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ORIGINAL PAPER

Effect of soy protein isolate concentration and whipping time on physicochemical and functional properties of strawberry powder

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Abstract

The objective of this work was to study the effect of soy protein isolate concentration (0.5–9%) and whipping time (1–8 min) on foam characteristics, physicochemical and functional properties of hot air foam-mat-dried strawberry powder. An optimization of foaming conditions was performed by response surface methodology to maintain the studied responses within acceptable limits. The foam was prepared using different concentrations of soy protein isolate solution (32%) and dried at 50 °C in a thin layer (4 mm as a thickness). The concentration of soy protein was the predominant parameter affecting foam density, expansion, and stability, and physicochemical and functional properties of strawberry powder. Total phenolic content, total flavonoid content, antioxidant activity, water holding capacity, and oil holding capacity increased by about 26, 47, 166, 21, and 48%, respectively, with an increase in the concentration of soy protein isolate, compared to the control sample. Contrary, the whipping time showed a contradicted effect on all studied responses except the foam expansion and oil holding capacity.

Keywords Strawberry powder · Foam-mat-drying · Total phenolic content · Flavonoids, antioxidant activity, water and oil holding capacity

Abbreviations

AOA	Antioxidant activity
DoE	Design of experiment
FD	Foam density
FE	Foam expansion
FMD	Hot air foam-mat drying
FMD strawberry	Hot air foam-mat-dried strawberry
HAD strawberry	Hot air dried strawberry
OHC	Oil holding capacity
RSM	Response surface methodology
SPI	Soy protein isolate
TFC	Total flavonoids content
TPC	Total phenolic content
VDL	Volume of drained liquid
WHC	Water holding capacity

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Introduction

Strawberries, *Fragaria ananassa*, belong to the genus of Fragaria in the rose family and are summer fruits grown in moderate climates. Strawberries have attractive sensory characteristics such as appealing flavor and red color. Moreover, they have potential health-promoting effects because they are rich in bioactive compounds such as polyphenols and flavonoids having antioxidant properties, which could prevent some chronic diseases such as cancer and cardiovascular diseases. Strawberries are very perishable and delicate fruits with short shelf life. In order to extend the shelf life, strawberries can be processed in the form of jam, frozen and dried products (pieces, snacks, and powder) [1]. Drying is the oldest technique for food preservation to improve food stability during storage as a result of water removal and lower water activity [2]. Conventional drying techniques (tray-drying, drum-drying, and spray-drying) are frequently used for strawberry drying but these techniques have some drawbacks such as high energy consumption and poor quality attributes (sensory, nutritive, and functional properties). These drawbacks are related to the shrinkage phenomenon resulting in texture compactness and case hardening, which in turn decrease the effective moisture diffusivity [3]. These phenomena render the drying operation longer time leading to poor quality of dried products, particularly the sensitive materials such as strawberries. Freeze drying produces a good quality dried product [4] but, the higher operation and capital costs limit its use for valuable products. Therefore, there is a need to develop alternative drying techniques to overcome these problems. Hot air foam-mat-drying (FMD) is a simple and alternative process that facilitates water removal and allows drying (at relatively low temperatures) of heat-sensitive food materials, viscous and high sugar foods that cannot be dried by conventional hot air drying techniques. For these reasons, the hot air FMD technique has received renewed significant interest over the past decade due to many advantages such as rapid drying, relatively low drying temperature, favorable rehydration, and retention of bioactive compounds and volatiles during the drying operation. This technique has been recently used for drying many food materials such as blueberry [5], mango [6], papaya [7], tomatoes [8], and cantaloupe [9]. But, few studies have been reported dealing with the production of strawberry powder by hot air FMD. Likewise, no studies were reported on the use of soy protein isolate as a foaming agent in the preparation of this powder. FMD technique is based on the transformation of food juice or puree to stable foam by whipping using an adequate foaming agent and foam stabilizer. The foam is subsequently dried by hot air at relatively low temperatures in a thin layer [10]. Proteins are widely used as foaming agents to incorporate gas (air) in food matrix because they provide good foamability and whipping properties and high foam stability owing to their hydrophobicity allowing their rapid adsorption at the air–water interface and forming of a coherent elastic adsorbed layer [11]. The commonly used proteins as foaming agents are egg white, soy proteins, and milk proteins (whey proteins and casein). The foaming agent allows incorporating gas (air) into food matrix where the porous matrix accelerates the drying operation owing to increased effective moisture diffusivity [12] which in turn decreases the required time for drying compared to traditional hot air drying. As a result, the quality attributes of dried products are improved. The whipping properties of a protein could be evaluated by the characteristics of formed foam (foam density, foam expansion, and foam stability) which are influenced by several factors such as whipping time, the concentration of the foaming agent, and total solid of the mixture. Foam density (FD) is the main parameter used to evaluate foam quality, mainly the whippability [13]. The extensive whipping time may lead to an increase in the FD owing to the thinning of liquid film and the mechanical deformation causing a rupture of bubble walls [14]. Mixture viscosity is another factor affecting the foam density where the addition of high levels of foaming agent increases the mixture viscosity exceeding the limited viscosity which in turn impedes the incorporation of more air bubbles into the foam structure leading to an increase in the FD [15]. A foam density of 300–600 kg m^{-3} is considered as an appropriate FD for hot air foam-mat-drying [16].The effect of foaming agent type and foaming conditions (the concentration of the foaming agent and whipping time) on foam characteristics was studied by many authors [10, 15, 17–20]. Similar to foam characteristics, total phenolic and flavonoid content, antioxidant activity, and functional properties of powder could be also influenced by these factors. Due to the limited studies reported on hot air FMD strawberry powder in the literature, the studies of other products will be discussed in this section. Brar et al. [21] found that the total phenolic content (TPC) is depending on the type of foaming agent where the TPC of hot air FMD peach powder was increased with an increase in the concentration of soy protein isolate (SPI) reaching a certain extent and started to decrease afterward, while it decreased with an increase in the concentration of pea protein isolate (PPI). On the other hand, a decreasing trend of flavonoids such as anthocyanin of hot air FMD sour cherry powder was observed with increasing the concentration of egg white and methyl cellulose [17]. The antioxidant activity is related to the presence of bioactive compounds at high levels. Hossain et al. [8] observed that the antioxidant activity of hot air FMD tomato powder increased with increasing the concentration of egg white as a foaming agent (from 3 to 7%) and carboxymethyl cellulose as a foam stabilizer (from 0.5 to 1%). Concerning the functional properties of hot air FMD powders, Ojo et al. [22] studied the effect of the type and the concentration of foaming agent on the water holding capacity (WHC) of hot air FMD pineapple and hot air FMD cashew apple. The authors found that the non-foamed powder had higher WHC than that of hot air FMD powder, while the WHC of FMD powder prepared with soy protein (1 and 2%) was higher than that of the powder prepared with egg white as foaming agents. On the other hand, the effect of air temperatures on these properties was also reported [23, 24]. The literature available on physicochemical and functional properties of hot air FMD strawberry powder is scanty and no reported studies on the use of soy protein isolate as a foaming agent in the preparation of hot air FMD strawberry powder, the objective of this study was therefore to optimize and evaluate the effect of the concentration of soy protein isolate (SPI) and whipping time, on foam characteristics and physicochemical and functional properties of hot air FMD strawberry powder.

