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Impact of spray drying conditions on the reconstitution, efficiency and flow properties of spray dried apple powder-optimization, sensorial and rheological assessment

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A R T I C L E I N F O

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A B S T R A C T

Spray drying is a preferred choice for development of highly soluble, rapidly dispersible apple powder. However, adhesion during spray drying of syrups and juices is encountered which leads to product loss. The main solution to reduce adhesion is using drying aids. Besides, control of spray drying operating parameters (inlet air temperature and feed flow rate) also closely govern the powder yield, physical, functional and microstructural properties of spray dried fruit powder. Thus, the aim of the study was to evaluate the effect of inlet air temperature (IAT), carrier agent concentration (MD:GA), feed flow rate (FFR) & feed TSS (FTSS) on moisture content, hygroscopicity, dispersibility, water solubility index (WSI), bulk density (BD), porosity (Φ), flowability, lightness (L*) and radical scavenging activity (RSA). Design expert predicted IAT of 160 °C, MD and GA concentration of 14% and 6% respectively, FFR of 350 rpm & FTSS of 15^{o}Brix as optimum condition for development of easily dispersible, highly soluble and least hygroscopic powder. The powder developed after following the optimized condition (SDAP) recorded moisture content as 2.91%, hygroscopicity as 25.29%, dispersibility as 92.50%, WSI as 94.17%, bulk density as 314.1 kg/m^3, porosity as 57.19, flowability as 25.83°, L* value as 70.54 and RSA as 14.37. Among different powder reconstitution concentrations, 25% w/v concentration came out to be the best for reconstitution on the basis of sensory evaluation and rheological test. Frequency sweep test for all the reconstituted juice samples showed higher storage modulus than loss modulus for all the applied frequencies. The results of the study conferred that the developed powder could be used for commercial purpose.

1. Introduction

Apple is known as a miracle fruit due to its rich macronutrient and phytochemical composition which are involved in optimal growth, wellness and overall well-being of humans [1]. Due to its health-promoting properties, apple is the third most frequently cultivated fruit all over the world only behind bananas and watermelons [2]. However, high perishability of apples limits its shelf-life

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Abbreviations

SDAP	Spray dried apple powder
TSS	Total soluble solids
Tg	Glass transition temperature
RSM	response surface methodology
IAT	inlet air temperature
MD	Maltodextrin
GA	Gum arabic
FFR	Feed flow rate
FTSS	Feed total soluble solids
MC	Moisture content
WSI	Water solubility index
BD	Bulk density
L*	Luminosity
Φ	Porosity
RSA	Radical scavenging activity
DPPH	α-diphenyl picryl hydrazine
DE	Dextrose equivalent
AoR	Angle of repose

and market distribution. To make their availability round the year possible, different preservative techniques are applied which works by removal of moisture and diminishing water activity. Drying is the most commonly employed preservation technique. It is basically a liquid–solid separation process during which moisture content of porous materials (often biopolymers) is removed besides simultaneous heat and mass transfer [3]. Several drying methods are currently employed for preservation and shelf-life extension of fruits due to their ease of operation and versatility. Spray drying is most commonly employed drying method for development of fruit powders due to its economic considerations, product recovery and relative control of the particle size distribution [4]. Michalska and Lech [5] recommended spray drying as suitable drying technique for production of apple powders due to the effectiveness and economic aspects of the process. However, during spray drying of fruit juices, the problem of wall adhesion and stickiness is encountered due to abundance of acids and low molecular weight sugars consequently leading to difficulty in the drying process. Besides, the high hygroscopicity, thermo-plasticity, molecular mobility and low Tg of these sugars and acids also leads to the stickiness problem. To overcome this, a carrier agent (high molecular weight additives) becomes a necessary part of the fruit juice drying [6].

Carrier agents modify the structure of powder particles thereby reducing particle adhesion, hygroscopicity, and increasing powder stability. Carrier type and concentration are critical in economical production of powder so that their physicochemical and reconstitutional properties are maintained [7]. Maltodextrin is the most commonly used carrier agent for spray drying due to its good solubility, low viscosity, neutral aroma and low cost. However, low Tg and amorphous nature of maltodextrin at high relative humidity storage conditions results in increased powder stickiness due to moisture absorption. Furthermore, glucose from maltodextrins is rapidly absorbed in the small intestine, promptly increasing glycemic load, which is unfavourable for health. Gum arabic has found wide spread use as a drying aid because of its high Tg, low viscosity, high solubility and good film-forming properties. However, high cost, short supply production and contamination by impurities limits its application [8]. Moreover, due to its low density, a lot of this carrier agent is used to achieve free-flowing powder. Thus, the final product contains more than half of low nutritional value additive, resulting in depletion of bioactive compounds concentration in the product and undesirable change to natural colour and taste of food powders. Thus, by combining two or more carriers during spray drying process, their disadvantages and limitations can be minimised. Gum arabic-maltodextrin blend has proven to be more successful in spray drying of fruit juices compared to other drying aids. Besides rectifying the stickiness problem by reducing powder hygroscopicity, these carrier agents also shield the sensitive components of food material including phenolics, vitamins and carotenoids against thermal degradation [9].

Literature survey have shown that Sarabandi et al. [10] studied the effect of different carriers on microstructure and physical characteristics of spray dried apple juice concentrate. Samborska et al. [11] investigated reformulation of spray-dried apple concentrate and honey for the enhancement of drying process performance and the physicochemical properties of powders. Qadri et al. [12] compared the apple juice concentrate and spray dried apple powder for nutritional, antioxidant and rheological behaviour. Qadri et al. [13] evaluated qualitative, rheological, structural characterization and sorption isotherm of spray dried apple powder. However, effect of spray drying operating conditions on physico-functional properties and anti-oxidant effect of developed apple powder have not studied till date. Therefore, keeping in view the rising consumer demands for apple powders, the present research work was undertaken with an aim to examine the effect of feed concentration (carrier agents in combination and feed total soluble solids) on efficiency of spray drying process and physico-functional characteristics of developed apple powder in order to produce high quality natural apple juice powder.

2. Material and methods

2.1. Raw material

The apple juice concentrate with a TSS of 70°Brix and 1.3% acidity was purchased from FIL Industries, Rangreth, Srinagar, J&K.

Table 1
Effect of feed composition and spray drying conditions on physico-chemical and anti-oxidant activity of SDAP.

