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Research article

Optimization of spray-drying parameter for production of better quality orange fleshed sweet potato (*Ipomoea batatas* L.) powder: Selected physiochemical, morphological, and structural properties

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ABSTRACT

Orange Fleshed Sweet Potato (OFSP) tuber is a rich source of β-carotene with potential antioxidants and phenolic compounds, nevertheless it is highly perishable root crop. Hence, we considered the optimization of parameters for the preparation of OFSP powder in spray drying technique. This study was designed by the Response Surface Methodology (RSM) with three factors in three levels considered in Central Composite Design (CCD). In case of spray drying process specification, inlet air temperature (IAT) (150 °C–190 °C), flow rate (FR) (10–20 ml/min), and carrier (Maltodextrin) concentration (MDC) (5–15%) were considered and optimized for better quality OFSP powder. As concentration of maltodextrin increased the powder yield, solubility, β-carotene content of OFSP powder increased, while *hygroscopicity* is decreased. The optimized conditions comprised of an inlet temperature of 172.71 °C, feed flow rate of 20 ml/min, and maltodextrin of 1% concentration. Under this optimized conditions, OFSP powder yield of 48.460%, with the solubility of 26.839%, β-carotene of 25.823 mg/100 g and minimum hygroscopicity of 13.862% was attained. The SEM images of spray-dried OFSP powder produced from the optimized conditions showed hexagonal in shapes, irregular in arrangement and compact. The OFSP powder had lower relative crystallinity (34.7%). In conclusion, the optimized OFSP powder with highest β-carotene and desirable physiochemical properties was produced and it can effectively utilize in the food formulation products.

1. Introduction

The OFSP (*Ipomoea batatas* L.) is a dicotyledonous plant and widely appreciated for higher quantities of β-carotene and its potential in the vitamin A deficiency [1]. The OFSP tubers are also a good source of energy, minerals, vitamins, phenolic compounds and antioxidants [2]. Phenolic compounds, β-carotene and other carotenoid isomers are accountable for the variation of flesh and skin shades in sweet potato beside antioxidant in nature [3]. Several researchers investigated and reported the OFPS unique role in

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Table 1
Experimental range of independent variables (inlet air temperature, flowrate and maltodextrin concentration) and response variables used for the optimization of Orange fleshed Sweet potato powder by spray drying.

Code	Factor	+1	0	−1
X1	Inlet air temperature (°C)	190	170	150
X2	Feed Flow rate (ml/min)	20	15	10
X3	Maltodextrin concentration (%)	15	10	5

enhancing the proper health promoting activities by anti-oxidant, anti-carcinogenic and cardio protective activity due to the presence of different phenolic compounds [4].

However, the OFSP tuber are perishable in the nature and these tubers are possible to consume after the boiling, hence incorporation and usage of OFSP in the different food preparations is limited. Application of the OFSP in baked products, extrusion products, infant food products, beverages were reported by different scientist [1]. However, the studies on the OFSP powder production by the drying process was scientifically reported by few researchers. For instance, Bechoff et al. (2009) [5] reported a study on drying of OFSP chips in hot air oven, solar drying and sun drying process and determined the effect of drying methods on retention of carotenoids. Bechoff et al. (2011) [6], reported the drying of OFSP chips by the blanching by different agents like (sodium metabisulfite, ascorbic acid, citric acid and common salt) for the maximum retention of the carotenoids after sun drying, further storage for 6 months. Similarly, Amajor et al. (2014) [7], reported a study on the fermented sundried OFSP flour. According to the available literature sources, only one study is reported on production of OFSP powder by the spray drying technique [8]. However, optimization of the processing parameters of the spray drying on the OFSP flour production was not reported scientifically.

Tontul & Topuz (2017) reported that, the spray drying is one of the effective and inexpensive process with the best retention of the nutritional properties with better quality of end product [9]. However, the optimization of the processing parameters like feed rate, temperature of inlet air and carrier type and its concentrations are considered as the most influencing factors on the end product quality of the spray dried product. Similarly, various fruits and vegetables and other plant products (spices and herbs) are converted to the powder effectively by the spray drying technique [10,11]. At this conditions, the produced powders are showed good physico-chemical properties with the extended shelf life.

The spray drying technique produces higher-quality powders that are easier to package, transport, and have a longer shelf life [12]. This is an appropriate technique since the resulting product meets stringent quality criteria for vitamins, minerals, solubility, hygroscopicity, and bulk density. Furthermore, spray drying powder from liquids is the low-cost process completes in short drying durations with increased yield, and has a greater moisture removal rate with better uniform product quality [13].

Still, micronutrient deficiency and food security is highly persistent in developing countries due to the perishability of root and tubers and lack of drying technology to produce desired products with prolonged shelf-life. Researchers reported that, OFSP has a special role in sub-Saharan Africa and providing the significant health benefits for consumers in order to combat the micronutrient malnutrition [1]. Hence the present research provides the divergent applications from the nutrition to product development point of view. The resultant powder from the OFSP tuber by using spray drying technology with better properties can be useful for the commercial production and make produce available in the market which can fortify in different food products like bakery products such as bread, cookies, cake, and biscuits.

Hence, the major objective of this study is to optimization of parameters such as temperature of inlet air, flow rate of feed and level (maltodextrin) of carrier levels for production of OFSP powder with higher β-carotene concentrations and desirable physico-chemical properties.

2. Materials and methods

2.1. Collections of raw materials

The OFSP tubers (100 kg) were collected from Bako Agricultural Research Center, which is situated 227 km away from Addis Ababa. Necessary chemicals requirements and reagent like sodium meta-bisulfite, Enzyme, Maltodextrin 10 DE (Dextrose Equivalence) were purchased from Mexico sub city Micron PLC Addis Ababa, Ethiopia.

2.2. Experimental design

Response Surface Methodology (RSM) is an illustrious and extensively used statistical experimental design method used to build models, and evaluate the effects of process parameters and optimization of the process. The RSM is appreciated for the minimum experimental runs and easier to implement compared to the other statistical techniques available for optimization [14]. For the experimental design, Design Expert version 8.0 (a commercial statistical package) (Statease, Minneapolis, USA) was used. This experiment was planned by the Central Composite Designs (CCD) of three factors with three levels. The temperature (°C) of inlet air, flow rate (ml/min) of feed and concentration (%) of maltodextrin were the three factors considered with three levels. The levels of the factors were considered according the observations in the preliminary study and the range of the factors were considered as shown in Table 1.

2.3. OFSP tuber preparation for spray drying

The freshly harvested OFSP tubers were hand sorted to remove the plant debris and other solid waste from soil. Further, the sound OFSP tubers were soaked in potable water to remove the adhering soil and drained the washed water. The tubers are allowed to dry in room temperature. The skin of the OFSP tubers were hand peeled manually with the help of the kitchen peeler. The pealed OFSP was countdown to small pieces by the kitchen knife and grained in the kitchen blender and passed through the cheese cloth to obtain the juice. The resultant juice was treated with 0.0007% pectinase enzyme and incubated at 35 °C for 80 min and filtered to remove the suspended material. The maltodextrin levels (5–15%) in OFSP juice were adjusted according to the experimental design and this mixture is considered as the feed mixture for the spray drying process [8].

