, bulk density, and yield (Shaari et al., 2018). Moisture Content is measured using the gravimetric method (AOAC, 2016). The Water Solubility Index (WSI) determines the percentage of dissolved solids, using a gravimetric method (Sari et al., 2022) (Grabowski et al., 2006). Hygroscopicity is analyzed in a saturated NaCl solution (75% RH) at room temperature for one week. Weight differences determine hygroscopicity (Izadi et al., 2020). Yield is calculated as the percentage ratio of the powdered product's mass to the initial solid feed (Hamad et al., 2020).

2.5. Total Phenolic Content (TPC) and Total Flavonoid Content (TFC) measurements

TPC and TFC analysis of the red dragon fruit powder drink follows the method described by Hartanti *et al*. (2023) (Hartanti & Hamad, 2023; Purnomo et al., 2023).

2.6. Antioxidant Activity Analysis

Antioxidant activity is assessed using the DPPH radical scavenging method and the *Ferric Reducing Antioxidant Power* (FRAP) method, based on the procedures outlined by Hartanti *et al*. (2023) (Hartanti & Hamad, 2023; Wirantika et al., 2023).

2.7. Data Analysis

Statistical analysis was performed using Two-Way ANOVA to determine whether there were significant differences between two independent groups including type and concentrations of foaming agents. Results are expressed as mean ± standard deviation, with a confidence level set at $\rho \leq 0.05$. If significant differences were found in the ANOVA, Duncan's Multiple Range Test (DMRT) was used as a post hoc analysis to identify specific group differences. DMRT provides pairwise comparisons and group treatments with statistically similar means, ensuring a clearer interpretation of significant differences between groups. All statistical analyses were conducted using SPSS software version 13 for Windows.

3. Results and Discussion

3.1. Effect of Type and Concentration of Foaming Agent on Foam Characteristics

Foam expansion (FO) refers to the ability of a foaming agent to increase the volume of a solution by trapping air and enlarging bubble size (Susanti et al., 2021). The effect of different types and concentrations of foaming agents on foam expansion is shown in Figure 1. Each type of foaming agent resulted in significantly different foam expansion values. This indicates that variations in the type of foaming agent led to different foaming properties due to differences in protein amino acid composition, molecular size, surface polarity, and hydrophobicity (Eduardo et al., 2022; Izadi et al., 2020). Fresh egg whites produced higher foam expansion than other types of foaming agents. Fresh egg white contains a large number of proteins—up to 40 different and complex proteins (Reis et al., 2021). During the homogenization process, proteins denature at the interface and interact to form a stable viscoelastic layer, which facilitates foam formation. Air bubbles are trapped in the foam, and prolonged homogenization increases foam expansion (Maciel et al., 2022). Increasing the concentration of the foaming agent in the red dragon fruit juice solution tended to decrease foam expansion. This may be because higher concentrations of the foaming agent increase the viscosity of the solution, making it harder to form foam. For instance, when fresh egg white was added at a concentration of 10%, foam expansion decreased from 87.88% to 66.67%. However, at a concentration of 20%, foam expansion increased to 97.44%. This can be attributed to the liquid nature of fresh egg white, allowing its proteins to denature more rapidly compared to powdered foaming agents (Thuwapanichayanan et al., 2012).

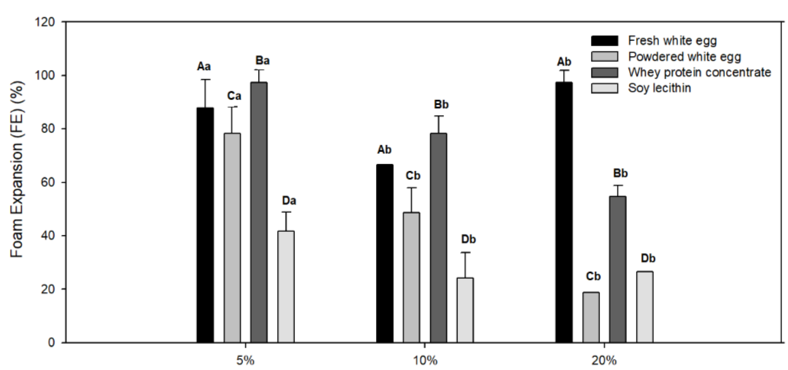

Figure 1. Effect of type and concentration of foaming agents on the foam expansion of foam during foam mat drying. Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