Materials and methods

Raw materials

Fully ripe red Strawberry fruits (*F. ananassa* Duch, cultivar Fortuna) were purchased from a local farm (Mashtool

El-souk, Sharkia government, Egypt). Fruit ripeness was visually determined by observing the full red color of the fruit and the firmness by touching it. Strawberries were prepared by manually sorting, washing with clean running tap water, calyx was removed, and cut into small pieces.

Foaming agent

Soy protein isolate (SPI: ~ 90% protein) was obtained from Agricultural Research Center (Dokki, Giza, Egypt). A 32% solution was prepared by dissolving SPI powder in distilled water with a ratio of 1:2 w/w (SPI: distilled water) ensuring a complete dissolution of SPI powder in the mixture. This solution was used for preparing the foam according to the experimental design (Table 1). It is worth mentioning that the solution became viscous at a higher level than 32% of SPI (like a paste).

Foam preparation and hot air drying

Strawberry puree was prepared using an electric hand blender (Braun Multi Quick 1 Hand Blender, 450 Watt, MQ 120, Poland). The puree was then whipped with soy protein isolate with a concentration ranging from 0.5 to 9% for 1 to 8 min, according to the experimental design (Table 1), using the same blender. Therefore, the final concentration of SPI which was prepared using a 32% solution, varied from 0.2 to 2.9%. The foam was subsequently spread in a thin layer (4 ± 1 mm as thickness) on a silicon sheet and hot air-dried at 50 °C with air velocity and relative humidity of 1.2 m s^{-1} and 1.9% respectively (Fig. 1). A control sample was used for comparison; 4 ± 1 mm thick strawberry slices were hot air-dried under the same conditions. The samples were referred to as HAD and FMD for traditional hot air-dried (control samples) and hot air foam-mat- dried samples, respectively. The dried samples were ground using a kitchen

Table 1 Experimental design of foaming conditions (SPI concentration and whipping time) for hot air foam-mat-dried strawberry powder

Parameter	control	01	02	03	04	05	06	07	08	09	10	11	12	13
Concentration[a] (%)	–	4.8	9	4.8	4.8	7.8	7.8	4.8	1.7	1.7	4.8	0.5	4.8	4.8
Whipping time (min)	–	4.5	4.5	8.0	4.5	7.0	2.0	4.5	2.0	7.0	4.5	4.5	1.0	4.5

[a]SPI concentrations were prepared from 32% solution of SPI, which varied from 0.2% to 2.9% as final concentrations of SPI

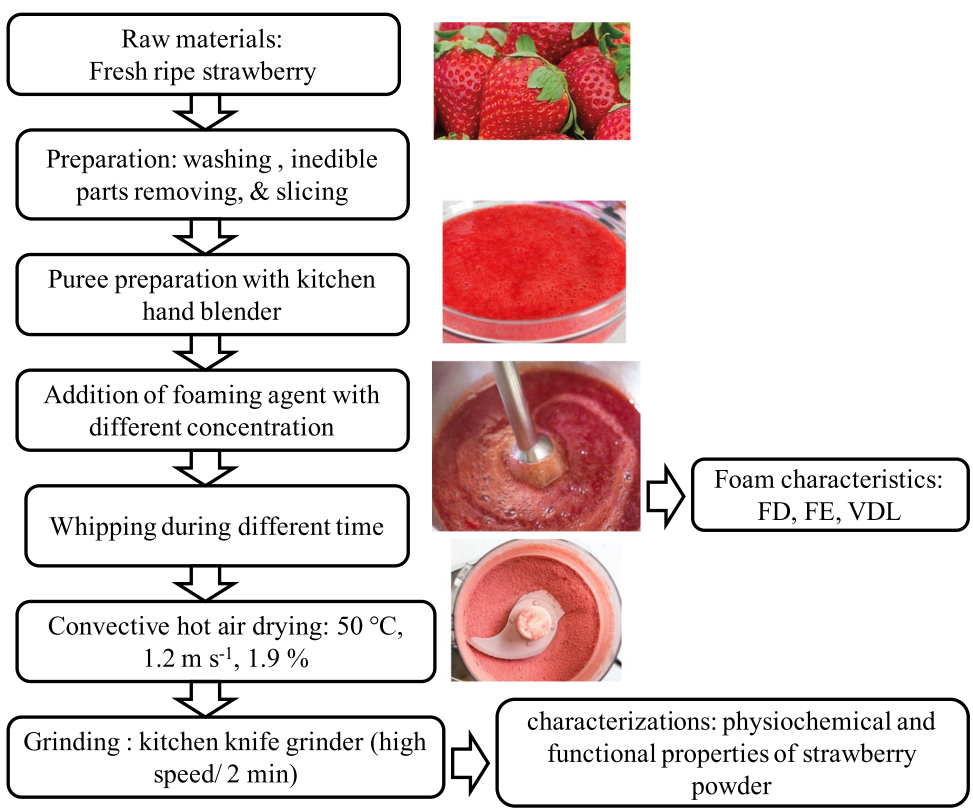

Fig. 1 Protocol of strawberry powder production by hot air foam-mat-drying

knife grinder (Moulinex, 500 W) at high speed for 2 min at room temperature (20 ± 2 °C) and all characterizations were performed on < 160 µm strawberry powder.

Assessments and characterizations

Foam characteristics

Foam density (FD) was determined according to Auisakchaiyoung and Rojanakorn [25]. It was calculated according to Eq. (1) and expressed as kg m^{-3}.

$$FD = \frac{\text{Mass of the foam}}{\text{Volume of the foam}} \quad (1)$$

Foam expansion (FE) was determined according to Rajkumar et al. [26] using Eq. (2).

$$FE = \left(\frac{V_1 - V_0}{V_0}\right) X100 \quad (2)$$

where: V_0: is the initial volume of strawberry puree with SPI (m^3) and V_1: is the volume of foam after whipping (m^3).