2.4. The spray drying process of OFSP juice

Spray drying of OFSP juice was accomplished using a small-scale pilot plant spray drier (GEA, Niro, Process Engineering, China) with co-current airflow. A peristaltic pump was used to spray feed mixture to the dryer according to the experimental design. According to an experimental design, temperature (150°C-190 °C) of inlet air, flow rate (10–20 ml/min) of feed, concentration (5–15%) of maltodextrin were adjusted in the process. The produced spray died powder sample was collected from drier chamber (Cyclone and Cylindrical Sections) after each experimental run by softly brushing the chamber walls [8]. The collected powders were packed separately in the polyethylene bags and sealed properly. All the packed OFSP powder samples were refrigerated at 4 °C and immediately used for the characterization of selected properties.

2.5. Analysis OFSP powder properties

The following parameters are collected for the prepared OFSP powder by the spray drying.

2.5.1. Powder yield

Powder yield was determined after effectively dried by spray drier according to equation (1).

$$\text{Power yield } (\%) = \frac{\textit{Obtained Dried powder } (g)}{\textit{OFSP juice weight}(g) + \textit{dried carrier weight } (g)} \text{ X100} \qquad \text{Eq. 1}$$

2.5.2. Water solubility index (WSI)

The WSI of the OFSP spray dried powder sample was carried bestowing to the Santhalakshmy et al. (2015) [15]. The prepared OFSP powder samples (2 g) mixed with 100 mL deionized water and centrifuged (Remi- R 8C 60X50) at 1552 G for 5 min. After, solution was allowed to settle completely. Later, 30 mL of supernatant was collected in the pre-weighed Petri dish and weight was determined. Then the petri dishes were subjected drying at 105 °C for 5 h in a hot air oven. The OFSP powder solubility (%) was calculated as the difference in weight.

2.5.3. Determination of β-carotene

The β-carotene in the OFSP powder sample was determined according to the method reported by the Mezgebo et al., [16]. Around 2 g of the OFSP powder was extracted with the 50 ml extraction solvent (50: 25:25 of hexane, acetone, and ethanol) by maintaining the temperature at 4 °C in refrigerator under subdued light. The absorption of the extract was measured by the using double beam UV–Vis spectrophotometer at 450 nm wavelength. The calibration curve was prepared with the standard concentrations of the analytical grade β-carotene. The β-carotene concentration in the sample was determined according to the calibration curve.

2.5.4. Determination of the hygroscopicity (%)

With small adjustments, hygroscopicity was determined by following procedures mentioned by Santhalakshmy et al. [15]. Around 2 g of the prepared OFSP powder sample was kept at 25 °C in desiccator filled with saturated (75.29% RH) NaCl solution. The sample weight was taken after one week, the gain in weight was considered as the hygroscopicity and expressed for 100 g by following equation (2).

$$\text{Hygroscopicity } (\%) = \frac{\textit{Gain in weight of the sample}}{\textit{Initial weight of the sample}} \text{ X100} \qquad \text{Eq. 2}$$

2.6. Data analysis and optimization of the spray-drying parameters

The experiment was carried in triplicate; the mean values are used for the analysis. The statistical software Design Expert 8.7.1, Stat-ease Inc., Minneapolis, USA was used to correlate the relationship between the variable and the response. The CCD was fitted with a second-order polynomial model, quadratic model, includes the linear models equation (3).

$$\mathrm{Y_k} = \beta_{0+}\ \beta_1\ \mathrm{X_1} + \beta_2\ \mathrm{X_2} + \beta_3\ \mathrm{X_3} + \beta_{11}\ \mathrm{X_1}^2 + \beta_{22}\ \mathrm{X_2}^2 + \beta_{33}\ \mathrm{X_3}^2 + \varepsilon \qquad \text{Eq. 3}$$

Where: $\mathrm{Y_k}$ = response variable yield of powder (%); solubility (%); β-carotene (mg/100 g) and hygroscopicity (%) independent coded

Table 2
Analysis of Variance (P-values) for Powder yield, Water Solubility Index, β-carotene and hygroscopicity of orange fleshed sweet potato powder.

Source	PY	SOL	BC	HG
Model	<0.0001	<0.0001	<0.0001	<0.0001
A (Inlet air temperature (^{0}C))	<0.0001	<0.0001	<0.0001	<0.0001
B (Feed flow rate (ml/min))	0.0137	0.0732	0.0003	0.0006
C (Maltodextrin (%))	0.0005	<0.0001	0.4992	<0.0001
AB	0.0020	0.1845	0.7185	0.0182
AC	0.0298	0.1234	0.2783	<0.0001
BC	0.0028	0.0893	0.4372	0.1129
A^2	<0.0001	0.0003	0.0001	0.1317
B^2	0.1340	0.5675	0.0173	0.0023
C^2	0.0018	<0.0001	0.1025	0.0091
Lack of fit	0.0807	0.0771	0.2706	0.9078

PY: Powder yield (%); SOL: Water solubility Index (%); BC: β-carotene (mg/100 g) and HG: Hygroscopicity (%). The values are given the P-values of ANOVA, values < 0.05 consider as statistically significant.

Table 3
The R^2, Adjusted R^2, and Predicted R^2 values of Orange fleshed sweet potato powder yield, solubility, pro-vitamin A, and hygroscopicity.

Property of the OFSP	R^2 value	Adjusted R^2	Adjusted R^2
PY	0.9763	0.9549	0.8462
SOL	0.9927	0.9862	0.9522
BC	0.9898	0.9805	0.9485
HG	0.9695	0.9421	0.8404

OFSP= Orange Fleshed Sweet Potato; PY: Powder yield; SOL: Water solubility Index; BC: β-carotene and HG: Hygroscopicity; R^2: Coefficient of determination.

variables include X_1 inlet air temperature (°C); X_2 = feed flow rate (ml/min); X_3 = maltodextrin concertation (%). The test of statistical significance was performed on the total error.

The models' adequacy was assessed using the Analysis of Variance, along with the coefficient of R^2 and adjusted R^2 for the models. The F-values and R^2 values of the response was calculated as a function of variables. The 3-D surface plots was generated as the function of the variables on each response by keeping two factors constant and varying the other factor [17].

Finally, the numerical optimization was performed to determine the best values of the inlet air temperature, feed flow rate and maltodextrin concentrations are required for the OFSP powder with the better physiochemical properties. In this case the properties like powder yield, water solubility index and β-carotene considered maximum and hygroscopicity was considered minimum in the optimization.

2.7. *Characterization of the OFSP from the optimized preparations*

After the numerical optimization, the OFSP powder was prepared with the optimized parameters. The resulting powder was used for the determination of following quality parameters along with the powder yield (%), water solubility index (%), β-carotene (mg/100 g) and hygroscopicity (%)

2.8. *Determination of crystal structure by scanning electron microscopy*

The micrographs of the OFSP powder was determined by Scanning electronic microscope (Stereo scan 250 Mk3, Japan) by ensuing the method outlined in the Chinnasamy et al. [18]. The OFSP powder was attached to the duel side adhesive tape taken on an aluminum stub, and OFSP powder shielded with gold. The OFSP powder were examined at magnifications of 500X.