Air fraction (AF) refers to the amount of air trapped within the foam. Theoretically, air fraction can range from 0 (no dispersed air) to 1 (entirely air)(Sanchez et al., 2002). The effect of the type and concentration of foaming agent on AF is shown in **Figure 2**. The results indicate that the type of foaming agent significantly influences air fraction ($p<0.05$). Whey protein concentrate showed a similar effect to fresh egg white and powdered egg white in producing AF. Like egg whites, whey protein concentrate can reduce surface tension between two phases and enhance foam formation (de Paula et al., 2020). In contrast, red dragon fruit juice solutions using soy lecithin as a foaming agent resulted in lower air fraction compared to other foaming agents. This indicates a lower amount of air trapped in the foam. The reduced air trapping could be due to soy lecithin's poor dispersion in the solution during homogenization, leading to insufficiently low air-liquid interfacial tension for significant foam formation. Additionally, soy lecithin has a compact tertiary structure, contributing to its less favorable foaming characteristics. Increasing the concentration of foaming agents in the red dragon fruit juice solution tended to decrease the resulting air fraction. This may occur because higher concentrations of foaming agents increase the solution's viscosity, making foam formation more difficult (Albernaz et al., 2017; Muhammad et al., 2018).

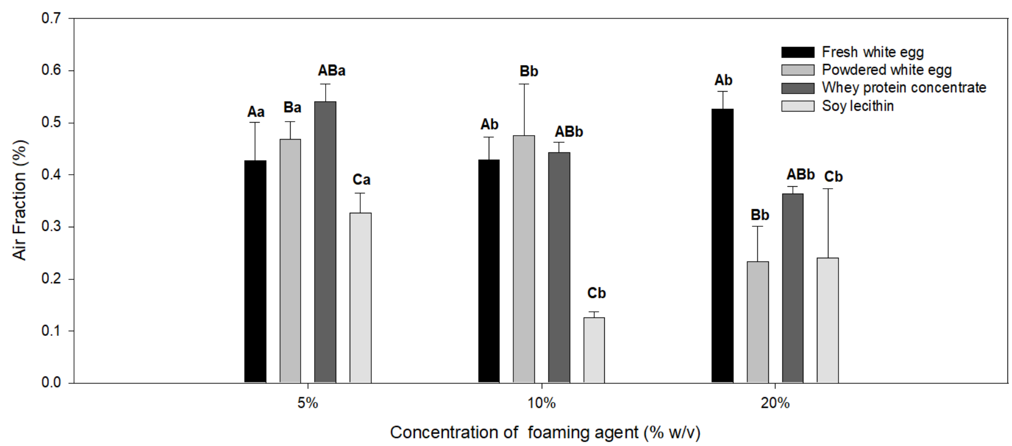

Figure 2. Effect of type and concentration of foaming agents on the air fraction during foam mat drying.
Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

Foam overrun (FO) refers to the percentage of foam volume expansion formed during the process (Kanha et al., 2020). The effect of the type and concentration of foaming agent on FO is shown in **Figure 3**. The results show that fresh egg white as a foaming agent produced significantly different foam overrun values compared to powdered egg white and soy lecithin. Fresh egg white and whey protein concentrate produced higher foam overrun compared to other foaming agents. This greater foam expansion is attributed to their high protein content, which acts as a viscoelastic film that can adsorb quickly at the air-liquid interface during homogenization (Susanti, Sediawan, Fahrurrozi, & Hidayat, 2021). For powdered foaming agents, such as powdered egg white, whey protein concentrate, and soy lecithin, increasing the concentration of the foaming agent in the red dragon fruit juice solution tended to reduce the foam overrun. This decrease occurs because higher viscosity limits the movement of water molecules as the interparticle spaces in the solution become narrower. Narrower interparticle spaces restrict the amount of air entering the solution during homogenization, resulting in lower foam overrun(Sanchez et al., 2002).