Foam stability (FS) was determined according to Nekrasov et al. [27]. The volume of drained liquid from the foam structure was measured for 60 min.

Preparation of the methanolic extract

The methanolic extract was prepared by dissolving about 10 g of powder in 100 mL of methanol (analytical grade) at room temperature (20 ± 2 °C) and filtered through Whatman No. 1 filter paper. The residue was re-extracted with 60 mL of methanol and filtered through Whatman No. 1 filter paper. The filtrate was evaporated under vacuum at 40 °C (Buchi Rotavapor R-124 Rotary Evaporator, Switzerland).

Total phenolic and flavonoid content

The total phenolic content (TPC) of the methanolic extract was determined using the Folin-Ciocalteu method according to Elfalleh et al. [28]. About 0.5 mL of methanolic extract was mixed with 0.5 mL of Folin-Ciocalteu reagent for 3 min and 4 mL of 1 M sodium carbonate (Na_2CO_3) was then added to the mixture. The mixture was incubated at 45 °C for 5 min in a hot water bath and then cooled in a cold water bath. The absorbance was read at 765 nm, using a spectrophotometer (Jenway 6705, UK), against a blank sample containing distilled water. The TPC was calculated based on the calibration curve of Gallic acid and expressed as mg equivalents of Gallic acid per 100 g dry basis (mg GAE/100 g db).

The total flavonoid content (TFC) of the methanolic extract was determined according to Elfalleh et al. [28] with slight modifications. A mixture of Methanolic extract (1 mL) and 1 mL of 2% $AlCl_3$ methanolic solution was allowed to stand for 15 min at room temperature (20 ± 2 °C) and the absorbance of the reaction mixture was read at 430 nm using a spectrophotometer (Jenway 6705, UK), against a blank containing distilled water. TFC was calculated on the basis of the calibration curve of quercetin and expressed as mg QE/100 g dry weight basis (mg QE/100 g db).

Antioxidant activity

The antioxidant activity of the methanolic extract was assessed by measuring their scavenging abilities to 2, 2-diphenyl-1-picrylhydrazyl stable radical. The DPPH assay was carried out as described by Miliauskas et al. [29], but with slight modifications. Briefly, 2 mL of methanolic extract was mixed with 2 mL of DPPH methanolic solution (0.1 mM) and the mixture was kept at room temperature (20 ± 2 °C) for 30 min in dark. The absorbance of the tested samples was read at 517 nm against a blank sample containing the same amount of methanol and DPPH solution (2 mL of each). The radical scavenging activity was calculated according to Eq. (3):

$$\text{Radical scavenging}(\%) = \left[\frac{Abs_{blank} - Abs_{sample}}{Abs_{blank}}\right] \times 100 \quad (3)$$

Water and oil holding capacity

The water holding capacity (WHC) and oil holding capacity (OHC) of strawberry powders were determined according to Mounir et al. [30] with slight modifications. A 2.5 g of powder was mixed with 10 mL distilled water or refined sunflower oil (density: 0.89877 g mL^{-1}) and allowed to stand for 30 min at room temperature (20 ± 2 °C) before the centrifuge at 960×*g* for 30 min (centrifuge: Model 3K15, rotor: 11133, SIGMA, Germany). The supernatant was gently drained after centrifugation and the new mass was recorded. WHC and OHC were calculated using Eqs. (4) and (5).

$$WHC(\%) = \frac{\text{Rehydrated mass} - \text{Dried mass}}{\text{Dried mass}} \times 100 \quad (4)$$

$$OHC(\%) = \frac{\text{Sampl mass with oil} - \text{Dried mass}}{\text{Dried mass}} \times 100 \quad (5)$$

Design of experiment and statistical analyses

The experiments were carried out with two parameters; the concentration of the foaming agent (*C*) which ranged between 0.5 and 9% SPI which was prepared from 32% solution of soy protein isolate and whipping time (*t*) which varied from 1 to 8 min using a central composite rotatable design of experiments (DoE) with 5 levels (− α, + α, − 1, + 1, and 0) of each parameter where the midpoint (0) was repeated 5 times resulting in 13 experiments. Response surface methodology (RSM) by Statgraphics plus (1994-4.1 version), that applied in the optimization of the extraction of bioactive compounds and in the production of food products [31], was used to describe the effect of foaming conditions (*C* and *t*) on the studied responses. RSM allows (1) describing and interpreting the effect of SPI concentration and whipping time on the response variables using Pareto charts, general trends, and 3-D response surface, (2) defining the empirical quadratic models with R^2, adjusted R^2, lack of fit (MAE), and coefficient of variation (CV) (Table 5), and (3) optimizing the foaming conditions(*C*, *t*) defining the appropriate combination of SPI concentration and whipping time which optimize as possible all the response variables. The optimization was based on the lowest values of FD and VDL, and on the highest values of FE, TPC, TFC, AOA, WHC, and OHC (Table 6). The obtained results were presented as mean value ± standard deviation of three replicates and statistically analyzed by ANOVA in order to identify the significant differences between the responses at $p \leq 0.05$.

Results and discussion

Foam characteristics

Foam density and foam expansion are used to describe the protein foamability and whipping properties; the higher the foamability of protein, the lower the foam density and the higher the foam expansion. The good foamability and whipping properties of a protein are related to the incorporation of a considerable amount of air into the foam structure during the whipping process [32]. Table 2 shows the foam characteristics such as foam density (FD), foam expansion (FE), and foam stability (FS). Foam stability is depending on the rate at which the liquid drains from the foam structure [33]; the lower the volume of drained liquid, the higher the foam stability.

The density of strawberry foam (FD) varied from 435.34 to 549.21 kg m^{-3} (Table 2), which was in the range of reported results; a foam density of 300–600 kg m^{-3} was reported as an appropriate FD for the foam mat drying process [16]. The expansion of strawberry foam (FE) was found to be in the range of 33.92–51.29%. While the volume of drained liquid varied from 0.75 to 1.1 mL. Figure 2 shows the effect of SPI concentration and whipping time on foam characteristics (FD, FE, and VDL). As a general trend, FD and VDL gradually decreased with increasing the SPI concentration and the whipping time reaching a certain extent and started to re-increase afterward while, FE exhibited the contradicted behavior. The effect of SPI concentration on foam characteristics was more pronounced compared to whipping time.