S. No.	IAT (°C)	MD:GA (%)	FFR (rpm)	FTSS (°Brix)	MC (%)	H (%)	D (%)	WSI (%)	BD (kg/m^3)	Φ (%)	F(°)	L*	RSA (% DPPH inhibition)
1	110 (−1)	0:20 (−1)	437.5 (0)	20 (0)	4.82	17.22	83.85	83.77	325	38.22	17.17	89	26.06
2	180 (+1)	0:20 (−1)	437.5 (0)	20 (0)	3.19	23.66	87.78	92.77	322	56.74	14.88	73.56	15.91
3	110 (−1)	20:0 (+1)	437.5 (0)	20 (0)	6.71	18.13	81.17	86.15	329	37.76	17.38	80.61	24.22
4	180 (+1)	20:0 (+1)	437.5 (0)	20 (0)	2.18	22.08	85.69	86.29	325	53.92	15.02	88.92	18.77
5	145 (0)	10:10 (0)	250 (−1)	8 (−1)	2.34	22.55	83.27	86.91	313	55.54	20.31	86.94	24.83
6	145 (0)	10:10 (0)	625 (+1)	8 (−1)	6.28	20.29	81.01	83.39	318	50.55	22.44	90.13	27.99
7	145 (0)	10:10 (0)	250 (−1)	32 (+1)	6.38	22.78	86.71	88.72	312	61.32	16.29	89.92	27.48
8	145 (0)	10:10 (0)	625 (+1)	32 (+1)	2.38	21.26	84.63	86.04	313	55.73	18.39	87.13	29.42
9	110 (−1)	10:10 (0)	437.5 (0)	8 (−1)	6.44	16.91	80.81	87.24	321	35.79	16.79	87.14	23.45
10	180 (+1)	10:10 (0)	437.5 (0)	8 (−1)	2.69	20.66	85.33	90.32	318	40.02	14.85	80.36	17.25
11	110 (−1)	10:10 (0)	437.5 (0)	32 (+1)	4.77	19.01	87.11	89.09	317	37.32	14.22	83.33	24.1
12	180 (+1)	10:10 (0)	437.5 (0)	32 (+1)	3.42	24.01	89.28	93.68	314	52.59	12.85	82.18	18.91
13	145 (0)	0:20 (−1)	250 (−1)	20 (0)	4.42	23.52	85.61	87.22	322	66.54	19.9	89.29	26.08
14	145 (0)	20:0 (+1)	250 (−1)	20 (0)	3.04	18.41	83.29	85.98	325	64.97	20.64	90.05	26.44
15	145 (0)	0:20 (−1)	625 (+1)	20 (0)	4.11	20.04	82.88	84.91	324	61.39	22.01	88.47	28.42
16	145 (0)	20:0 (+1)	625 (+1)	20 (0)	5.39	18.94	80.97	83.24	328	58.32	23.37	92.38	29.04
17	110 (−1)	10:10 (0)	250 (−1)	20 (0)	5.24	19.24	83.16	84.76	320	60.12	19.88	91.97	26.48
18	180 (+1)	10:10 (0)	250 (−1)	20 (0)	2.65	23.19	87.67	89.05	317	60.74	17.12	85.48	20.71
19	110 (−1)	10:10 (0)	625 (+1)	20 (0)	5.78	17.72	80.17	82.22	323	50.04	22.37	89.57	28.7
20	180 (+1)	10:10 (0)	625 (+1)	20 (0)	3.67	21.67	85.59	85.94	318	62.61	20.22	86.88	23.09
21	145 (0)	0:20 (−1)	437.5 (0)	8 (−1)	4.54	19.86	84.82	86.99	324	40.77	18.08	83.79	22.79
22	145 (0)	20:0 (+1)	437.5 (0)	8 (−1)	3.33	17.71	80.01	84.39	329	37.03	21.19	84.28	24.97
23	145 (0)	0:20 (−1)	437.5 (0)	32 (+1)	3.28	20.65	90.13	88.36	321	44.42	16.89	82.71	26.67
24	145 (0)	20:0 (+1)	437.5 (0)	32 (+1)	5.17	21.67	84.73	87.67	326	41.27	16.83	81.72	25.32
25	145 (0)	10:10 (0)	437.5 (0)	20 (0)	5.51	19.24	85.79	85.41	313	60.09	20.03	85.31	25.46
26	145 (0)	10:10 (0)	437.5 (0)	20 (0)	5.45	20.22	84.22	86.79	318	65.21	20.7	84.29	25.46
27	145 (0)	10:10 (0)	437.5 (0)	20 (0)	5.57	20.45	84.91	85.22	313	63.34	19.89	85.28	26.78
28	145 (0)	10:10 (0)	437.5 (0)	20 (0)	5.59	20.54	84.66	84.32	312	57.98	21.22	86.63	24.33
29	145 (0)	10:10 (0)	437.5 (0)	20 (0)	5.15	20.37	84.39	84.99	315	50.22	20.7	84.11	24.72

IAT: inlet air temp; MD: Maltodextrin; GA: Gum Arabic; FFR: Feed Flow rate; FTSS: Feed TSS; MC: Moisture content; WSI: Water solubility Index; H: Hygroscopicity; D: Dispersibility; BD: Bulk density; Φ: Porosity; F: Flowability; L*: lightness; RSA: radical scavenging activity.

Apple juice concentrate was prepared initially at plant by crushing apples for juice recovery. The obtained juice was treated with enzymes for pectin degradation. The freshly pressed and enzyme treated apple juice was concentrated using ultrafiltration membrane and was directly packed into bottles without any thermal or chemical treatment.

Carrier agents- Gum arabic (Food grade) and Maltodextrin (DE 10)-were procured from High Purity Laboratory Chemicals, Mumbai, India. All other chemical reagents were of AR grade and acquired from Merck and Loba Chemicals Limited, Mumbai, India.

2.2. *Preparation of apple juice concentrate slurry*

Apple juice concentrate slurry with varying Total Soluble Solids (TSS), carrier agent concentration was prepared as per the experimental design (S1). Maltodextrin and gum arabic in different concentrations were dissolved in 100 ml of distilled water. Maltodextrin dissolves easily in water with minimum or no stirring while solution containing gum arabic was placed on magnetic stirring in order to bring its complete dissolution. After complete dissolution, both solutions were mixture together. To this prepared solution, 70 ml of apple juice concentrate was added and the required TSS was adjusted with dilution by distilled water.

2.3. *Spray drying*

The procedure described by Sarabandi et al. [10] with some modifications was followed to develop apple powder from apple fruit juice slurry (prepared above) using co-current air flow type pilot scale spray dryer fitted with two-fluid nozzle atomizer having orifice diameter of 0.5 mm (SM Scienctech, Kolkata). The drying chamber which composed of food-grade stainless steel had dimensions of 90 × 35 cm and water evaporative capacity of 3 l/h. It was furnished with a dehumidified air-drying system via a stretchable air duct which supplied dehumidified air to the drying chamber. Peristaltic pump was employed for pumping feed slurry to the dryer while compressed air after dehumidifying was also directed towards the drying chamber through air inlet nozzle provided on the top of the drying chamber. Spray drying was carried out at varying operating parameters (inlet air temperature and feed flow rate) and feed composition (maltodextrin, gum arabic concentration and feed TSS) according to an experimental design (Table 1; S1). Time taken by powder to get formed and collected at the end of spray drying operation depended on rate of flow of feed inside the chamber and feed TSS besides other factors. During spray drying, outlet temperature, atomizer disc speed, air flow rate and air pressure were kept constant at 80 °C, 18000 rpm, 25 m^3/h and 0.80 MPa respectively. Outlet temperature was fixed by control panel of the spray dryer and monitored with the help of thermometer installed at the outlet air pathway. Immediately after completion of the experiments, the developed powder collected in the outlet jars and on the lining of the cylindrical parts of the drying chamber were taken out before being packed in polyethylene bags and stored in desiccator for further analysis. The schematics for development of spray drying apple powder from apple juice concentrate is shown in Figure S-3.