Foam stability (FS) is a crucial characteristic for the foam mat drying process. A foam that is stable both mechanically and thermodynamically facilitates fast and efficient water removal. If the foam structure is severely damaged, the drying time will increase, and the quality of the final product will decrease (Sari et al., 2022). Foam stability is influenced by factors such as the thickness, permeability of the air-liquid interface, and bubble size distribution. However, the type and concentration of the foaming agent used are the primary factors that affect foam stability (de Paula et al., 2020; Kanha et al., 2020). The impact of the type and concentration of foaming agents on foam stability is shown in Figure 4. The results indicate that the type of foaming agent significantly influences foam stability. The addition of fresh egg white had a similar effect on foam stability as powdered egg white in red dragon fruit juice solutions. Meanwhile, whey protein concentrate had an effect similar to that of soy lecithin. Foam stability in red dragon fruit juice solutions with whey protein concentrate and soy lecithin was higher compared to those with fresh and powdered egg whites. This suggests that the red dragon fruit juice solutions with whey protein concentrate, and soy lecithin had higher viscosities. The amount of drainage is naturally influenced by the solution's viscosity. Higher viscosity increases the viscoelasticity and strength of the lamella at the liquid-air interface, which prevents the rupture of the thin layer and stabilizes the foam (Guazi et al., 2019). As for the variation in foaming agent concentration, no significant effect was observed on the foam stability produced.

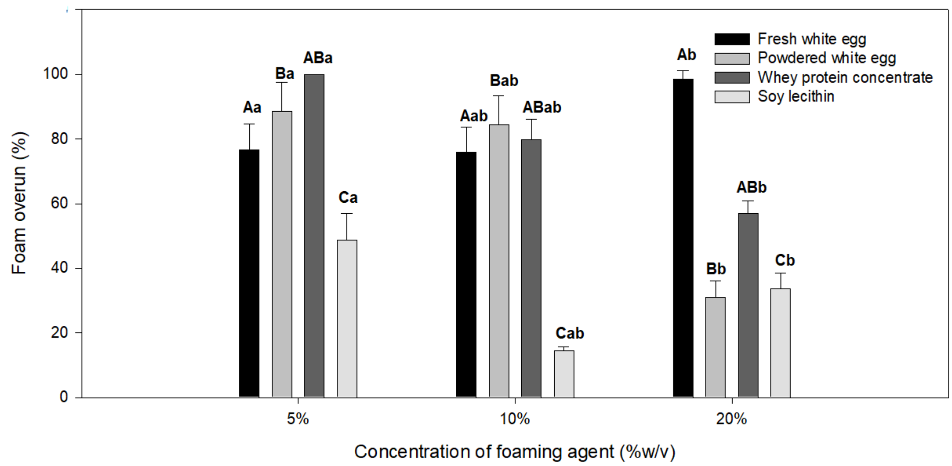

Figure 3. Effect of type and concentration of foaming agents on the foam overrun during foam mat drying.
Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