2.9. *Determination of crystallinity of X-ray diffraction analysis*

The X-ray diffraction spectra of prepared OFSP powder sample was evaluated using an X-ray diffractometer (XRD-7000, SHIMADZU Corporation, Japan) by technique illustrated by Huang et al., [19]. The necessary parameters such as X-ray, 40 kV, Cu–K radiation, 30 mA, and angle (2θ) of scanning was considered from 5° to 80° with speed of scanning 4.0 °C/min were considered. For calculating the overall area under the curve and the area under each notable peak, the Origin Pro 2018 software program was utilized. The following formula was used to compute the crystallinity% as shown in equation (4):

$$\text{Crystallinity } (\%) = \frac{(\text{area under peaks})}{\text{Total area}} \quad \text{Eq. 4}$$

Table 4
The physiochemical properties of the Orange fleshed sweet potato powder as the composition at various inlet air temperature, feed flow rate and maltodextrin concentration.

Run	The studied parameters			Studied properties of OFSP powder			
	Inlet air temperature (°C)	Feed flow rate (ml/min)	Maltodextrin (%)	Powder yield (%)	Water Solubility Index (%)	β- carotene (mg/100g)	Hygroscopicity (%)
1	190	10	5	40.64	27.16	18.98	16.4
2	150	10	5	40.85	16.61	27.31	12.15
3	190	15	10	45.23	30.15	19.35	15.96
4	150	20	15	41.08	20.21	28.68	14.35
5	170	15	10	48.45	27.02	25.14	15.52
6	150	15	10	41.69	21.06	27.51	14.65
7	170	15	10	48.46	26.48	25.65	15.22
8	190	20	5	42.64	25.14	20.35	16.68
9	150	20	5	37.21	15.36	28.21	13.24
10	170	15	5	44.14	22.31	24.94	15.9
11	170	15	15	46.25	27.02	24.09	14
12	190	10	15	43.01	29.51	19.65	12.31
13	170	15	10	47.25	27.28	25.42	15.62
14	170	15	10	48.1	27.14	24.81	15.61
15	170	10	10	45.36	26.64	24.88	14.15
16	170	15	10	47.89	27.3	25.69	16.6
17	170	20	10	47.35	27.4	26.5	15.38
18	150	10	15	39.28	19.91	27.05	11.67
19	170	15	10	48.46	27.27	25.02	15.72
20	190	20	15	47.94	28.58	21.25	12.83

OFSP: Orange fleshed sweet potato.

3. Results and discussions

After the analysis variance, P-values of the parameters are presented in Table 2.

3.1. Model suitability and interactive effects of process variables with properties of OFSP powders

Coded design having 8 factorial points, 6 axial points, and 5 center points. Polynomial equations with quadratic terms for response variables were generated using Design-Expert Software. The powder yield, solubility, β-carotene, and hygroscopicity model P-values in Table 2 suggested that the model was significant. The relevance of model terms is considered significant when P-value of less than 0.0001. All replies had a non-significant lack of fit, implying that the polynomial model satisfactorily suited all design points. The generated models were considered statistically significant if the R^2, Adjusted R^2, and Predicted R^2 (Table 3) values were more than 0.80 [20].

The fit summary findings showed that the quadratic model was the most intriguing of all the models of comparison. In quadratic model F-value of 47.6981, $P < 0.0001$ was showed for powder yield; F-value of 27.1277, $P < 0.0001$ for water solubility index; F-value of 25.1608, and $P < 0.0001$ for β-carotene, and F-value of 15.6985, $P < 0.0001$ for hygroscopicity and the polynomial equation of second order for powder yield, solubility, pro-vitamin A, and hygroscopicity generated from code values of independent variables as shown in Table 3.

3.2. OFSP powder yield

Powder yield is an essential parameter to determine the effectiveness of the spray drying process. Powder yield was significant in the quadratic model and a non-significant in lack of fit was found in analysis of variance (Table 2). The OFSP powder yield in this study was ranged from 37.21% to 48.48%. A maximum powder yield of 48.46% was observed in the experimental run with the 170 °C IAT, 15 ml/min FFR, and 10% MDC, respectively. In contrast, minimum powder yield of 37.21% was observed from the process operated at 150 °C IAT, 20 ml/min FFR, and 5% MDC, as shown in Table 4.

Equation (5) showed a positive correlation between IAT and the yield of OFSP powder. Fig. 1(a and b) demonstrated that increasing the IAT resulted in a higher yield of OFSP powder. As indicated by Cai and Corke [21], greater drying IAT led to quicker drying (higher drying rate) and better powder production reported, which can also be related to the stronger heat and mass transfer in the drying processes.

The identical trend on the powder yield was reported by researchers in wide fruits and vegetable juice powders produced by spray drying technique. For instance, Daza et al. [22] reported the increase in the Cagaita (*Eugenia dysenterica* DC.) fruit powder as the air inlet temperature ranged from 120 to 160 °C. Similarly, Santhalakshmy et al. reported the spray dried powder yield as the temperature raised from 140 to 160 °C in jamun fruit powder production [15]. Comparable outcomes also reported by the Fazaeli et al. (2012) in case of mulberry juice as the inlet air temperature increased to 150 from 110 °C [23]. However, few scientific reports reported the decrease in the yield of spray dried powders reported. For example, Chegini and Ghobadian [24] reported the decrease of the orange