2.4. *Experimental design and process optimization*

Response surface methodology (RSM) coupled with four factors three level Box Behnken Design (BBD) listed in S-1 was employed to investigate the individual and interactive effects of four independent variables viz Inlet air temperature (A), Carrier agent concentration (B), feed flow rate (C) and Feed TSS (D) on Moisture content (MC), hygroscopicity, dispersibility, Water Solubility Index (WSI), Bulk density (BD), porosity, flowability, Luminosity (L*), and Radical Scavenging Activity (RSA) via Design- Expert 10 (State-Ease Inc., Minneapolis, MN, USA) statistical package. Second order polynomial mathematical models were developed to show the relationship between dependent and independent variables. Analysis of variance (ANOVA) investigated the adequacy of developed mathematical models which were used to plot the prediction contour graphs to study the interactive effect of independent variables on the responses. Optimum conditions were determined by BBD's desired function methodology. The optimum condition criteria applied for numerical optimization was to maximize WSI (%), Dispersibility (%), Porosity (%), flowability (^{o}), RSA (% DPPH inhibition) and L* and minimize: Hygroscopicity (%), BD (kg/m^3) and MC (%). Finally, validation of developed models was carried out by conducting additional experiments within the selected independent variables range.

2.5. *Physico-functional analysis of apple juice concentrate powder*

2.5.1. *Moisture content*

Standard AOAC [14] procedure was followed for determination of powder moisture content.

2.5.2. *Hygroscopicity, dispersibility and water solubility index (WSI)*

Hygroscopicity was measured based on the procedure given by Kumar et al. [15]. About 1 g of the spray dried apple powder was placed in a container containing saturated NaCl solution at 25 °C (75.29% RH). After one week, the samples were taken out and weighed. Hygroscopicity was expressed as the percent of moisture adsorbed per 100 g dry solids.

Dispersibility was determined by reconstituting the powder followed by sieving and drying as per the method described by Santhalakhshmy et al. [16]. Half a gram of powder was placed in 25 ml beaker containing 5 ml of water and stirred vigorously for complete dissolution. The reconstituted powder was then passed through a 650 mm sieve and its total solids content was estimated by drying in an oven overnight (100 °C). Dispersibility was recorded as per equation (1):

$$Dispersibility\ (\%) = \frac{(10+\alpha)\times TS}{\alpha b}\times 100 \tag{1}$$

Where TS = retentate weight, α = initial weight of powder and b = moisture content of powder.

Solubility of powder was estimated by weight difference method as described by Hasan et al. [17]. Two g of powder was dissolved in 25 ml of distilled water at room temperature followed by centrifuge at 7000 rpm for 15 min. The supernatant was discarded and the sediment was dried in an oven at 80 °C to a constant weight. Difference in weight before and after drying was noted as powder solubility.

2.5.3. Bulk density (BD) and porosity (Φ)

Sample of known weight was taken in a 10 ml graduated cylinder and volume occupied was recorded. BD (kg/m^3) was calculated as ratio of weight and volume. For tapped density, the same cylinder was tapped several times and more powder was added up to the mark. Weight of the powder was noted and tapped density was calculated as weight upon volume [16].

Equation (2) given below was followed for calculation of porosity of developed powders

$$\mathbf{\Phi} = \frac{particle\ density - tapped\ density}{particle\ density}\times 100 \tag{2}$$

2.5.4. Flowability (angle of repose)

Flow behaviour of powders were determined by measuring angle of repose (AoR). Fixed cone bottom method expressed by Camacho et al. [18] was followed for evaluation of AoR. When a powder is poured through a funnel, the angle formed between the slope of the cone and the horizontal surface onto which the powder drops is AoR. Values between 28 and 30 represent excellent flowability while values > 66 depict poor flow properties of powders [19]. equation (3) given below was followed for calculation of flowability of developed powders

$$AoR = archtan\frac{2h}{d} \tag{3}$$

Where h = height from the top of the formed product cone to the horizontal surface (cm); d = maximum cone product diameter (cm).

2.6. Luminosity (L*)

Luminosity (L*) of apple powder was measured using hunter colour meter (Hunter associates laboratory, Inc, Reston, V.A) calibrated against white tiles. L* value in the range between 0 and 50 indicates darkness while values between 51 and 100 indicates light.

2.7. 2,2-DPPH radical scavenging activity

The procedures for estimation of DPPH radical scavenging activity of apple powder extract provided by Mishra et al. [20] was followed. Two ml of powder extract was mixed with 2 ml of methanolic solution containing 1 mM DPPH solution and shaken vigorously. The mixture was placed in dark for 30 min after which the samples were analyzed spectrophotometrically at 517 nm against methanolic solution as blank. DPPH was determined by below given equation (4):

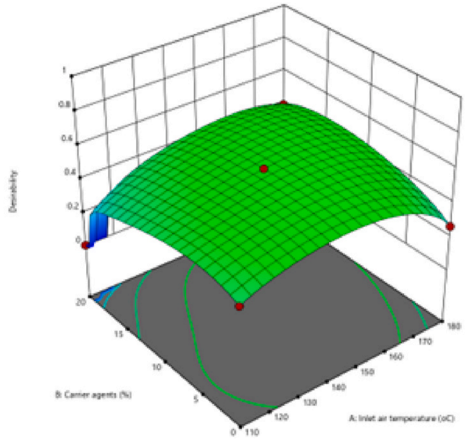
$$\text{DPPH radical scavenging activity} = \frac{\boldsymbol{Absorbance\ of\ blank - Absorbance\ of\ sample}}{\boldsymbol{Absorbance\ of\ blank}}\times 100 \tag{4}$$

2.8. Organoleptic evaluation

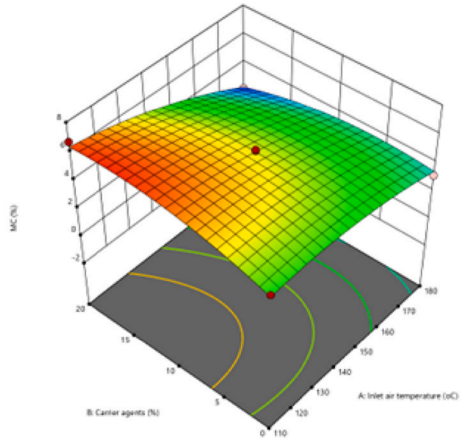
Organoleptic evaluation of different reconstituted juice samples was carried out by following the approach given by Bhat et al. [21]. Based on their capacity to distinguish between a broad variety of sensory qualities, a panel of 50 semi-trained judges from the Division of Food Science and Technology, SKUAST-K, were chosen. The sensory assessment was done using a 9-point hedonic scale (1-dislike extremely to 9-like extremely). Each panellist conducted sensory evaluation in a separate room that was totally devoid of dust, food, chemicals, odour, unwanted lighting, and sounds. Prior to the test, consent of panellists was taken regarding their participation in sensory evaluation. Before commencement of test, they were familiarised with the rating technique, the vocabulary for each attribute, and the desirable sensory qualities of the powder. Sensory evaluation of spray dried apple powder (SDAP) was carried out only after reconstitution using clean drinking water free from any impurities and suspended particles in clean transparent glass in order to check for consistency/sediments. Apple powder was reconstituted at different concentrations (10%, 15%, 20%, 25% and 30% w/v). Each sample were coded unsystematically and were rated by judges on the basis of colour, flavour, taste, consistency and overall acceptability (Annexure I).