Table 2 Characteristics of strawberry foam (foam density, Foam expansion, and volume of drained liquid from foam structure) prepared with different concentrations, prepared from 32% solution of soy protein isolate, during different times of whipping

Foaming conditions	FD	FE	VDL
Non-foamed (control)	–	–	–
C = 9%, t = 4.5 min	501.4 ± 0.02^{d}	33.92 ± 0.02^{i}	1.0 ± 0.03^{b}
C = 4.8%, t = 8 min	452.48 ± 0.02^{g}	48.18 ± 0.01^{b}	0.80 ± 0.02^{f}
C = 4.8%, t = 4.5 min	435.34 ± 0.02^{i}	51.29 ± 0.03^{a}	0.75 ± 0.02^{g}
C = 7.8%, t = 7 min	439.43 ± 0.01^{h}	39.63 ± 0.02^{g}	0.95 ± 0.02^{c}
C = 7.8%, t = 2 min	471.28 ± 0.01^{f}	37.19 ± 0.01^{h}	1.1 ± 0.01^{a}
C = 1.7%, t = 2 min	541.84 ± 0.02^{b}	44.78 ± 0.02^{e}	0.85 ± 0.01^{e}
C = 1.7%, t = 7 min	503.6 ± 0.01^{c}	46.98 ± 0.02^{c}	0.80 ± 0.01^{f}
C = 0.5%, t = 4.5 min	549.21 ± 0.02^{a}	43.91 ± 0.03^{f}	0.85 ± 0.01^{e}
C = 4.8%, t = 1 min	481.54 ± 0.03^{e}	45.93 ± 0.01^{d}	0.90 ± 0.01^{d}

Superscript letters are statistically significantly different ($P < 0.05$)

C Concentration of soy protein isolate (%), *t* whipping time (min), *FD* foam density (kg m^{-3}), *FE* foam expansion (%), *VDL* volume of drained liquid from foam structure (mL)

A similar trend was reported by Asokapandian et al. [34] who found that foam density of Muskmelon pulp decreased with increasing the concentration of SPI and whipping time reaching a certain extent and started to increase afterwards, while FE exhibited the contradicted behavior. Similarly, Khamjae and Rojanakorn [15] and Karim and Wai [35] observed a gradual increase in FD of passion fruit aril and star fruit, respectively, after maximum decrease with increasing the concentration of methylcellulose.

The low FD and VDL and the high FE may be due to (1) incorporation of a high amount of air bubbles that are entrapped into the foam structure enlarging the foam volume [36], and (2) reduction of surface and interfacial tension of the aqueous system forming a stable viscoelastic film which can resist the thermal and mechanical stresses [15]. In contrast, the high FD and VDL and low FE could be explained by (1) instability of air bubbles particularly at low concentrations of SPI because the critical thickness required for the interfacial film could not be formed [37], (2) weakening the air bubbles owing to the mechanical stresses resulting from an excessive whipping leading to the collapse of foam structure [38], and (3) increasing the mixture viscosity exceeding the limited viscosity as a result of adding high concentrations of SPI, which in turn impede the incorporation of more air bubbles into the foam structure [15]. Moreover, a combination of a high concentration of SPI and a long whipping time increased the VDL. This could be explained by the formation of a

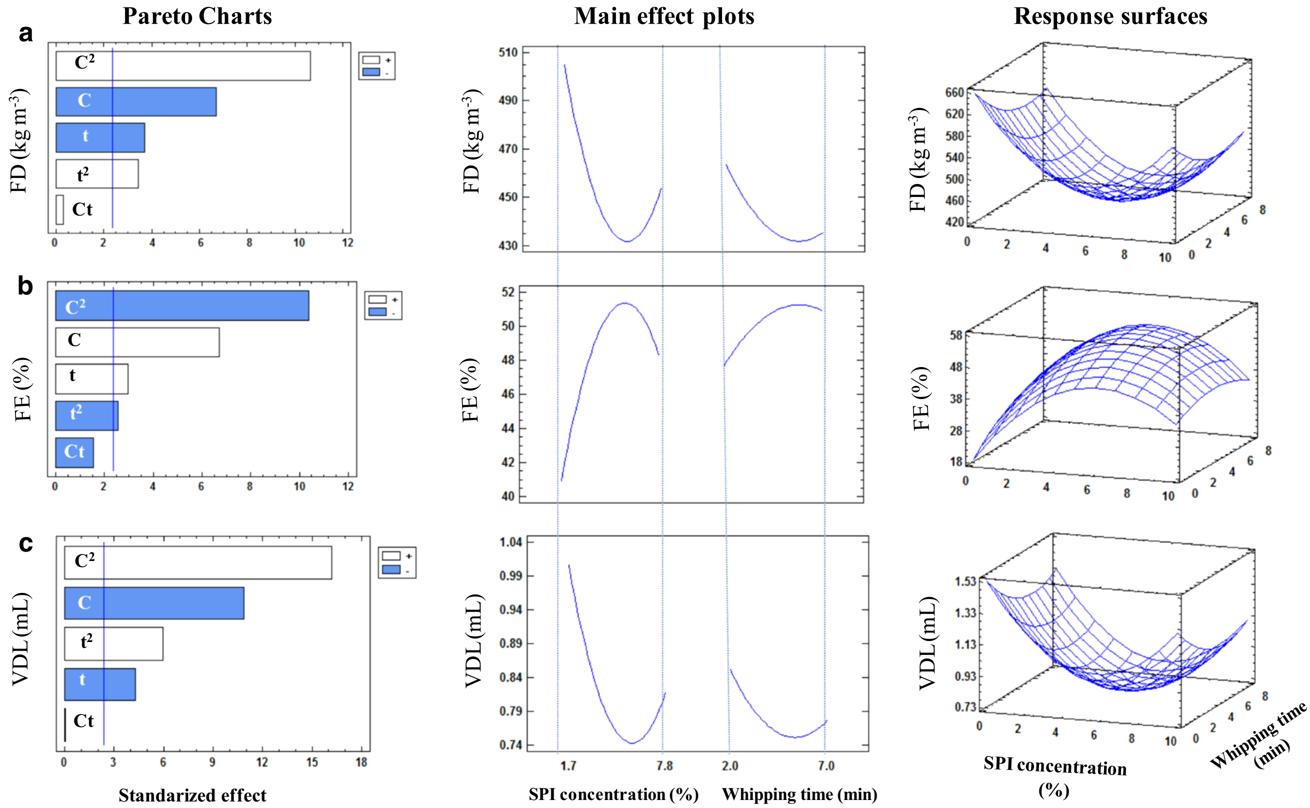

Fig. 2 Effect of foaming parameters (*C*, *t*) on **a** foam density (FD, kg m^{-3}), **b** Foam expansion (FE, %) and **c** volume of drained liquid (VDL, mL) of strawberry foam prepared with different concentrations of SPI, prepared from 32% solution of soy protein isolate, during different times of whipping

large number of small bubbles resulting in unstable foam which collapses quickly [9].