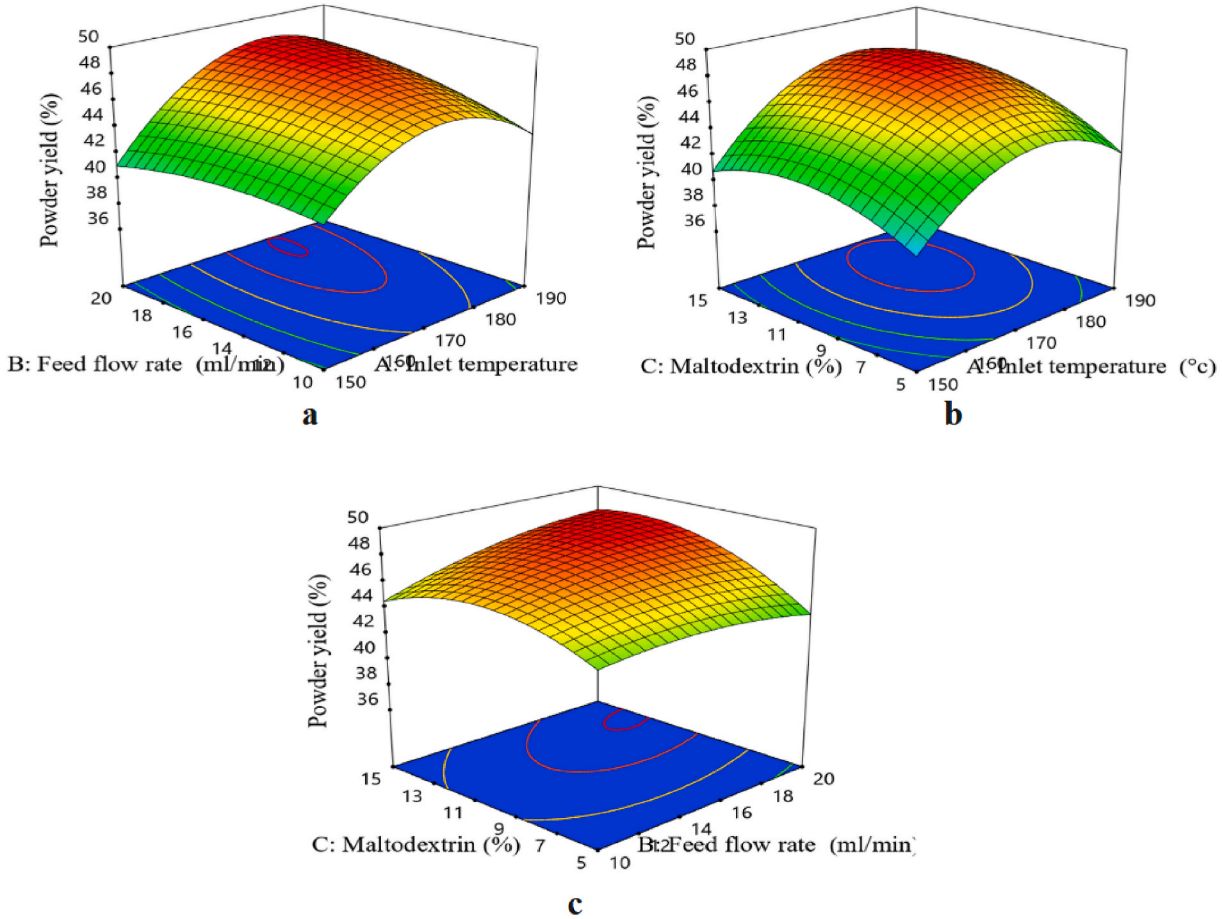

Fig. 1. Three-dimensional surface plots showed the interaction effects of inlet air temperature (^{o}C), feed flow rate (ml/min), and maltodextrin (%) on Orange fleshed sweet potato powder yield (%) in spray drying. Where a). Effect of feed flow rate and inlet air temperature in powder yield (%); b). Effect of maltodextrin (%) concentration and inlet air temperature (^{o}C) in powder yield (%); c). Maltodextrin (%) and inlet air temperature (^{o}C) in powder yield (%). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

juice powder yield as the inlet air temperature varied from 130 to 150 °C. Goula & Adamopoulos, (2010) also reported the decrease in the process of orange juice spray drying at 110 to 140 °C [25]. This variation in the yield may be due to the influence of other parameters considered in the spray drying operations process like carrier material and their concentration, outlet temperatures and the instrumental variation. The same was mentioned by the Shishir and Chen, (2017) in the review article on spray drying of fruits and vegetable juices [26].

The higher powder yield was observed with the greater concentration of maltodextrin was used (Fig. 1b and c). The addition of maltodextrin increase the TSS in the arrangement of drying carrier as well as the reduction in stickiness via encapsulation [26]. Usually, in the spray drying process maltodextrin enhanced the solid content, while limited amount of water evaporated. This was consistent with recent studies [31], which revealed that increasing maltodextrin content enhanced the yield of spray drying powders. Carrier compounds promote drying and result in a less sticky product by changing the surface stickiness of low molecular weight sugars and organic acids [29]. Similarly, the orange juice powder yield increased as the raise in the MDC [25]. The same trend was observed in the spray drying studies reported on pink guava juice [27], sage (*Salvia fruticosa* Miller), ginger rhizomes [28].

However, difference in feed flow rate had a detrimental impact on powder yield, which might be attributed to lower transfer rates of heat and mass (Fig. 1 a and c). The moisture content of spray-dried powder increases with higher feed flow rates. Additionally, faster feed flow rates don't provide enough time for feed droplets and hot air to mix, which results in less efficient heat and mass transfer and increased moisture content in the finished product [30]. Similar results were published by Bazaria and Kumar [12], beetroot juice powder yields are reduced as the feed flow rate increased (feed flowrate of 400–600 ml/h). Similarly, orange juice [24] yield decreased as feed flow rate (15–30 ml/min) increased. The regression model equation for the powder yield is presented in equation (5).

The regression model F-value of 45.72 indicates that the model is significant.