Index of acceptability (IA%) was calculated as per equation (5) [22]

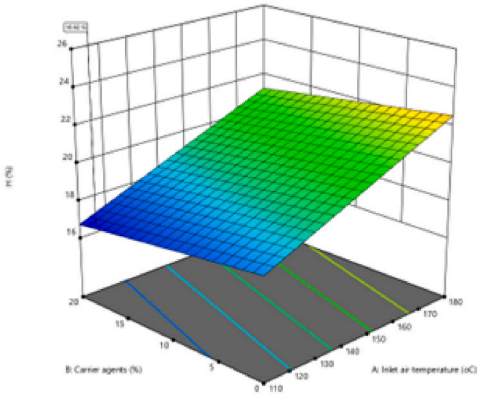
$$\text{IA}\ (\%) = \frac{\text{Score}\times 100}{9} \tag{5}$$



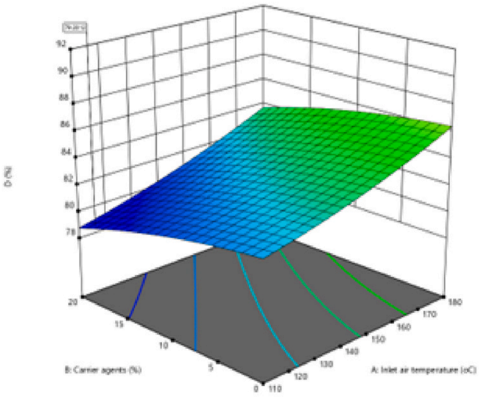
a. Desirability function response surface plots



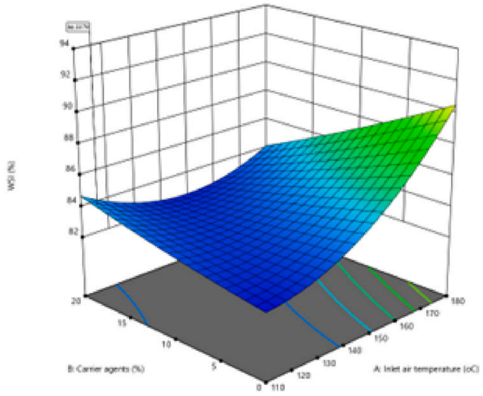
b. Effect of independent variables on moisture content (%)



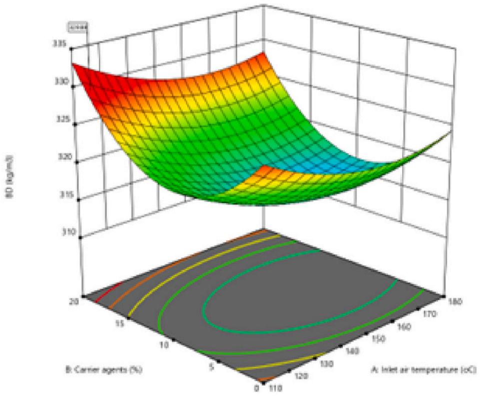
c. Effect of independent variables on hygroscopicity (%) (H)



d. Effect of independent variables on Dispersibility (%) (D)

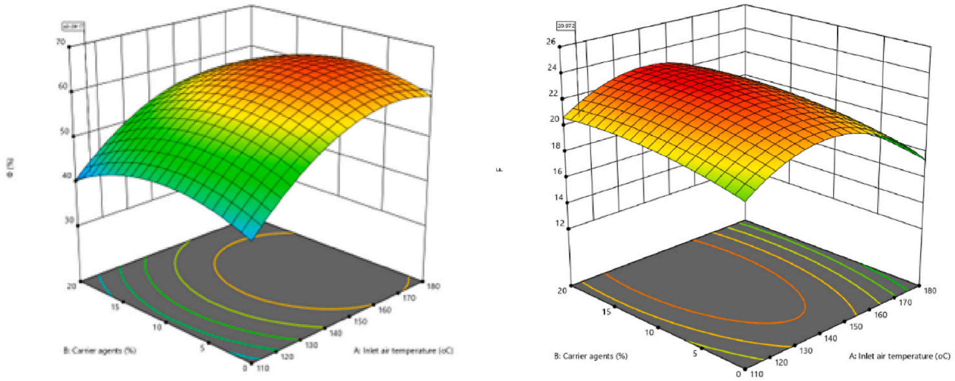


e. Effect of independent variables on (WSI) Water solubility index (%)

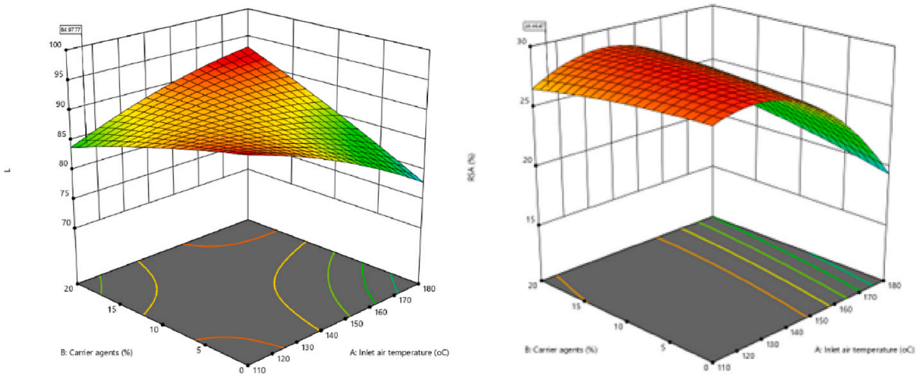


f. Effect of independent variables on bulk density (BD) (kg/m^3)

Fig. 1. Predictive plots depicting desirability function and effects of inlet air temperature, carrier agent ration, feed flow rate and feed TSS on moisture content, hygroscopicity, dispersibility, Water solubility index, bulk density, porosity, flowability, luminosity and radical scavenging activity of spray dried apple powder (SDAP).



g. Effect of independent variables on porosity (Φ) h. Effect of independent variables on flowability (F)



i. Effect of independent variables on luminosity (L) j. Effect of independent variables on radical scavenging activity (RSA) (%DPPH inhibition)

Fig. 1. (*continued*).

2.9. *Rheological properties of reconstituted SDAP*

A frequency sweep test as per the method described by Muzaffar et al. [23] was carried out to study the rheological characteristics of spray dried powder. The powdered samples were reconstituted with deionized water at the appropriate concentrations (10, 15, 20, 25%, and 30% w/v) prior to the test in order to determine the rheological parameters. A Modular Compact Rheometer (MCR-102, Anton Paar, Austria), outfitted with a parallel plate system (50 mm diameter) at a gap of 0.5 mm was used to measure the rheological characteristics (storage modulus, G′, and loss modulus, G″) of reconstituted solutions at a constant temperature of 20 °C. Frequency sweeps over the range of 0.1–100 rad/s at 3% strain were carried out to obtain the rheological data. For determination of storage modulus (G′) and loss modulus (G″), experimental data were collected using a Rheoplus data analysis programme (32 V3.40).

3. Results and discussion

3.1. *Fit summary and regression model*

The relationships between moisture content (MC), hygroscopicity (H), dispersibility (D), water solubility index (WSI), Bulk density (BD), Porosity (**Φ**), Flowability (F), Luminosity (L*) and radical scavenging activity (RSA), and four independent variables (Inlet air temperature (A), carrier agent concentration (B), feed flow rate (D) and feed TSS (E)) were studied. The experimental design listed in Table 1 provides the responses for MC, hygroscopicity, dispersibility, WSI, BD, **Φ**, flowability, L* and RSA for each experimental run. Using a polynomial equation, the result from Table 1 was correlated with these independent factors. The acquired data were fitted using least squares regression.