Total phenolic and flavonoid content

Conventional hot drying techniques may cause adverse effects on phenolics and flavonoids as a result of applied high temperatures, resulting in thermal degradation of heat-sensitive components [39] while, drying processes at low temperatures, such as freeze-drying, can retain these antioxidants [40, 41]. Therefore, there is a great need to develop alternative drying processes in order to maintain the antioxidants and improve the quality of dried fruits and vegetables. In this study, the effect of hot air foam-mat drying as an alternative technique to conventional hot air drying on antioxidants was investigated. The total phenolic content (TPC) of hot air FMD strawberry powder increased by about 26% compared to conventional HAD powder. The TPC of hot air FMD powder was found to be in the range of 438.20–533.45 mg GAE/100 db against 423.01 mg GAE/100 g db for conventional HAD powder (Table 3). Similarly, the total flavonoid content (TFC) of hot air FMD strawberry powder increased by about 47% compared to conventional HAD powder. The TFC of hot air FMD powder ranged from 230.58 to 288.85 mg QE/100 g db against 196.81 mg QE/100 g db for conventional HAD powder (Table 3). Figure 3 shows the effect of SPI concentration and whipping time on TPC and TFC of hot air FMD strawberry powder. It was observed that the TPC and TFC increased with an increase in the concentration of SPI and decreased with increasing the whipping time. The lower contents of TPC and TFC of conventional HAD strawberry powder may be related to the thermal degradation of these compounds as a result of long time drying [21, 42]. Moreover, the enzymatic process by polyphenol oxidase altering the structure of polyphenols is another supporting explanation [43]. While, the increase in the TPC and TFC of hot air FMD strawberry powder may be due to (1) retention of the original polyphenols owing to the short drying time as a result of the increased specific surface (exchange surface), accelerating the water removal, (2) release of the matrix-bound polyphenols owing to breaking down the cell walls during the whipping process causing the free phenolic compounds to increase [38, 44], and (3) the inherent content of SPI from phenols and flavonoids contributing to an increase in TPC and TFC. Therefore, the increase in TPC and TFC

Table 3 Physicochemical and functional properties of hot air FMD strawberry powder prepared with different concentrations, prepared from 32% solution of soy protein isolate, during different times of whipping

Foaming conditions	TPC	TFC	AOA	WHC	OHC
Non-foamed (control)	423.01 ± 0.01[j]	196.81 ± 0.02[j]	18.35 ± 0.02[j]	3.80 ± 0.03[g]	0.98 ± 0.03[h]
C = 9%, *t* = 4.5 min	533.45 ± 0.02[a]	288.85 ± 0.02[a]	48.90 ± 0.01[a]	4.61 ± 0.01[a]	1.45 ± 0.01[a]
C = 4.8%, *t* = 8 min	456.92 ± 0.01[f]	265.60 ± 0.01[f]	32.95 ± 0.02[f]	4.02 ± 0.02[e]	1.37 ± 0.02[d]
C = 4.8%, *t* = 4.5 min	465.99 ± 0.03[e]	273.73 ± 0.02[e]	37.66 ± 0.03[e]	4.15 ± 0.01[c]	1.40 ± 0.01[c]
C = 7.8%, *t* = 7 min	501.53 ± 0.03[c]	279.88 ± 0.01[c]	40.56 ± 0.02[c]	4.55 ± 0.02[b]	1.43 ± 0.01[b]
C = 7.8%, *t* = 2 min	513.68 ± 0.01[b]	282.55 ± 0.02[b]	44.96 ± 0.02[b]	4.52 ± 0.02[b]	1.40 ± 0.02[c]
C = 1.7%, *t* = 2 min	452.62 ± 0.01[g]	260.93 ± 0.01[g]	29.89 ± 0.02[g]	3.98 ± 0.02[ef]	1.13 ± 0.02[g]
C = 1.7%, *t* = 7 min	450.81 ± 0.02[h]	244.46 ± 0.02[h]	27.91 ± 0.02[h]	4.00 ± 0.01[de]	1.14 ± 0.01[fg]
C = 0.5%, *t* = 4.5 min	438.20 ± 0.01[i]	230.58 ± 0.02[i]	22.97 ± 0.01[i]	3.95 ± 0.02[f]	1.16 ± 0.01[f]
C = 4.8%, *t* = 1 min	477.42 ± 0.03[d]	278.64 ± 0.03[d]	38.80 ± 0.02[d]	4.01 ± 0.03[d]	1.20 ± 0.02[e]

Superscript letters are statistically significantly different ($P < 0.05$)

C concentration of soy protein isolate (%), *t* whipping time (min), *TPC* total phenolic content (mg GAE/100 g db), *TFC* total flavonoid content (mg QE/100 g db), *AOA* antioxidant activity (%), *WHC* water holding capacity (%), *OHC* oil holding capacity (%)

of FMD powders is a net result of a combined increase in their extractability (the original phenolics and the bound phenolics released) and the inherent content of SPI from these compounds. In contrast, the decrease in the TPC and TFC due to long whipping time may be due to the thermal degradation of these compounds caused by heat generated during the whipping process (an experimental observation). The obtained results are in concurrence with Chandrasekar et al. [45] who found that the TPC of foam mat dried vegetable powder increased with increasing the concentration of egg albumin as a foaming agent. Likewise, Chaux-Gutiérrez et al. [6] reported similar results. In contrast, Vasudevan et al. [46] found a decrease in the TPC of hot air FMD soursop powder with an increase in the concentration of Arabic gum and fish gelatin as foaming agents. On the other hand, Kadam et al. [47] reported an insignificant effect of the concentration of foaming agent on phenolic content of hot air FMD pineapple powder.

Antioxidant activity

The retention of phytochemicals and their antioxidant activity may be affected by several factors such as the chemical composition of food being foamed, temperature applied during the drying process, foaming parameters (the type and the concentration of foaming agent and whipping time), and foam layer thickness. Brar et al. [21] showed that the antioxidant activity of foamed peach powder depends on the type of foaming agent and the drying temperature.