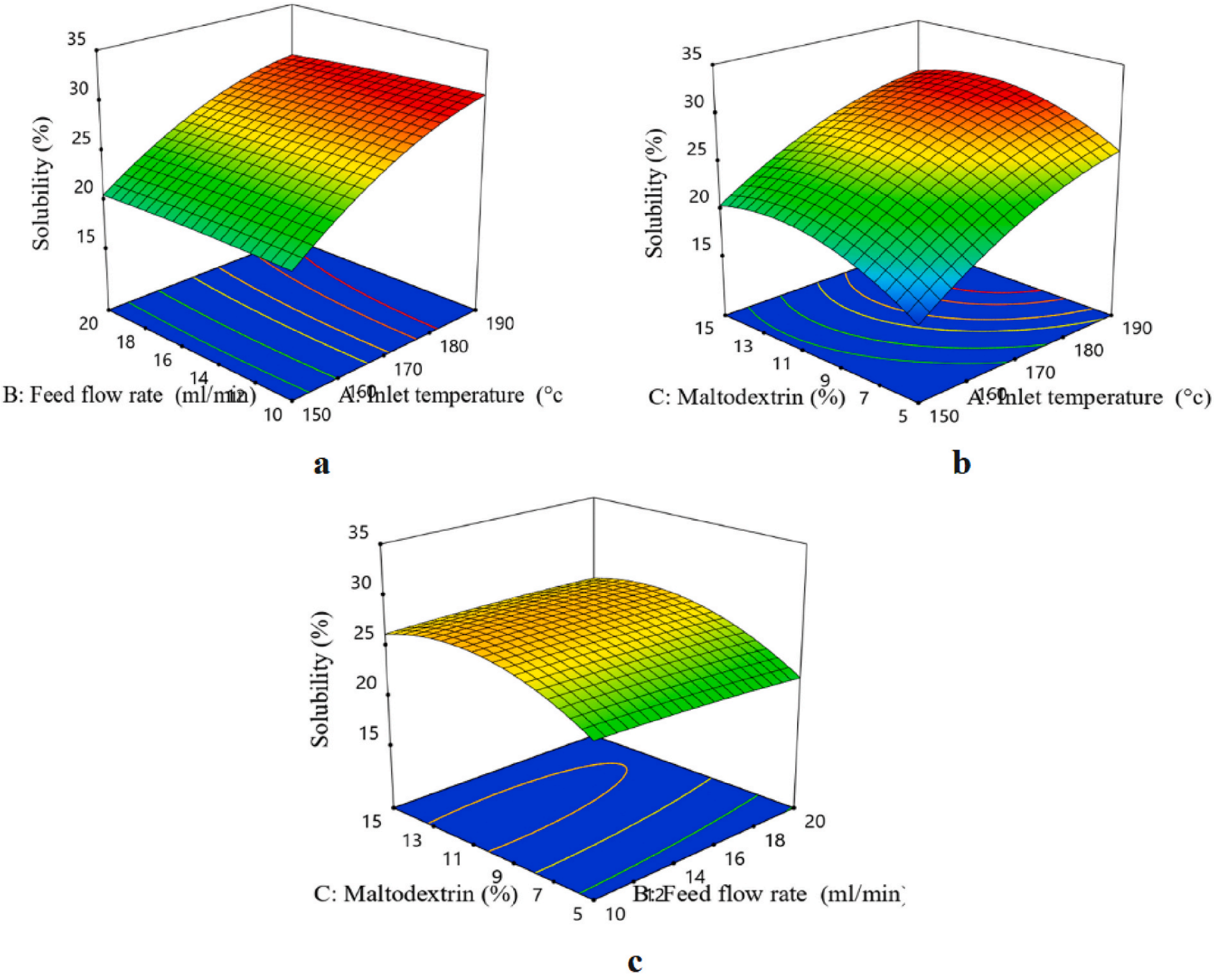

Fig. 2. Three-dimensional surface plots revealing the effects of temperature (°C) of inlet air, flow rate (ml/min) of feed, and concentration (%) of maltodextrin on water solubility index (%). Where a). Effect of feed flow rate and temperature (°C) of inlet air on water solubility index (%), b). Effect of concentration (%) of maltodextrin and temperature (°C) of inlet air on water solubility index (%), c). Concentration (%) of maltodextrin and temperature (°C) of inlet air on water solubility index (%).

$$\text{Powder yield }(\%) = 47.6981 + 1.935A + 0.708B + 1.208C + 1.09625AB + 0.67125AC + 1.04625BC + -3.63273A^2 + -0.737727B^2 + -1.89773C^2 \tag{Eq. 5}$$

where, A = temperature of inlet air; B = Flow rate of feed, and C = Level of maltodextrin. The linear effects temperature of inlet air, feed flow rate and concentration of maltodextrin were significant ($p \leq 0.05$) on the yield (Table 2).

3.3. Water solubility index of the OFSP powder

The measurement of a powder's solubility in water serves as a benchmark for how well a powder dissolves in water. Another crucial attribute of powders is solubility, which has a direct impact on the capacity of spray-dried powder products reconstitution [26]. The WSI of OFSP powder ranged from 15.36% to 30.15%. The OFSP powder prepared with inlet air temperature of 190 °C, feed flowrate of 15 ml/min and 10% of the maltodextrins showed the highest water solubility index of 30.15%. In contrast, the lower (15.36%) water solubility index was showed powder prepared from the combination of 150 °C, 20 ml/min and 5% (Table 4).

The following (Equation (6)) showed the second-order polynomial equation generated from independent variables for WSI:

$$\text{Water Solubility Index }(\%) = 27.1277 + 4.739A + -0.314B + 1.865C + -0.25AB + -0.295AC + 0.33BC + -1.59182A^2 + -0.176818B^2 + -2.53182C^2 \tag{Eq. 6}$$

where, A = Temperature of inlet air, B = Flow rate of feed, and C = Concentration of maltodextrin.

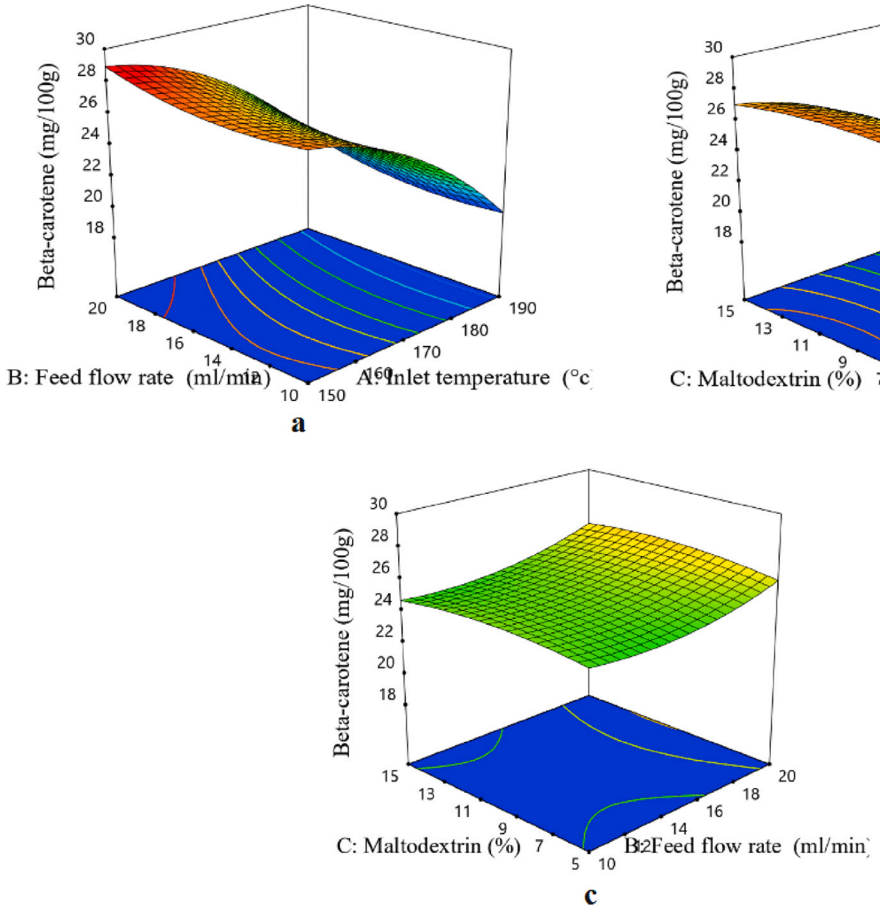

Fig. 3. The optimized surface plots revealing the effects of temperature (°C) of inlet air, flow rate (ml/min) of feed, and Concentration (%) Maltodextrin on *β*-carotene (mg/100 gm). Where a). Effect of feed flow rate and inlet air temperature on *β*-carotene content; b). Effect of Maltodextrin (%) and Inlet air temperature (°C) on *β*-carotene content; c). Maltodextrin (%) and Inlet air temperature (°C) on *β*-carotene.

The F-value (151.67) suggests the model is substantial. Less than 0.05 of P-vale indicate that model terms are significant.

equation (6) showed a positive correlation between IAT and MDC and the WSI of OFSP powder, while negative correlation observed between FFR on the WSI of OFSP powder.

The process parameters considered in present study, IAT, MDC and their interaction exhibited significant ($P < 0.05$) effect on the WSI of the OFSP powder. However, flow rate did not have any impact on OFSP powders water solubility index ($P > 0.05$).

Higher WSI observed for the OFSP powder prepared at high air inlet temperatures (Fig. 2 a and b). This trend might be attributed to the result of higher processing temperature and lower residual moisture in the produced powder. As the finished powder moisture content decreased, less time is required for powder dissolution, indicating improved water solubility of the powders. The WSI of cagaita powders augmented with rise in temperature considered from 120 to 160 °C [22] in spray drying process. Similarly, same trend is reported in the powders (spray drying) of Jamun fruit juice (140–150 °C) [15], Black mulberry juice (110–150 °C) [23], Tomato pulp (110–140 °C) [32] and in Sage (*Salvia fruticosa* Miller) (140–180 °C) [33] were reported.