ANOVA analysis of the developed models, described in S-2, suggested their capability of accurately describing the spray drying process. For MC, BD, **Φ**, WSI, flowability and L*, quadratic models were suggested; while linear model fitted significantly to dispersibility, hygroscopicity and RSA by output of fit summary statistics. The parameters F-value, R^2, p-value, and lack of fit were used to assess how well the proposed model fit the experimental data. F-values (Fischer variation ratio) for all nine dependent variables ranged from 9.77 to 38.48 which suggested significance of the quadratic model for each response. The importance of each term in the model was also checked and a p-value less than 0.05 suggested that the model term was highly significant. All independent factors had significant ($p < 0.05$) linear effect on these dependent variables. Moreover, quadratic and interactive effect of some independent variables were also found to be significant ($p < 0.05$).

Validity of models was evaluated as a function of their goodness of fit (R^2), goodness of predicted (Predicted R^2), and regression equations. Models having high correlation coefficient ($R^2 = 0.81–0.93$) were developed which indicated the significance of these regression equations. In order to validate the developed models, actual and predicted values of R^2 were compared. Predicted R^2, a measurement of the amount of variation around the mean explained by the developed models, was found to be in fair agreement with adjusted R^2. Coefficient of variance (CV), a measure of the variability of data in suggesting model's accuracy and reproducibility, ranged from 1.67 to 11.87%. All the models showed a highly desirable precision range (13.17–27.10), which indicated that model discrimination in all the parameters is adequate. All parameters showed non-significant lack of fit, indicating that second order polynomial models corresponded well with the measured data. These findings suggested that the established mathematical model can provide a fairly reliable description of the spray drying process.

3.2. Physico-functional properties of apple powder

3.2.1. Moisture content (MC)

Moisture content is related to drying efficiency and determine physical and chemical stability as well as the overall acceptability of powders. Thus, moisture is an important property of powder [24]. Low MC of powders is desirable for their safe storage. MC of developed powders ranged from 2.18% to 6.71.% (Table 1) which is in the desired range for a powder to be considered a dry product and microbiologically stable [15].

$$MC\ (\%) = 4.05–0.796A + 0.266C + 0.041AB – 0.018BCE – 0.202CD – 0.08A^2 \tag{6}$$

Regression equation (6) and Fig (1b) depicted significant ($p < 0.05$) linear effect of inlet air temperature (A) and feed flow rate (C) on powder moisture content. Moisture content varied inversely with the increase in inlet air temperature while a linear relationship was observed with feed flow rate. Moreover, significant effect ($p < 0.05$) of interactive terms of inlet air temperature with carrier agent concentration (AB), carrier agent concentration with feed flow rate (BC) and feed flow rate with feed TSS (CD) were also observed on MC. Besides, quadratic effect of inlet air temperature was also found to be significant ($p < 0.05$).

As the temperature of inlet air was increased, a decrease in moisture content of developed powder was recorded as represented by negative coefficient of linear term of A. Increased inlet temperature results in higher temperature potential between the feed material and drying agent, which results in greater driving force for moisture evaporation and speeds up heat transfer and accelerates rates of moisture evaporation [25] consequently reducing final powder moisture content. The results for MC are in concomitance with those reported by Nayak et al. [26].

Higher rate of feed flow resulted in enhanced MC of developed powder (equation (6)). Increased feed flow rates resulted in less efficient heat transfer between feed droplets and the drying air, which slowed water evaporation and produced powder with higher moisture content. Similar increase in powder moisture content with increase in feed flow rate was reported by Thirugnanasambandham and Sivakumar [27].

3.2.2. Hygroscopicity and dispersibility (D)

Hygroscopicity predicts powder behaviour and is a measure of powders' stability during storage [28] while dispersibility determines the ability of a powder to separate into distinct particles when dissolved in water. Thus, low hygroscopicity and high dispersibility values are desired for instant dissolution of powders [22,29]. For all the experimental runs, hygroscopicity and dispersibility of apple powder varied from 16.91 to 24.01% and 80.01–90.13% respectively (Table 1). Similar hygroscopicity values have been reported by Sarabandi et al. [10] for apple concentrate powder.

$$H\ (\%) = 21.70 + 1.49A–0.37B - 0.15C + 0.66D \tag{7}$$

$$D\ (\%) = 86.77 + 1.93A–2.55B – 0.217C + 0.791D \tag{8}$$

All of the independent variables significantly ($p < 0.05$) affected powder hygroscopicity as well as dispersibility as shown by the fitted regression equations (7) and (8) and Fig (1c &d). The positive coefficient of linear term of air inlet temperature (A) and feed TSS (D) implies a direct relation while negative coefficient of linear term of carrier agent concentration (B) and feed flow rate (C) signifies an inverse relation of these variables with hygroscopicity and dispersibility. Powder dispersibility and hygroscopicity increased as inlet air temperature rose. Spray drying creates low moisture powder with a propensity to absorb moisture from the environment due to changes in vapour pressure that promote hygroscopicity [30]. Higher the inlet air temperature, lower is the powder moisture content which produces highly dispersible powder. Seth et al. [31] also reported similar increasing trend of powder dispersibility with the increase in inlet air temperature.

A decrease in the concentration of carrier substance in the feed slurry increased the dispersibility and hygroscopicity values of the powder due to the presence of less amount of insoluble residue and formation of very few lumps [32]. In addition, the larger molecular weight of maltodextrin (B) significantly reduces the number of binding sites accessible in powder, which negatively effects the powder's ability to hold water [15].

Higher feed flow rate led to decrease in hygroscopicity and dispersibility of powder. Increase in feed flow rate causes inadequate removal of moisture from powder thereby restricting porosity and in turn decreasing powder dispersibility and hygroscopicity as dispersibility of developed powder is governed by its porosity [33]. Hygroscopicity and dispersibility increased linearly with the increase in feed solids (D) (Equations (7) and (8)). Presence of large number of hydrophilic groups from various sugars in feed slurry leads to enhanced hygroscopicity and dispersibility. Ipar et al. [22] also reported an increase in dispersibility values for Baobab powder due to addition of sugars.

3.2.3. Water solubility index (WSI)

WSI is the prime factor which governs the overall quality of powder reconstitution [34] as fast and complete dissolution of powder is main quality criteria. In the present study, solubility of powder ranged from 82.22 to 93.68% (Table 1)

$$\text{WSI}\ (\%) = 90.68 + 0.85A - 0.91B - 1.63C + 1.63D - 0.42\ AB - 0.49A^2 - 0.53C^2 + 0.77D^2 \tag{9}$$

Fitted regression equation (9) and Fig (1e) illustrated that air inlet temperature (A) and feed TSS (D) exhibited significant ($p < 0.05$) positive linear effects on solubility of powder while carrier agent addition (B) as well as feed flow rate (C) negatively affected the powder dissolution. Moreover, a significant ($p < 0.05$) negative quadratic effect of A and C and positive effect of D were also observed on powder dissolution. Interactive effect of inlet air temperature and carrier agent concentration (AB) was also found to be significant ($p < 0.05$).