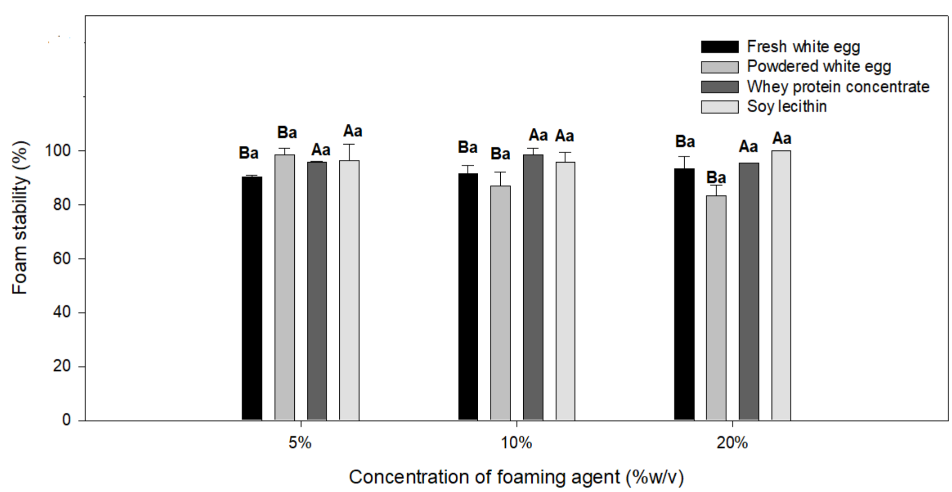

Figure 4. Effect of type and concentration of foaming agents on the foam stability during foam mat drying.
Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

3.2. Effect of Type and Concentration of Foaming Agent on physical characteristics of the Red Dragon Fruit powdered drinks

The physical characteristics of red dragon powdered drinks including moisture content, water solubility index, hygroscopicity, and yield as affected by the type and concentration of foaming agents are shown in **Table 1.** The type of foaming agent significantly affected the moisture content of the red dragon fruit powdered drink. The moisture content of the red dragon fruit powdered drink produced with whey protein concentrate as a foaming agent was lower than with fresh egg white, powdered egg white, and soy lecithin. This is because whey protein concentrate helps maintain foam stability during the drying process. The foam provides a porous structure in the red dragon fruit juice solution, increasing the surface area exposed to hot air and thus optimizing the evaporation of water. The concentration of foaming agent also significantly affected the moisture content of the red dragon fruit powdered drink. The addition of 10% foaming agent resulted in higher moisture content compared to 5% and 20% concentrations. This difference in moisture content is due to the varying amounts of water evaporated during the drying process. The more water evaporated, the lower the moisture content of the red dragon fruit powder (de Paula et al., 2020; Hamad et al., 2023).

Table 1. Effect of Type and Concentration of Foaming Agent on the Physical Characteristics of Red Dragon Fruit Powdered Drink

Type of *Foaming Agent*	**Concentration (%)**	***Moisture Content* (%)**	***Water Solubility Index* (%)**	***Hygroscopicity* (%)**	***Yield* (%)**
Fresh white eggs	5	4.06 ± 0.35^{ABb}	84.73 ± 3.58^{Aa}	18.80 ± 0.36^{Aa}	100.00 ± 2.05^{Aa}
	10	4.52 ± 0.08^{ABa}	86.80 ± 0.00^{Ab}	18.13 ± 0.31^{Ab}	100.00 ± 0.58^{Ab}
	20	5.56 ± 0.37^{ABb}	88.87 ± 3.58^{Ac}	15.29 ± 0.28^{Ac}	98.23 ± 0.71^{Ac}
Powdered white eggs	5	3.97 ± 0.24^{ABb}	78.53 ± 3.58^{Ca}	16.68 ± 0.08^{Ba}	90.70 ± 2.02^{Ca}
	10	5.16 ± 0.24^{ABa}	74.40 ± 6.20^{Cb}	15.34 ± 0.25^{Bb}	94.44 ± 3.58^{Cb}
	20	4.24 ± 0.28^{ABb}	68.20 ± 6.20^{Cc}	15.74 ± 0.19^{Bc}	85.84 ± 4.08^{Cc}
Whey Protein Concentrate	5	4.18 ± 0.28^{Bb}	82.67 ± 3.58^{Ba}	16.49 ± 0.11^{Ca}	90.99 ± 4.24^{Ca}
	10	4.67 ± 0.26^{Ba}	83.70 ± 4.38^{Bb}	15.15 ± 0.41^{Cb}	89.19 ± 0.54^{Cb}
	20	4.13 ± 0.39^{Bb}	74.40 ± 0.00^{Bc}	13.97 ± 0.47^{Cc}	89.50 ± 1.23^{Cc}
Soy Lechitin	5	5.16 ± 0.53^{Ab}	76.47 ± 3.58^{Da}	16.52 ± 0.42^{Ba}	94.81 ± 0.37^{Ba}
	10	5.20 ± 0.92^{Aa}	68.20 ± 0.00^{Db}	15.83 ± 0.97^{Bb}	92.46 ± 1.37^{Bb}
	20	4.20 ± 0.23^{Ab}	55.80 ± 0.00^{Dc}	16.83 ± 1.59^{Bc}	91.22 ± 0.74^{Bc}