Similarly, increase in maltodextrin concentration raised the water solubility index of OFSP powder (Fig. 2 b and c). This trend is attributed to the higher quantities of low molecular weight molecules present in maltodextrin [34]. This rise in solubility might also be attributed to MDC, it is soluble and has an encapsulating efficiency [29]. A similar rising trend in the WSI was found in the mango powder (spray drying) with increased MDC and spray dryer IAT [20,35]. However, water solubility is a complex phenomenon broadly effected by different constraints like raw materials' characteristics, type of carrier materials used in the spray drying process, and properties of the powders (moisture content, size of the particle and physical state of the particle) [10,35]. In addition, the starch centered carrier ingredients like maltodextrins are described for good solubility of the spray dried powders.

3.4. *β-carotene content in OFSP powder*

The β-carotene amounts of OFSP powder diverse from 18.98 to 28.68 mg/100 g. A maximum β-carotene of 28.68 mg/100 g was determined in the OFSP powder sample prepared from the combination of 150 °C of IAT, 20 ml/min of FFR, and 15% MDC in spray

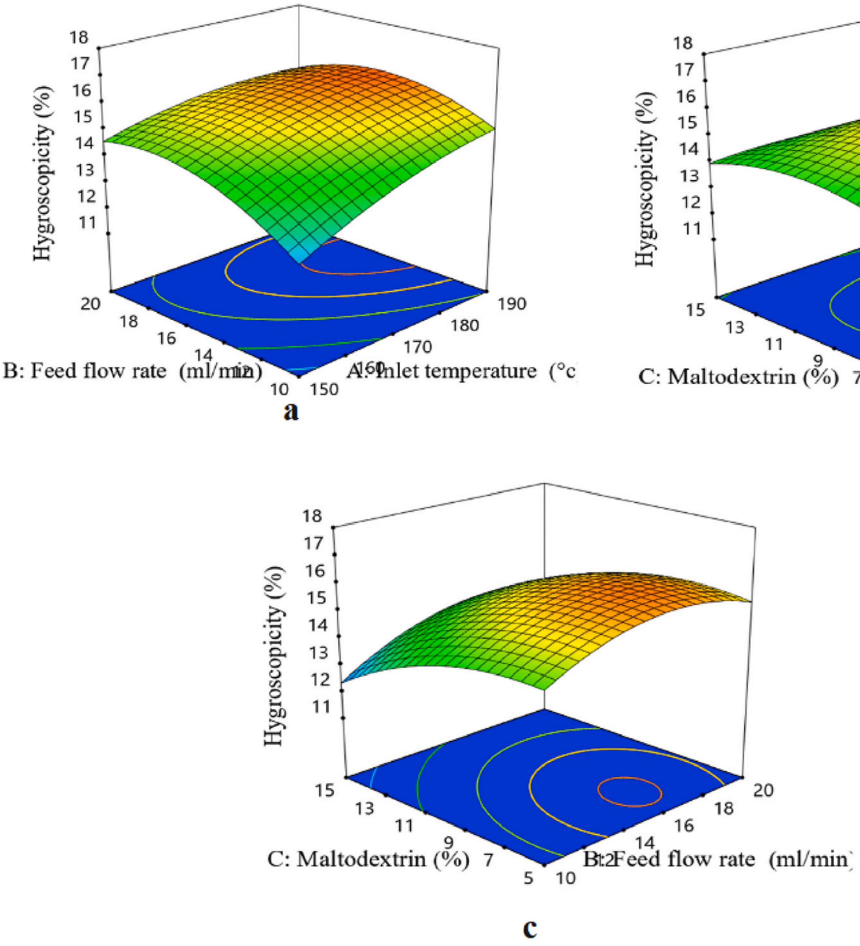

Fig. 4. Three-dimensional surface plots revealing the effects of temperature (° C) of inlet air, flow rate (ml/min) of feed, and concentration (%) of maltodextrin on hygroscopicity (%). Where a). Effect of flow rate of feed and temperature of inlet air on hygroscopicity (%); b). Effect of concentration (%) Maltodextrin and temperature (°C) inlet air on hygroscopicity (%); c). Concentration (%) of Maltodextrin and temperature (°C) of inlet air on hygroscopicity (%).

drying. Whereas, the lower β-carotene (18.98 mg/100 g) content was observed in process occurred at the 190 °C, 10 ml/min, and 5% IAT, FFR, and MDC, respectively as presented in Table 4.

The polynomial equation of second order showed that, β-carotene increased significantly by reducing the inlet air temperature in the OFSP preparation (Equation (7)). Inlet air temperature, feed flow rate were found to have maximum influence on β-carotene content of OFSP powder (Table 4). However, maltodextrin concentration was not showed any significantly affected on β-carotene concentrations in OFSP powders.

$$\beta - \text{carotene content (mg / 100g)} = +25.1608 - 3.918\text{A} + 0.712\text{B} + 0.093\text{C} + 0.055\text{AB} + 0.17\text{AC} + 0.12\text{BC} \\ -1.53955\text{A}^2 + 0.720455\text{B}^2 - 0.454545\text{C}^2 \qquad \text{(Eq 7)}$$

where, A = Temperature of inlet air, B= Flow rate of feed, and C= Concentration of maltodextrin.

The $P < 0.05$ suggest that model terms are significant. The process factors, inlet air temperature and their interaction had a significant influence on solubility ($P < 0.05$). However maltodextrin content and feed flow rate had no effect on OFSP powders β-carotene content ($P > 0.05$). Fig. 3a and b depicted β-carotene amounts in OFSP powder showed lower amounts as increase in IAT used in spray drying operations. As per the literature availability, there is no reported data on the effect of spray drying parameters on the β-carotene in OFSP powder. However, similar results are observed in different fruits powders prepared by spray drying process. For instance, Quek et al. [36] stated the decline in β-carotene content in watermelon powder produced by spray drying as the IAT increased from 145 to 175 °C. Similarly, Solval et al. [37] reported the decrease of β-carotene in Cantaloupe (*Cucumis melo*) powder produced in spray drying technique. This decrease in β-carotene content attributed to the heat sensitivity. It is clearly observed that, as the higher temperature in the spray drying, pigments in the fruit juices are decreased. It is also cleared that, other thermolabile components are subjective by spray drying temperature due to thermal and oxidative degradation. In line with this, Knockaert et al. [38] reported β-carotene is sensitive for higher temperatures and oxidation conditions.

As seen from the p-value, the feed flow rate is significantly affected the β-carotene (mg/100 gm) content of the OFSP flour prepared in this study. The moisture content of spray-dried powder rises as the feed flow rates (Fig. 3 a and c). Additionally, due to insufficient contact time between feed droplets and hot air due to the greater feed flow rate, heat and mass transfer is less efficient, which results in a higher moisture content in the final product. In this condition the heat sensitive bioactive compounds like β-carotene retrains in higher quantities. The similar results were reported by the Movahhed and Mohebbi [39] on carrot–celery juice by accumulative FFR, higher β-carotene is preserved and concluded that by raise in the FFR in the process produced powder particle size and lesser ration of surface to volume for bigger particles primes to higher β-carotene retaining in the spray dried powders. Similar inference is also given by Mestry et al. [40] on higher carotenoids retention in carrot and water melon during spray drying process.

The concentration of maltodextrin on β-carotene retention in the spray dried powder is not significantly effected in this study. However, previous research findings are reported the addition of maltodextrin is effective in preserving carotenoids [41,42]. The higher amount of the β-carotene in different spray dried fruits and vegetables like carrot [41]; blackcurrant, apricot and raspberry juices [43]; guava juice [44] and pineapple juice [45] were reported.