It is evident from equation (9) that increase in air inlet temperature increased solubility of powder by reducing the powder moisture content as low moisture content of powder is known to enhance its solubility [35]. Tran and Nguyen [36] also observed an increase in solubility of lemongrass leaf extract powder as the inlet air temperature rose. However, in the present study, solubility of powders decreased significantly ($p < 0.05$) after excessive increase in inlet air temperature as shown by negative coefficient of quadratic term of A. Reduced solubility with excess increase in inlet air temperature may be attributed to the formation of hard surface layer over powder particle at high temperature which prevents escape of moisture through particle, thereby, decreasing wettability and reducing powder dissolution [7]. Similar decrease in solubility with excess increase in inlet air temperature was recorded by Souza et al. [37] for acerola powder.

Solubility of powders was found to decrease with the incorporation of carrier materials (maltodextrin and gum arabic) although solubility values for powder were still higher. Addition of carrier agents decrease powder moisture content (equation (6)) consequently decreasing its solubility as low moisture content of powder results in its fast rehydration [38]. Moreover, low moisture yields powder with lesser degree of stickiness due availability of larger powder surface to rehydrated water which consequently enhancing powder dissolution [34].

Increasing feed flow rate and reducing feed TSS decreased the solubility of developed powder (Equation (9)). Rapid transfer of feed material across heating chamber causes removal of inadequate moisture from particles thereby leading to denser particles with reduced solubility as bulk density and solubility is inversely related [13]. Increasing TSS of feed enhanced powder solubility by providing high amount of sugars with increased solubility in aqueous solutions. Solubility results are in concomitance with Qadri et al. [13] for apple powder produced via spray drying.

3.2.4. Bulk density and porosity

Bulk density (BD) and porosity (**Φ**) are functional parameters of instant powders with commercial importance. Bulk density and porosity, in the present study, varied from 312 to 329 kg/m^3 and 35.79–66.54 respectively (Table 1). BD values observed in this study were different than those described by Sarabandi et al. [10] for apple powder. This difference might be due to variation in molecular size of MD and GA and spray drying processing parameters which affects the particle size of final powder as particle size and BD is inversely related [11].

$$\text{BD}\ (\text{kg/m}^3) = 329.65 – 3.13A + 1.96B + 3.70C – 3.12D \tag{10}$$

$$\Phi\ (\%) = 65.06 + 1.63A – 2.49C + 2.81D \tag{11}$$

Regression equations (10) and (11) and Fig (1f & g) depicts the significant ($p < 0.05$) linear negative effect of air inlet temperature (A) and feed TSS (D) while positive linear effect of carrier addition (B) incorporation and feed flow rate (C) on BD of developed powder. The positive coefficients of linear term of feed flow rate and carrier concentration (maltodextrin and gum arabic) signifies their direct relationship while the negative coefficient of linear terms of inlet air temperature and feed TSS implied an inverse exists between BD and them. A negative correlation exists between porosity and powder density [39]. Denser powders are naturally less porous.

Porous powder with reduced density was obtained as the temperature of air increased. As the temperature of inlet air rose, the rate of evaporation enhanced which resulted in porous fragmented structures and created the ballooning or puffing effect in powder particles [40].

Addition of carrier agents in combination resulted in denser powders due to their skin-forming ability which trap water molecules within powder particles [41] as water is considered denser than dry matter [42].

As the rate of feed flow enhanced, denser powders with reduced porosity were obtained. Rapid flow of slurry across chamber results in inadequate removal of moisture which might probably have enhanced the powder density [43]. High TSS of feed slurry yielded porous powder probably due to the dilution effect from low molecular weight sugars [44] as water is considered denser than dry matter.

3.2.5. Flowability (angle of repose)

Flowability, a measure of powder's free-flow characteristics, is the ease with which powder particles move with regard to one another. For all the experimental runs, flowability of developed powders ranged from 12.85° to 23.37° (Table 1). Powder having angle of repose value between 25 and 30° is considered free flowing. Low flowability values implies better flow characteristics [10].

$$\text{Flowability } (^{o}) = 34.72 – 1.33A + 1.90C – 1.91D – 4.13A^2 – 2.29D^2 \tag{12}$$

Powder flowability was linearly affected by inlet air temperature (A), feed flow rate (C) and feed TSS (D) as depicted in Fig (1h). Quadratic effect of inlet air temperature (A) as well as feed TSS (D) also exhibited significant ($p < 0.05$) effects on powder flowability. Positive coefficient of linear term of C implied direct relation of feed flow rate with flowability while negative coefficient of linear term of A and D represent an inverse relation of flowability with these variables. Flowability of powders improved as the temperature of inlet air increased (equation (12)). Higher inlet temperature results in dry powder with low moisture content and reduced cohesion between powder particles which consequently improves flowability [37].

Increasing feed flow rate decreased powder flowability by increasing stickiness and wall deposits of particles due to limited moisture evaporation. Significant ($p < 0.05$) increase in powder flowability was observed with the decrease in feed TSS (Equation (12)). High feed TSS causes inefficient drying of low molecular weight substances which resulted in powder with increased stickiness and lower flowability.

3.3. Luminosity (L*)

Dark colour products are usually less appealing to the consumers as it may indicate deterioration. Thus, lower L* value is undesirable. In the current work, lightness of developed powders varied from 73.56 to 92.38 (Table 1)

$$L^* = 63.03 – 2.44A + 0.31B - 0.131AD – 0.148CD \tag{13}$$

Regression equation (13) and Fig (1i) illustrated significant ($p < 0.05$) linear effect of inlet air temperature (A) and carrier agent concentration (B) on luminosity of developed apple powder. Interactive effect of inlet air temperature with feed TSS (AD) and feed flow rate with feed TSS (CD) was also found to be significant. Luminosity of powder varied linearly with carrier agent addition (B) while an inverse relation was observed with inlet air temperature (A). Dark colored powder was obtained at higher inlet temperature as high temperature favors browning reactions which decreases powder luminosity [19]. Maltodextrin and gum arabic addition resulted in light colored powder due to their ability to form homogenous droplets which radiates lights equally [45].

With the increase in Feed TSS and inlet air temperature (AD), luminosity of resultant powder decreased probably due to the enhanced rate of browning at higher inlet temperature because of the presence of more solids in feedstock [46].

3.4. Radical scavenging activity (%DPPH inhibition)

Radical scavenging activity (RSA) quantifies the hindrance of free radicals, which results in sufficient harm to bodily tissues and cells if present in food and other biological systems [47]. For all the developed powders, RSA varied from 16.91 to 24.01 %DPPH inhibition (Table 1).

$$\text{RSA (\%DPPH inhibition)} = 16.44 – 1.16A + 0.83D + 1.16E \tag{14}$$

Radical scavenging activity of developed apple powder was significantly affected by inlet air temperature (A), feed flow rate (C) and feed TSS (D). Inlet air temperature (A) exhibited direct relation with RSA while all the other independent variables negatively affected RSA of the developed powder as depicted in equation (14) and fig (1j). As the temperature of inlet air rose, RSA of the developed powders diminished due to thermal effect and oxidative degeneration of biologically active compounds [48]. Similar results were reported by Mishra et al. [20] for free RSA in amla powder.

High feed flow rate enhanced RSA of powder by reducing thermal degradation of bioactive compounds through reduction of contact time between drying agent and the feed [49]. With the increase in feed solids, RSA of powders was improved as higher solids consequently provides higher number of bioactive compounds with significant RSA. The results of RSA are in concomitance with those reported by Saha and Jindal [50] for spray dried beal powder.