Table 3 shows the antioxidant activity (AOA) of strawberry powder. An increase of ~ 166% was observed in the AOA of hot air FMD strawberry powder compared to conventional HAD powder. The AOA of hot air FMD strawberry powder varied from 22.97 to 48.90% against 18.35% for conventional HAD strawberry powder. Figure 3 shows the effect of foaming parameters on the AOA of hot air FMD strawberry powder; the AOA was significantly affected by SPI concentration and whipping time. The higher the SPI concentration, the higher the AOA, while the longer the whipping time, the lower the AOA. The increase in the AOA of hot air FMD strawberry powder is related to the presence of phenolic compounds and flavonoids with high levels as mentioned above.

A similar trend was observed by Farid et al. [48] who reported that an increase in the AOA of hot air FMD tomato with an increase in SPI concentration, from 1 to 5%, while it decreased with increasing the whipping time from 2 to 14 min. The obtained results are in concurrence with Hossain et al. [8] who found that the AOA of hot air FMD tomato powder increased by increasing the concentration of egg white from 3 to 7%. Similar results were reported Lobo et al. [49] who found that the hot air FMD Tommy Atkins mango prepared with soy lecithin and carboxy methylcellulose had higher AOA than those of non-foamed powder (conventional hot air dried sample).

Water and oil holding capacity

The water holding capacity (WHC) or oil holding capacity are the ability of a powder to bind and hold water or oil against gravity or mechanical forces such as centrifugal force. Table 3 shows the WHC and OHC of conventional HAD and hot air FMD strawberry powders. Hot air FMD powder had higher WHC and OHC than those of conventional HAD powder by about 21% and 48%, respectively.

Figure 4 shows the effect of foaming parameters on WHC and OHC of hot air FMD strawberry powder. The concentration of SPI had a significant effect on WHC and OHC compared to whipping time which had a significant effect only on OHC. A gradual increase in WHC and OHC was

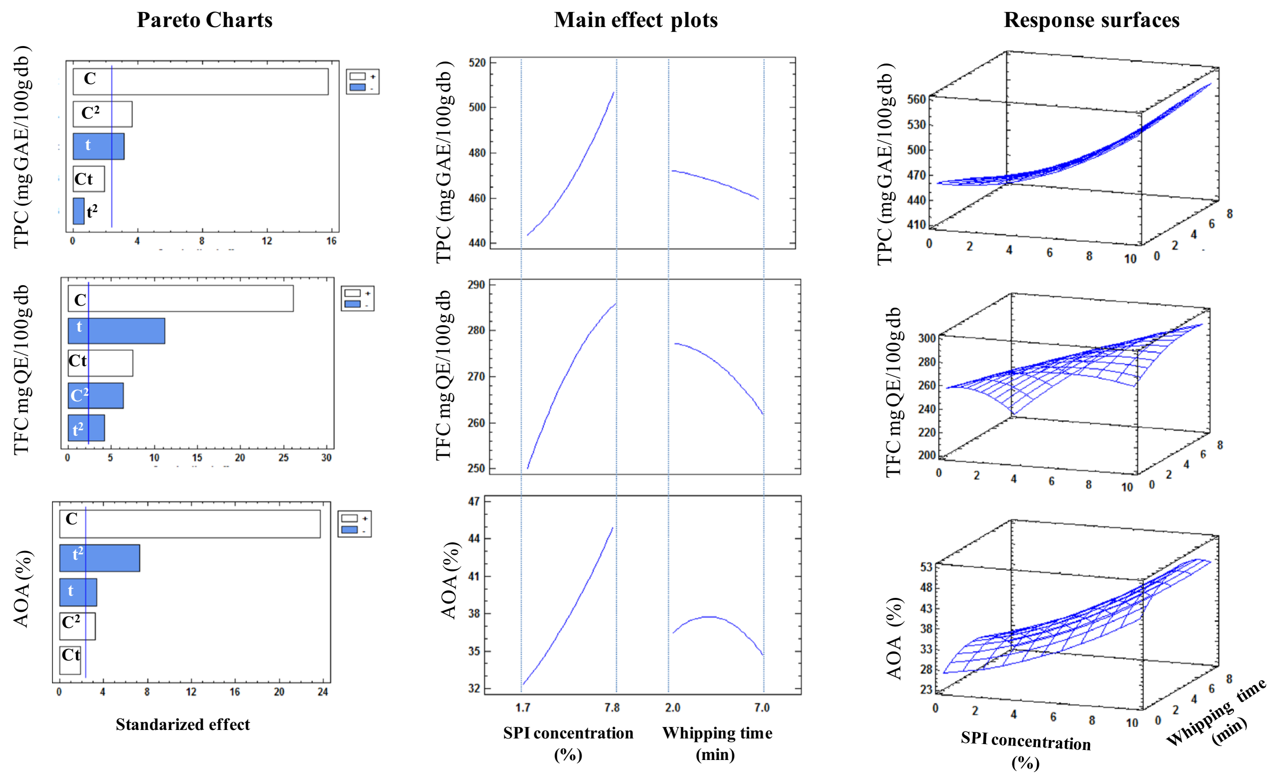

Fig. 3 Effect of foaming parameters (*C*, *t*) on **a** total phenolic content (TPC, mg GAE/100 g db), **b** total flavonoid content (TFC, mg QE/100 g db), and **c** antioxidant activity (AOA, %) of hot air FMD strawberry powder prepared with different concentration of SPI, prepared from 32% solution of soy protein isolate, during different times of whipping