Movahhed and Mohebbi [39] reported the significant reduction in the carotenes amounts as the MDC raised from 10% to 30%. This is attributed to the greater MDC yields to lower proportions of the carotene in the feed juice. In contrast, researchers also reported the raise in encapsulation occurred in higher maltodextrin concentrations. Encapsulation facilitates the protection of the carotenoid content in spray dried powders [41and 42].

3.5. Hygroscopicity of OFSP powder

The capacity of a food powder to absorb moisture from the environment is known as hygroscopicity [46]. A food powder with low hygroscopicity is preferred since high hygroscopicity has a greater propensity to absorb water and become sticky [47]. Lower hygroscopicity is very important in storage or displacing powder since this feature affects the flowability. The hygroscopicity of prepared OFSP powder samples are varied from 11.67% to 16.68%. Maximum hygroscopicity of 16.68% was observed for the OFSP powder prepared from 190 °C of IAT, 20 ml/min FFR, and 5% MDC, respectively. In contrast, lower hygroscopicity of 11.67% was observed in the powder prepared from 150 °C, 10 ml/min, and 15% at IAT, FFR, and MDC, respectively, as shown in Table 4. According to Nurhadi et al. [48] powder was considered as not extremely hygroscopic, if its hygroscopicity was less than 20%. Produced powders with low hygroscopicity is preferred since higher hygroscopicity increases a substance's propensity to absorb water and become sticky [47]. Hence, the OFSP powder produced in this study from all the runs are reported <20% of hygroscopicity.

The second order polynomial equation (Equation (8)) of hygroscopicity revealed that raising in the maltodextrin content in the OFSP considerably reduced hygroscopicity (Fig. 4 b and c). The content of maltodextrin had the greatest impact on hygroscopicity, whereas FFR and IAT had a positively influence on OFSP powder (Fig. 4 a and c).

$$\text{Hygroscopicity}\ (\%) = +15.6985 + 0.812\mathrm{A} + 0.58\mathrm{B} - 0.921\mathrm{C} - 0.37125\mathrm{AB} - 1.07125\mathrm{AC} + 0.22875\mathrm{BC} - 0.368636\mathrm{A}^2 - 0.908636\mathrm{B}^2 - 0.723636\mathrm{C}^2 \quad \text{(Eq. 8)}$$

where, A = Temperature of inlet air, B = Flow rate of feed, and C =Concentration of maltodextrin.

The F-value (35.36) shows the significant. The $P < 0.0500$ showed significant. Fig. 4 depicted the effect of IAT, FFR, and MDC on spray dried powder hygroscopicity. All the studied factors are reported the significant impact on the hygroscopicity of the prepared OFSP powder.

Reduction in IAT resulted in lower hygroscopicity, which might be explained by the increased moisture retention with lower IAT. Another possible reason may be the development of higher porous particles at the greater temperature [49]. Previous research by Bazaria and Kumar [12] found that increasing the inlet air temperature improved the hygroscopicity of beetroot juice powder. However, contentious assumptions on the effect of IAT on the hygroscopicity of spray dried powders. Similar to the present study findings, few researchers [13,50,51] confirmed that hygroscopicity increased with an increase in the IAT, while some others reported the contrast trend [25,52,53]. In addition, previous studies were reported the hygroscopicity of the powder usually connected to its configuration [54], category and amount of the carriers and the size of the particles in powder [55].

The FFR significantly influenced the hygroscopicity of the spray dried flours. As the flowrate increased, the hygroscopicity of the flours were decreased. The same trend was reported by the many previous studies [50,56,57]. This can be attributed to the lower residential time available for the evaporation of moisture in feed. Hence, the higher moisture retention in the flours shows the lower hygroscopicity. In addition, higher FFR produces the spray dried powder with the less porous particles. This lower porous nature cannot support the absorption of the moisture and reduces the hygroscopicity of the spray dried powders.

The quantity of maltodextrin had a substantial impact on the hygroscopicity, which decreased as the concentration increased. There is a controversial result on the influence of carrier materials levels and type on the hygroscopicity of the produced powder. Chong and Wong [58] reported that increasing MDC in the juice produced the lower hygroscopic product in case of sapodilla juice. Relatively comparable findings also stated by different authors for different fruits and vegetables (Acai, jujube, sapodilla, cherry, black berry, amla, and cactus pear) by different researchers [42,47,50,51,54,58,59].

The more hygroscopic product is produced at a higher IAT, when MDC is added in greater amounts to produce a lower-hygroscopic product [49]. This inclination was ascribed to formation of shapeless and greatly hygroscopic powders owing to the profligate elimination of moisture in drying [52].

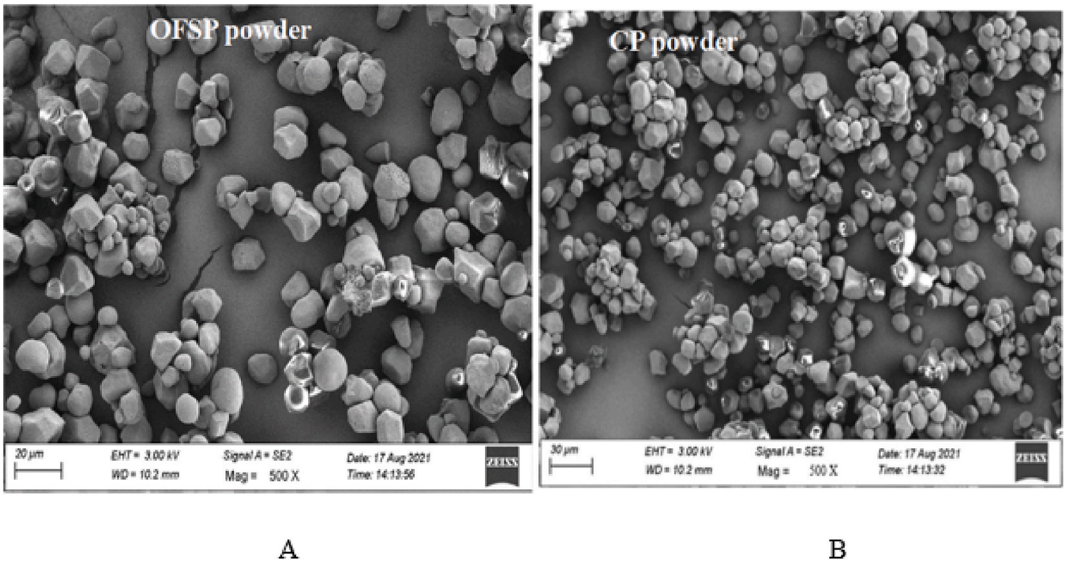

Fig. 5. SEM images of Spray dried Orange Fleshed Sweet Potato (OFSP) powder (A) and commercial potato (CP) powder (B) at 500 X resolution.