3.5. Process optimization

Derringer's desired function methodology was used for optimization after analysing the polynomial equation illustrating the impact of dependent and independent factors on the spray drying process. The best option was chosen based on its highest desire score of 0.70 (Fig. (1a)) suggested that inlet air temperature of 160 °C, carrier agent concentration (MD:GA) of 14 and 6% respectively, feed flow rate of 350 rpm and feed TSS of 15^{o}brix were optimum for development of powder from apple concentrate with acceptable physical and reconstitutional attributes. The predicted value of moisture content (2.83), hygroscopicity (24.71), dispersibility (90.21), water solubility index (94.90), bulk density (321.46), porosity (58.93), flowability (25.20), L* (72.83) and radical scavenging activity (15.04) were almost similar to the actual values of developed powder (SDAP) recorded after following optimized conditions of spray drying with a variation of ≤3.24% (Table 2).

3.6. Physico-functional behaviour of developed apple powder (SDAP)

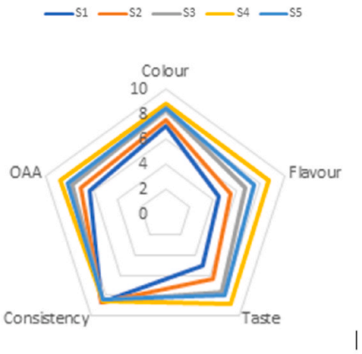
Table 2 lists the physico-functional characteristics of spray dried apple powder (SDAP) developed after following the above obtained optimized condition. SDAP recorded 2.91% moisture content. The low moisture content of the developed powder is due to higher inlet air temperature (160 °C) encountered during spray drying [51]. Moisture content values recorded in the present study were similar to those reported by Sarabandi et al. [10] for apple powder. Bulk density and porosity of SDAP was recorded as 314.1 kg/m^3 and 57.19% respectively. Moisture content besides other factors govern bulk density of powder. Higher the moisture content, higher will be the bulk density. Ferrari et al. [39] also reported similar bulk density values (443 kg/cm^3) for blackberry powder having moisture content 3.20%. WSI of SDAP came out to be 94.17% while hygroscopicity and of SDAP was noted as 25.29%. The comparatively low solubility and high hygroscopicity values of SDAP might probably be due to relatively low moisture content of SDAP and high bulk density as solubility and bulk density are inversely correlated [13]. Sarabandi et al. [10] also reported that powders produced using maltodextrin and gum arabic as carrier agent had high hygroscopicity and low WSI. Dispersibility of SDAP was found around 92.50%. Porosity of powder governs its dispersibility [52]. The low porosity of powder due to its relatively high bulk density might have negatively impacted the dispersibility of SDAP. Flowability of SDAP turned out to be around 25.83°. Flowability of powder depends on the surface characteristics and composition of powder. Difference in chemical structure of carrier agents along with relatively high moisture content might have yielded low flowability values of SDAP [39]. Luminosity of developed powder was recorded as 70.54 which might possibly be due to inherent colour characteristics of carrier agents which affect final colour attributes of powder [10]. The results for colour attributes of SDAP are in accordance with the results of Phan et al. [53] for *Terminalia ferdinandiana* fruit powder. Radical scavenging activity (RSA) of SDAP came out to be 14.88%DPPH inhibition. Adding carrier agents in combination (maltodextrin and gum arabic) efficiently encapsulated the bioactive materials of apple thereby yielding enhanced anti-oxidant activity [12].

3.7. Organoleptic evaluation

Sensory profiling of reconstituted SDAP at varying concentration (10–30% w/v) were presented in Fig. 2. Powder reconstituted at 25% concentration received highest score for all sensory parameters (8-like moderately to 9-like extremely). Colour is a crucial quality characteristic that influences consumer acceptance. Score for visual colour of different reconstituted juice samples ranged from 7.00 to 8.80. Juice developed after reconstituting 25% of powder received highest score for visual colour (8.60) while further increase in powder concentration resulted in substantial decrease in colour score of reconstituted juice. Powder concentration at 25% resulted in a transparent amber colour of apple juice after reconstitution, which is a desirable colour as far as apple juice is considered [54]. However, increasing the powder concentration beyond 25% conferred darker brown opaque colour to the juice which is undesirable, consequently lowering visual colour scores. Taste, described as a sensation recognized by the nervous system in the cavity of the mouth [55], was found in range of 5.00 to 8.85 while flavour was recorded in the range of 4.50 to 8.70 for all reconstituted samples. Maximum score for taste and flavour parameter was received by juice prepared after reconstituting 25% powder. At lower SDAP concentration, a bland taste was reported in reconstituted juice samples while with the increase in SDAP, a characteristic apple flavour was detected in juices. However, juice prepared after reconstituting SDAP at 30% concentration recorded slightly sour aftertaste and dry oral surface. Sour aftertaste may get developed on account of reaction between tannins from fruit and salivary proteins [56] which further cause dryness of oral surface. Score for consistency of the reconstituted juice samples varied from 8.75 to 8.40 with highest score obtained by juice reconstituted at 10% SDAP concentration. Consistency, a measure of the mouthfeel, is governed by the number, shape, and size of the insoluble particles present in solids [57]. With the increase in SDAP concentration in reconstituted juice samples, low scores for consistency were obtained. Increase in SDAP concentration caused increased insoluble solids (sediments) due to presence of gum arabic which forms highly dense network and leads to increased viscosity and sedimentation of juice samples and reduced consistency.

Table 2
Actual and Predicted Physico-chemical values of spray dried apple powder (SDAP).

Parameters	SDAP (Actual)	SDAP (Predicted)	Variation (%)
Moisture content (%)	2.91 ± 0.04	2.83	2.74
Hygroscopicity (%)	25.29 ± 0.17	24.71	2.34
Dispersibility (%)	92.50 ± 0.20	90.21	2.53
Water Solubility Index (%)	94.17 ± 0.150.15a	94.90	1.82
Bulk density (kg/m^3)	314.1 ± 0.14	321.46	2.28
Porosity (%)	57.19 ± 0.21	58.93	2.32
Flowability (^{o})	25.83 ± 0.11	25.20	2.43
L*	70.54 ± 3.83	72.83	3.24
Radical Scavenging activity (%DPPH inhibition)	14.88 ± 0.06	15.04	1.06



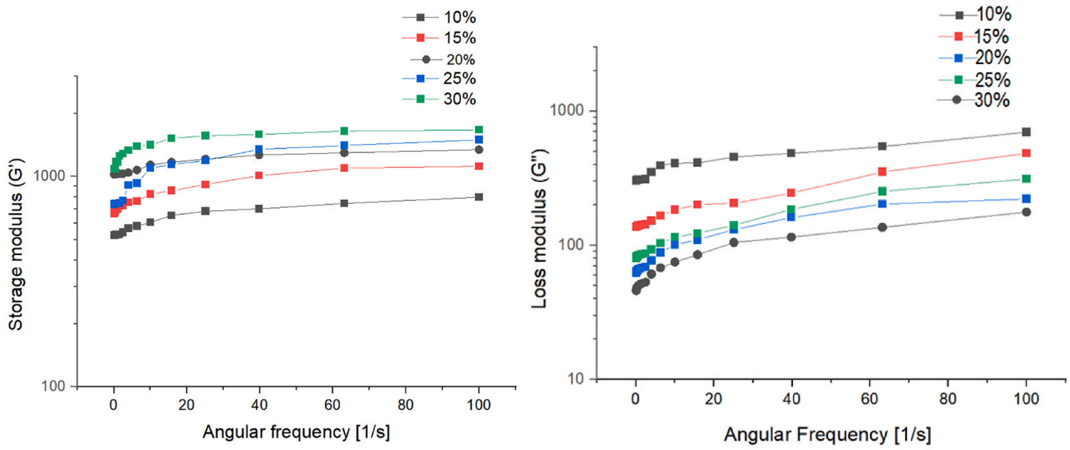
Reconstituted apple juice was prepared by dissolving
S1: 10g powder in 100ml
S2: 15g powder in 100ml
S3: 20g powder in 100ml
S4: 25g powder in 100ml
S5: 30g powder in 100ml

Fig. 2. Sensory evaluation of spray-dried apple powder (SDAP) reconstituted at different concentrations.