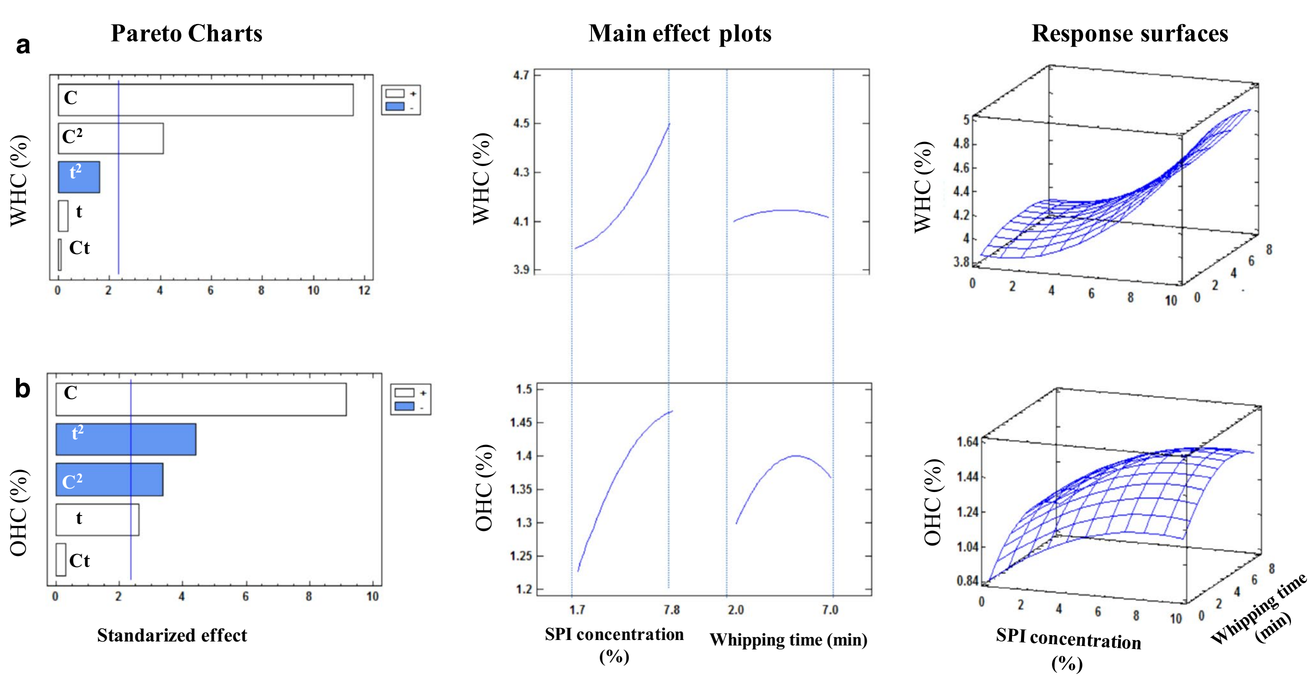

Fig. 4 Effect of foaming parameters (*C*, *t*) on **a** water holding capacity (WHC, %) and **b** oil holding capacity (OHC,%) of hot air FMD strawberry powder prepared with different concentrations of SPI, prepared from 32% solution of soy protein isolate, during different times of whipping

observed with increasing the concentration of SPI reaching a certain extent and started to decrease afterward.

The lower WHC and OHC of conventional hot air strawberry powder may be related to the texture compactness and the high density of powder which impede the absorption of water or oil during a specific time. While, the increase in the WHC and OHC of hot air FMD strawberry powder may be due to (1) the open structure which allows the rapid absorption of water or oil during a specific time, (2) the amphiphilic behavior of SPI allowing it to simultaneously react with water and oil as an emulsifier, (3) the high surface hydrophobicity which contributes to increasing the OHC, and (4) lower density powder (hot air FMD strawberry powder), which allows the powder to hold more of oil than the higher density powder (HAD strawberry powder) [50].

The obtained results are in disagreement with that reported Ojo et al. [22] who found that the concentration of foaming agent had no effect on the WHC of pineapple and cashew apple powders and the conventional hot air had higher WHC than those of hot air FMD powders. Similarly, Orishagbemi et al. [51] reported that the concentration of glycerol monostearate as a foaming agent at a higher level than 4% had an insignificant effect on the WHC of hot air FMD banana powder.

Correlation matrix

A correlation matrix was performed to define the relationship between the foaming parameters and the response variables and each to other. Table 4 shows the correlations between foaming parameters; SPI concentration (*C*) and whipping time (*t*), and the responses studied. These correlations showed the predominant effect of the concentration of SPI on these responses. In addition, these correlations could explain some phenomena taking place during foam preparation: (1) a direct relationship was found between FD and FE owing to volume increases as a result of the incorporation of more air bubbles which are subsequently trapped into the foam structure, (2) low density foam showed less drainage owing to the unfolding of SPI at the interphase forming a stable viscoelastic film. However, an extensive whipping may induce some mechanical stresses leading to thinning of this film and rupture of bubble walls which in turn increase the FD and VDL, (3) adding SPI at high concentrations increased the mixture viscosity impeding the incorporation of more air bubbles into the foam structure, which in turn increased both FD and VDL, and decreased the FE, (4) adding of SPI with high concentrations increased each TPC, TFC, and AOA. This could be explained by the fact that soy protein isolate contains high levels of polyphenols providing high antioxidant properties. But, a long time of whipping generated heat resulting in the thermal damage of these compounds decreasing the antioxidant properties, (5) direct relationship was observed between SPI concentration and each OHC and WHC. This may be due to the unfolded proteins increasing the surface hydrophobicity and to the amphiphilic properties of soy protein isolate, and (6) a positive correlation was found between FD and OHC. This could be explained by the large specific surface area and the low density of hot air FMD powder that allows the powder to hold more oil.

Optimization of foaming conditions

The optimization of foaming conditions was based on the lowest value of FD and VDL, and on the highest level of FE, TPC, TFC, AOA, WHC, and OHC. Table 5 shows the

Table 4 Correlation matrix between foaming parameters C and t and foam characteristics and physicochemical and functional properties of hot air foam-mat-dried strawberry powder prepared with different concentrations, prepared from 32% solution of soy protein isolate, during different times of whipping

Correl. Coef.	*C*	*t*	FD	FE	VDL	TPC	TFC	AOA	WHC	OHC
C	1	0.00	− 0.501	0.517	− 0.534	0.936	0.862	0.928	0.907	0.819
t	0.00	1	− 0.271	0.223	− 0.209	− 0.187	− 0.364	− 0.130	0.028	0.229
FD	− 0.501	− 0.271	1	− 0.989	0.988	− 0.253	− 0.497	− 0.377	− 0.264	− 0.768
FE	0.517	0.223	− 0.989	1	− 0.983	0.263	0.498	0.374	0.269	0.733
VDL	− 0.534	− 0.209	0.988	− 0.983	1	− 0.308	− 0.560	− 0.432	− 0.292	− 0.777
TPC	0.936	− 0.187	− 0.253	0.263	− 0.308	1	0.859	0.964	0.943	0.690
TFC	0.862	− 0.364	− 0.497	0.498	− 0.560	0.859	1	0.868	0.707	0.741
AOA	0.928	− 0.130	− 0.377	0.374	− 0.432	0.964	0.868	1	0.942	0.806
WHC	0.907	0.028	− 0.264	0.269	− 0.292	0.943	0.707	0.942	1	0.706
OHC	0.819	0.229	− 0.768	0.733	− 0.777	0.690	0.741	0.806	0.706	1