3.6. Optimization and validation of the process parameters

In the present study, obtained second order polynomial models were used for each response parameters and also find the optimum conditions. The desirability function method was used for simultaneous optimization of the various dependent variables. The optimization target was to maximize powder yield, solubility, and β-carotene while hygroscopicity consider as the minimize. The numerical optimization provided that, 172.71 °C of IAT, 20 ml/min of FFR and MDC of 15% as the optimum conditions. Also, numerical optimization given that, OFSP powder developed with optimum compositions would yield the 48.46% of powder with 26.83% of solubility, 25.82 mg/100 g of β-carotene, and 13.86% of hygroscopicity with overall desirability of 74.5%.

The system generated optimum condition was used to validated experimentally in order to confirm the adequacy of the model. The optimized value from the developed empirical model equations were used to carried out experiments in triplicate and OFSP powder was produced and analyzed. Experimental results with the predicted values of the responses were compared. The OFSP powder from the optimized processing parameters showed (measured) 48.409% for powder yield, 26.389% for solubility, 25.671 mg/100 g for β-carotene, and 13.745% for hygroscopicity. The variation of 0.051%, 0.45%; 0.152%; 0.11% was observed in the powder yield, solubility, β-carotene and hygroscopicity, respectively in the experimental validation then the numerical optimized. These physiochemical properties observed were found to be in agreement with the predicted values and clearly indicated the suitability of the developed quadratic models. It should be emphasized that these optimal values are valid within the stated range of process parameters given the results of the validation trials, which demonstrate the applicability of the generated quadratic models.

Different researchers are optimized the spray drying parameters for the fruit and vegetables juices to produce the best quality powders. The review by the Shishir & Chen [26] summarized the different studies on the optimization of spray dried fruits and vegetable powders preparation and many authors are suggested the common temperature of range 120 °C-180 °C, maltodextrin concentration is 7%–20%. However, the optimum feed flow rate is depending on many factors like temperature used, type of carrier materials, concentrations of the carrier materials, physical, compositional properties of the feed and the desired end properties required for the produced powder.

3.7. Characterization of optimized OFSP powder

3.7.1. Granule morphology by SEM

Granule morphology is an appropriate parameter used to illustrate and recognize the size and shapes of powder granules [18]. The spray dried OFSP and commercial potato powder were analyzed by scanning electron microscopy to study the microstructure and surface morphology. It is revealed that various shapes and sizes of OFSP powder molecules (Fig. 5A). The SEM images of spray-dried OFSP powder showed hexagonal in shapes, irregular arrangements, compact and fewer agglomerates. While, commercial potato powder had polygonal in shapes and some cracked or fractured and round edges of few granules (Fig. 5B). The microstructure of powder significantly affected by range of the parameters used in the spray drying method like carrier agent type, carrier concentration (maltodextrin concentration) and inlet air temperature [40]. In addition, the drying types had significantly influenced the SEM micrographs of blood fruit juice powder [60]. The present outcomes authorize earlier reports experimental in spray dried custard apple powder [29].

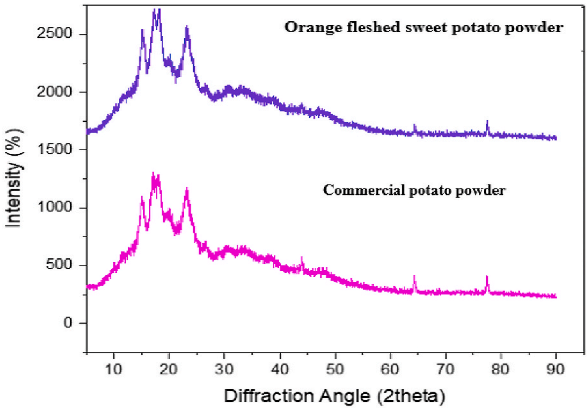

Fig. 6. XRD analysis of spray dried of orange fleshed sweet potato and commercial potato powder. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Diffractograms parameters of OFSP and CP powder.

Sample	Diffraction peaks at 2 θ (°)					Crystallinity (%)
OFSP powder	15.71 (+)	17.06 (+)	18.10 (+)	20.00 (+)	23.11 (+)	34.7 ± 0.0377^a
CP powder	15.16 (+)	17.06 (+)	18.10 (+)	20.00 (+)	23.30 (+)	40± 0.281^b

Different letters in the same column indicate significant differences ($P < 0.05$)

± indicates the standard deviations of data represent mean values of three samples, OFSP = Oranges fleshed sweet potato; CP= Commercial potato.

3.7.2. X-ray diffraction analysis

A typical method for determining whether dried products in powder form are crystalline or amorphous is X-ray diffraction. Crystalline matter often exhibits a series of high peaks, whereas amorphous material exhibits a broad background pattern. The X-ray diffraction spectra of OFSP and commercial potato powder are presented in Fig. 6. The diffractograms comprising diffraction peaks, crystal pattern, and relative crystallinity as shown in Table 5 and Fig. 6. The OFSP powder exhibited strong diffraction peaks at (2θ) of 15.71°, 17.06°, 18.10°, 20.00°, 23.11°, and 15.16°, 17.06°, 18.10°, 20.00°, 23.30°. Both OFSP and CP powder have the comparable diffraction peaks. The OFSP powder had lower relative crystallinity (34.7%), while commercial potato powder had higher relative crystallinity (40%). Anastasiades et al. [61] described the gelatinization procedure sources permanent variations in the physical edifice of starch, which occurred in OFSP powder preparation and resulting in degradation of molecular structure and loss of crystallinity. The crystallinity of the flour directly affects the properties like, followability, bulk density. The diffractogram of spray-dried OFSP powder attained in this study was similar to the one reported by Caparino et al. [35]. Fruit powder from the spray drying is considered as amorphous or lower relative crystallinity in nature, and this state is metastable and experience to phase and state transitions during storage. The common issue persistent with the lower relative crystallinity of fruit powder is the stickiness and caking potential. These changes directly affect other powder properties, including the flowability, compressibility, and compatibility [62].

4. Conclusion

In this study Response surface methodology was used to investigate the physiochemical characteristics of OFSP powder at varying levels of inlet air temperature, feed flow rate, and maltodextrin content. Spray drying factors had a considerable impact on the physiochemical, morphological, and structural aspects of OFSP powder. According to this study as the maltodextrin attentiveness augmented the powder yield, solubility, of OFSP powder increase, but hygroscopicity decreases. The powder yield, solubility, β-carotene, and hygroscopicity content values of the OFSP powder models were statistically significant. The current study found that incorporating 15% maltodextrin concentration in OFSP juice during spray drying at an inlet air temperature of 172.71 °C and a feed flow rate of 20 ml/min results in a maximum powder yield of 48.460%, solubility of 26.839%, and β-carotene of 25.823 mg/100 g with a minimum hygroscopicity of 13.862%. The SEM analysis demonstrated that the optimized OFSP powder had a consistent microstructure with the commercial potato powder. The improved OFSP powder displayed stronger diffraction peaks and lower relative crystallinity than the commercial potato powder. The Maltodextrin usage as the carrier molecule helps as the low cost ingredient however, questionable in health aspects. Maltodextrin metabolized to glucose in the human digestive tract, resulting in an increased glycemic load and therefore post-meal glycaemia associated with negative health implications. So, further research should be conducted to evaluate the other carrier molecules in the spray drying of the OFSP powder preparation.

Author contribution statement

Medanit Assefa Arebo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Jireta Danadesa Feyisa: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Kenenisa Dekeba Tafa: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Neela Satheesh: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

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