Different in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to type and concentration of foaming agent, respectively.

The water solubility index (WSI) refers to the ability of a powder to mix homogeneously with water. During dissolution, an ideal powder should absorb water easily, wet thoroughly, sink, and dissolve or disperse without clumping (Shaari et al., 2018). The type of foaming agent significantly affected the WSI of the red dragon fruit powdered drink. The WSI of the drink produced with fresh egg white was higher than with powdered egg white, whey protein concentrate, and soy lecithin. Solubility is closely related to the protein content in the red dragon fruit powdered drink. Fresh egg white consists of many proteins—up to 40 different and complex proteins (Muhammad et al., 2018). The high protein content and low hydrophobic compound content affect the WSI value (Drapala et al., 2017). The polar amino acid groups provide a hydrophilic property to the protein molecules, allowing them to bind with water. Ionic interactions or protein-water interactions lead to increased solubility (Locali Pereira et al., 2019). The concentration of foaming agents also significantly affected the WSI of the red dragon fruit powdered drink. As the concentration of the foaming agent increased, the WSI of the red dragon fruit powdered drink tended to decrease. This could be due to the increased total solids as the foaming agent concentration increased, disrupting the hydrophilic interactions of the protein with water (Kanha et al., 2020).

Hygroscopicity is the ability of a powder to absorb water vapor from its surroundings until it can no longer absorb additional moisture. Hygroscopicity is related to the physical, chemical, and microbiological stability of the powder. Hygroscopicity analysis is critical in determining drying, packaging, and storage conditions (Ramakrishnan et al., 2018). The dried materials with hygroscopicity <10% are considered non-hygroscopic, 10.1%-15% are slightly hygroscopic, 15.1%-20% are hygroscopic, 20.1%-25% are very hygroscopic, and >25% are highly hygroscopic (Kumar et al., 2022). The type of foaming agent significantly affected the hygroscopicity of the red dragon fruit powdered drink. The hygroscopicity of the drink produced with fresh egg white was higher than with powdered egg white, whey protein concentrate, and soy lecithin. This is due to the polar conformation in the structure of fresh egg white, which increases the powder's capacity to attract water molecules when in contact with the surrounding air (Shaari et al., 2018). In fruit powders, glucose, and fructose play a significant role in strong interactions with water molecules because of the polar groups present in these molecules. The concentration of foaming agents significantly affected the hygroscopicity of the red dragon fruit powdered drink. As the concentration of foaming agents increased, the hygroscopicity of the red dragon fruit powdered drink tended to decrease. A high hygroscopicity value indicates a low moisture content. Powders with low moisture content have a higher ability to absorb ambient moisture due to the high-water concentration gradient between the product and the environment. Therefore, powders with low moisture content exhibit high hygroscopicity (Zhang et al., 2018).

Yield is defined as the ratio of the mass of powder obtained at the end of drying to the mass of the initial material being dried (Susanti, Sediawan, Fahrurrozi, Hidayat, et al., 2021). The type of foaming agent significantly affected the yield of the red dragon fruit powdered drink. The yield of the red dragon fruit powdered drink produced with fresh egg white was higher than with powdered egg white, whey protein concentrate, and soy lecithin. This indicates that the loss of solids during drying was minimal. The concentration of foaming agents also significantly affected the yield of the red dragon fruit powdered drink. As the concentration of foaming agents increased, the yield of the red dragon fruit powdered drink tended to decrease. This decrease in yield may be due to the sticking of the red dragon fruit juice solution to the pan during the drying process.