C concentration of soy protein isolate (%), *t* whipping time (min), *FD* foam density (kg m^{-3}), *FE* foam expansion (%), *VDL* volume of drained liquid from foam structure (mL), *TPC* total phenolic content (mg GAE/100 g db), *TFC* total flavonoid content (mg QE/100 g db), *AOA* antioxidant activity (%), *WHC* water holding capacity (%), *OHC* oil holding capacity (%)

Table 5 Regression model, R^2, Adjusted R^2, mean absolute error (MAE), and coefficient of variation (CV) for foam characteristics and physicochemical and functional properties of hot air foam-mat-dried strawberry powder prepared with different concentrations, prepared from 32% solution of soy protein isolate, during different times of whipping

Response variables	Regression equation						R^2	Adj. R^2	MAE	CV
FD	+ 657.289	− 54.2867C	− 26.9096t	+ 4.73068C^2	+ 0.217081Ct	+ 2.25316t^2	96.2	93.5	5.2	8.91
FE	+ 18.7303	+ 8.27224C	+ 3.60073t	− 0.668221C^2	− 0.157754Ct	− 0.244615t^2	96.0	93.1	0.89	12.8
VDL	− 1.52929	− 0.188285C	− 0.0962249t	+ 0.0165332C^2	+ 0.0000265995Ct	+ 0.00900526t^2	98.4	97.2	0.01	16.5
TPC	+ 459.226	− 0.919574C	− 3.85137t	+ 0.852001C^2	+ 0.713241Ct	± 0.229684t^2	97.5	95.8	2.70	5.80
TFC	+ 257.222	+ 6.47202C	− 3.10692t	− 0.509456C^2	+ 0.945158Ct	− 0.493609t^2	99.3	98.7	1.13	6.31
AOA	+ 26.9514	+ 0.701965C	+ 2.20114t	+ 0.0997582C^2	+ 0.0910628Ct	− 0.331939t^2	98.9	98.2	0.39	14.8
WHC	+ 3.85526	− 0.0188867C	+ 0.0569701t	+ 0.0106863C^2	+ 0.000348122Ct	− 0.00616172t^2	95.7	92.6	0.03	5.46
OHC	+ 0.845469	+ 0.0849681C	+ 0.0995901t	− 0.0051623C^2	+ 0.000739482Ct	− 0.00994688t^2	94.5	90.5	0.02	8.95

C concentration of soy protein isolate (%), *t* whipping time (min), *FD* foam density (kg m^{-3}), *FE* foam expansion (%), *VDL* volume of drained liquid from foam structure (mL), *TPC* total phenolic content (mg GAE/100 g db), *TFC* total flavonoid content (mg QE/100 g db), *AOA* antioxidant activity (%), *WHC* water holding capacity (%), *OHC* oil holding capacity (%)

high levels of R^2 and adjusted R^2, and the low values of mean absolute error (MAE), and coefficient of variation (CV) which validated the obtained models representing the correlation between the studied response variables.

Surface response methodology (RSM) was used to define the optimum value of each response and the optimum foaming conditions as well. The predicted optimum concentration of SPI was about 9% for the physicochemical and functional properties of strawberry powder. But, it was 5.6% (close to the experimental concentration) for foam characteristics. The predicted optimum whipping time was about 5.5 min for all responses except AOA and WHC which was shorter than 5 min (close to the experimental whipping time) (Table 6). Hence, the optimum SPI concentration and whipping time were found in the range of 5.5–9% and 4.6–5.7 min respectively. It is worth mentioning that the predicted optimum value of each response under the optimum foaming conditions was close to the experimental value. While, a slight increase in the experimental whipping time is recommended in order to optimize all the studied responses. The obtained results showed a wide range of optimization using adequately developed models with satisfactory levels of R^2, adjusted R^2, MAE, and CV.

Conclusion

Hot air foam-mat-drying was used in this study as an alternative technique to spray and freeze-drying for the production of strawberry powder in order to improve the powder quality

Table 6 Optimization of foaming conditions for hot air foam-mat-dried strawberry powder prepared with different concentrations, prepared from 32% solution of soy protein isolate, during different times of whipping

Response variable	Foaming conditions		Optimum value	Objective
	Concentration of 32% soy protein isolate solution: ranged from 0.5 to 9%	Whipping time: ranged from 1to 8 min		
	Optimum concentration	Optimum time		
FD	5.6	5.7	428.4	Minimize the foam density
FE	5.5	5.6	51.6	Maximize the foam expansion
VDL	5.7	5.3	0.74	Minimize the drained liquid
TPC	9	5.6	527.1	Maximize the total phenolic content
TFC	9	5.5	288.9	Maximize the total flavonoids content
AOA	9	4.6	48.2	Maximize the antioxidant activity
WHC	9	4.9	4.7	Maximize the water holding capacity
OHC	8.6	5.4	1.5	Maximize the oil holding capacity

FD foam density (kg m^{-3}), *FE* foam expansion (%), *VDL* volume of drained liquid from foam structure (mL), *TPC* total phenolic content (mg GAE/100 g db), *TFC* total flavonoid content (mg QE/100 g db), *AOA* antioxidant activity (%), *WHC* water holding capacity (%), *OHC* oil holding capacity (%)

attributes in terms of physicochemical and functional properties. Hot air FMD strawberry powder showed high levels of polyphenols and antioxidant activity compared to conventional HAD powder. Moreover, the functional properties of hot air FMD powder were significantly higher than those of conventional HAD powder. Response surface methodology (RSM) was used to define the effect of foaming parameters on the responses studied and to optimize the foaming conditions. The concentration of soy protein isolate was the predominant parameter affecting the foam characteristics and physicochemical and functional properties of strawberry powder. The predicted optimum value of each response was close to the experimental value. While, a slight increase in whipping time is recommended in order to optimize all responses. Using SPI as a foaming agent in the production of hot air FMD strawberry powder is a promising technique due to its important role in increasing TPC, TFC, and AOA. Therefore, hot air FMD strawberry powder could be used as a functional food in the preparation of different food formulations such as bakery products, beverages, and ice creams.

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Author contributions EF: Carried out the experimental work (foam characteristics, WHC, and OHC). SM: Conceived the research idea, contributed to experimental design, data treatment, wrote the article, and responsible for dissemination (publication). HS: Conceived the research idea, supervised the work and corrected the manuscript. SE: Conceived the research idea, contributed to experimental design, supervised the work. ET: Data treatment and carried out the experimental work (TPC, TFC, AOA).

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Code availability Not applicable.

Declarations

Competing interests The authors declare that they have no competing interests.

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Consent to participate Not applicable.

Consent for publication Not applicable.

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