3.3. Effect of Type and Concentration of Foaming Agent on Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

The effect of foaming agent type and concentration on the TPC of red dragon fruit powder beverage is presented in Figure 5. The type of foaming agent significantly influenced TPC. Red dragon fruit powder beverages made with soy lecithin as the foaming agent exhibited higher TPC values compared to those using fresh egg white, powdered egg white, and whey protein concentrate. This may be attributed to soy lecithin's ability to produce stable foam. Stable foam forms a robust film that protects components within the foam system, including betacyanins and betaxanthins, which are phenolic compounds in red dragon fruit, thus minimizing damage during drying (Tavares et al., 2020). The concentration of the foaming agent also significantly influenced TPC. As the concentration of the foaming agent increased, the TPC of the red dragon fruit powder beverage tended to rise. Higher concentrations of foaming agents increase the viscosity of the solution, which contributes to foam stability. Stable foam has a thicker film surrounding the air bubbles. A thicker film provides greater protection for phenolic compounds in red dragon fruit juice (David et al., 2019). Additionally, stable foam can maintain a porous structure, enhancing the surface area of the material exposed during drying and accelerating the drying process (Reis et al., 2021).

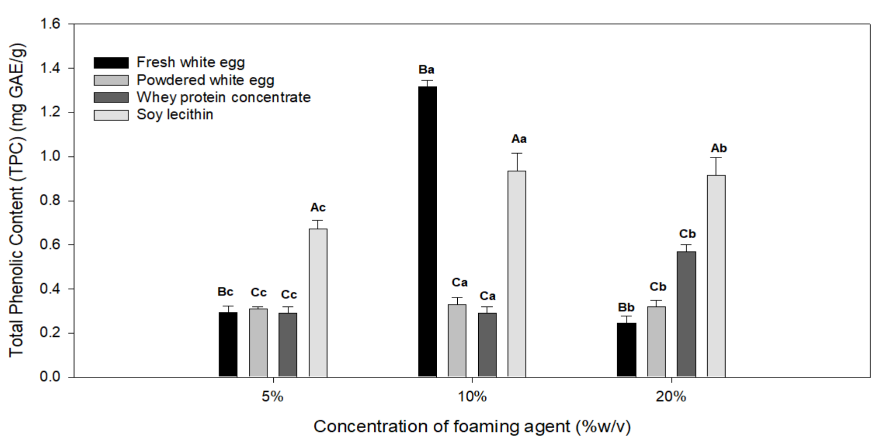

Figure 5. Effect of type and concentration of foaming agents on TPC red dragon fruit drink powder.

Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

The effect of foaming agent type and concentration on the TFC of red dragon fruit powder beverage is shown in Figure 6. The type of foaming agent significantly influenced TFC. Red dragon fruit powder beverages prepared with soy lecithin as the foaming agent had higher TFC values compared to those using fresh egg white, powdered egg white, and whey protein concentrate. Soy lecithin produced stable foam that could protect flavonoid compounds present in red dragon fruit juice, minimizing damage during the drying process (Rodr & Espino, 2020). The concentration of the foaming agent also significantly influenced TFC. As the concentration of the foaming agent increased, the TFC of the red dragon fruit powder beverage tended to rise. Higher concentrations of foaming agents increase the viscosity of the solution, contributing to foam stability. Stable foam has a thick film surrounding the air bubbles, which provides better protection for bioactive compounds, including flavonoids, located between the air bubbles. Furthermore, stable foam maintains a porous structure, enhancing the surface area of the material being dried, which accelerates the drying process (Naufalin et al., 2021; Ruengdech & Siripatrawan, 2022).

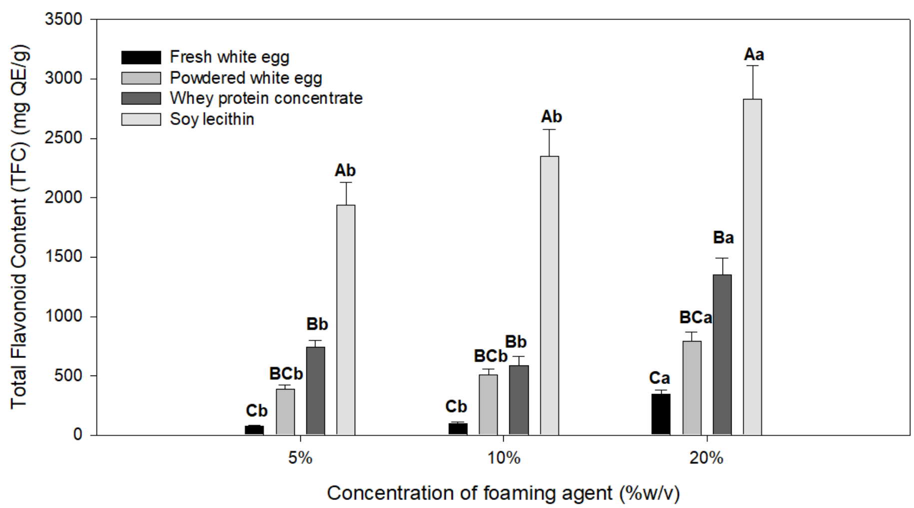

Figure 6. Effect of type and concentration of foaming agents on TFC red dragon fruit drink powder. Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

3.4. Effect of Type and Concentration of Foaming Agent on Antioxidant Activity of the Red Dragon Fruit Powdered Drinks

3.4.1. Antioxidant Activity Using the DPPH Free Radical Scavenging Method

The effect of foaming agent type and concentration on antioxidant activity analyzed by the DPPH method is shown in Figure 7. The type of foaming agent significantly influenced the antioxidant activity of the red dragon fruit powder beverage. The results indicated that beverages prepared with soy lecithin exhibited higher antioxidant activity compared to those made with fresh egg white, powdered egg white, and whey protein concentrate. Soy lecithin, as a foaming agent, produced stable foam and accelerated the drying process, thereby minimizing the degradation of phenolic and flavonoid compounds, which act as antioxidants during the drying process (Baria et al., 2019). Antioxidant activity is closely related to phenolic and flavonoid content. A reduction in total phenolic and flavonoid content leads to decreased antioxidant activity because these compounds in red dragon fruit serve as antioxidants (Luu et al., 2021). The concentration of the foaming agent also significantly influenced antioxidant activity analyzed by the DPPH method. Antioxidant activity tended to decrease with the addition of foaming agents at 20% concentration. This may be attributed to the increased total solids in the powder due to the higher concentration of the foaming agent, which results in lower measurable antioxidant activity. Additionally, antioxidant activity is affected by factors such as pH, temperature, light, oxygen, and interactions with other compounds (Khamjae & Rojanakorn, 2018; Purnomo et al., 2023).

3.4.2. Antioxidant Activity Using the Ferri Reduction Antioxidant Power (FRAP) Method

The effect of foaming agent type and concentration on antioxidant activity analyzed by the FRAP method is shown in Figure 8. The type of foaming agent significantly influenced the antioxidant activity of the red dragon fruit powder beverage as measured by the FRAP method. Beverages produced using soy lecithin exhibited higher antioxidant activity compared to those made with fresh egg white, powdered egg white, and whey protein concentrate. Soy lecithin produced more stable foam, which expedited the drying process and minimized the degradation of phenolic and flavonoid compounds that serve as antioxidants during drying (Wirantika et al., 2023). The concentration of the foaming agent also significantly affected the antioxidant activity of the red dragon fruit powder beverage tested with the FRAP method. Antioxidant activity tended to increase with higher concentrations of the foaming agent. This increase in antioxidant activity correlated linearly with the rising total phenolic and flavonoid content of the red dragon fruit powder beverage(Purnomo et al., 2023; Zorzenon et al., 2020).

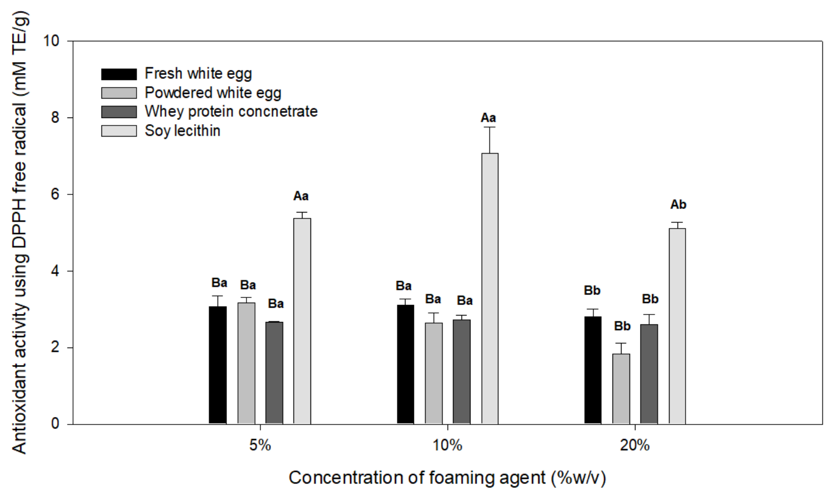

Figure 7. Effect of type and concentration of foaming agents on antioxidant activity using DPPH free radical of red dragon fruit drink powder.

Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

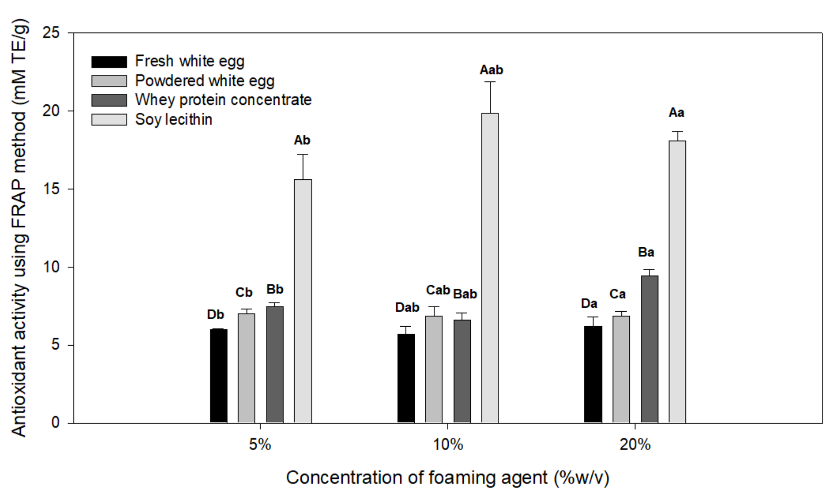

Figure 8. Effect of type and concentration of foaming agents on antioxidant activity using FRAP method of red dragon fruit drink powder.

Differences in the capital and lowercase letters show a statistically significant difference ($p < 0.05$) due to the type and concentration of the foaming agent, respectively.

4. Conclusion

The type and concentration of foaming agents significantly impacted the foam characteristics, physicochemical properties, and antioxidant activity of red dragon fruit powdered drinks produced via foam mat drying. Soy lecithin created the most stable foam, preserving bioactive compounds like phenolics and flavonoids during drying, resulting in higher antioxidant activity (TPC, TFC, DPPH, and FRAP). Whey protein concentrate and fresh white egg excelled in foam formation, producing powders with lower moisture content, better solubility, and higher yield. However, higher foaming agent concentrations sometimes reduce solubility and yield due to increased total solids. Overall, soy lecithin is ideal for preserving antioxidant properties, while whey protein concentrate, and fresh egg white are more suited for achieving favorable foam formation and physical attributes. The proper choice of foaming agent and concentration is key to optimizing the quality of red dragon fruit powder for functional food applications.

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