A low viscous beverage offers good pourability and mouthfeel [58]. Overall acceptability lied between 6.30 and 8.80 while Index of acceptability was recorded between 70 and 95% for all reconstituted juice samples implying good acceptability of almost all samples. A product is considered acceptable when it has IA (%) score of >75% [59]. Juice prepared after reconstituting 25% SDAP recorded highest IA values which inferred that reconstitution at 25% SDAP concentration is prepared as far as consumer acceptability is concerned. Based on the sensory scale used (1-indicate dislike extremely and 9-indicate like extremely), the inference drawn out of sensory evaluation was that juice prepared after reconstituting 25% and 30% SDAP was rated in the scale of like very much while juice prepared after reconstituting 20% and 15% SDAP was rated in the scale of like moderately while 10% reconstituted juice received lowest rating in the range of like slightly.

3.8. *Rheological behaviour*

Reconstituted SDAP was characterised Rheologically at various concentrations (10–30% w/v) in terms of viscoelastic moduli (storage modulus, G′, and loss modulus, G″), under constant temperature. The behaviour is studied in these samples to determine suspension stability and mouthfeel desirability during drinking [58]. A dynamic frequency sweep rheogram of SDAP developed by plotting loss or viscous (G″) and storage or elastic modulus (G′) against angular frequency (1–100 rad/s) is depicted in Fig. (3a)&b. All of the reconstituted solutions were found to have a predominately elastic behaviour (G′> G″) over the entire frequency range investigated as depicted in Fig. 3. This suggests that the reconstituted solutions behaved similar to a gel-like substance. Suhag et al. [60] also reported G′> G″ for spray dried honey powder. Gel like behaviour of reconstituted juice samples might probably be due to interaction of gum arabic and maltodextrin molecules with each other and with neighbouring protein molecules [23]. Long molecular chains of



a. **b.**

Fig. 3. Rheological behaviour of spray-dried apple powder (SDAP) reconstituted at different concentrations a. Plot of Storage modulus (G′) as a function of angular frequency (ω) for SDAP at different concentrations b. Plot of Loss modulus (G″) as a function of angular frequency (ω) for SDAP at different concentrations.

gum arabic and maltodextrin comprised of strongly solvated particles which resulted in formation of macromolecular network consequently giving rise to a concentrated mesh [60]. A slight dependency of both G′ and G″ was noted on frequency which implied that G′ and G″ enhanced as angular frequency was increased. Comparing the G′ and G″ of different reconstituted samples, 10% reconstituted juice recorded lowest G′ and highest G″ while 30% reconstituted juice recorded highest G′ and lowest G″. Muzaffar et al. [23] also reported higher G′ and G″ for higher concentration (30%w/v) of spray dried tamarind pulp powder after reconstitution. A lower storage modulus (G′) is preferable for easily gulping of juice whilst higher storage modulus (G′) facilitates long term storage [61]. As the more of SDAP was added for reconstitution, higher percent of carrier agents is available as drying aid in SDAP to form more concentrated gel network in presence of water thereby increasing G′. Furthermore, lower G″ values imply increased sedimentation in reconstituted juice and thus validates decreased consistency scores of juice reconstituted at higher SDAP concentration. Reconstituted juice at higher SDAP concentration (30% w/v) recorded lower G″ due to presence of highly concentrated mesh structure and insoluble matrix which leads to increased sediments.

4. Conclusion

The results of the research work revealed that spray drying operating parameters i.e. inlet air temperature of 160 °C, feed flow rate of 350 rpm and feed composition i.e. maltodextrin and gum arabic concentration of 14% and 6% respectively and FTSS of 15^{o}Brix were suitable for development of apple powder. Incorporation of carrier agent in combination resulted in powder with reduced adhesion and enhanced dispersibility (92.50%) and solubility (94.17%). High inlet air temperature also resulted in low moisture content of powder (2.91%) and increased powder stability. The developed powder recorded lower bulk density (314.1 kg/m^3) and higher flowability (25.83°) in comparison to apple powders developed earlier. Lower bulk density and higher flowability of the developed powder can have advantages in certain processes or applications where good flow and dispersibility are desired. Powders with higher flowability tend to disperse more easily in liquids or other mediums. The improved dispersibility can lead to better product performance and consumer experience. RSM was successful in achieving the desired values for all the tested responses by optimising the process variables for the production of spray-dried apple powder. The actual values of different physico-chemical properties of powder developed after following the optimized conditions of spray drying showed a variation of <3.24% with the values predicted by the software which validated the process optimization for development of spray dried apple powder. Organoleptic studies of SDAP revealed that reconstituted powder has better overall acceptability at 25% which yielded high index of acceptability (IA%) of the order of 97.77% for reconstituted juice prepared at 25% powder concentration. Frequency sweep test of SDAP performed at different concentration of powder (10%, 15%, 20%, 25%, 30%) revealed that beyond 30%, storage modulus (G') exceeded rapidly thereby validating 25% (w/v) powder concentration as best reconstitution concentration for preparing juice. Thus, the study revealed that the developed powder had excellent reconstitutional properties, sensory characteristics and superior functional behaviour. The findings of the study could create new opportunities for the processing of apples in J&K and will provide required impetus for better flourishment of already existing fruit processing industry.

Ethics statement

Consent of Participants were taken before undergoing Sensory evaluation.

Author contribution statement

Tahiya Qadri: Performed the experiments; Wrote the paper.
Haroon Rashid Naik: Conceived and designed the experiments.
Syed Zameer Hussain: Analyzed and interpreted the data.
Tashooq Ahmad Bhat, Bazila Naseer, Imtiyaz Zargar, Mushtaq Ahmad Beigh: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e18527.

References

[1] S. Hussain, B. Naseer, T. Qadri, T. Fatima, T. Bhat, Apples (Pyrus Malus)—Morphology, Taxonomy, Composition and Health Benefits, 2021, pp. 17–35, https://doi.org/10.1007/978-3-030-75502-7_2. Ch. 1.

[2] V.B. Fedrigotti, C. Fischer, Why per capita apple consumption is falling: insights from the literature and case evidence from South Tyrol, Horticulture 6 (2020) 79, https://doi.org/10.3390/horticulturae6040079.

[3] O. Kahraman, A. Malvandi, L. Vargas, H. Feng, Drying characteristics and quality attributes of apple slices dried by a non-thermal ultrasonic contact drying method, Ultra, Sonochem 73 (2021), 105510.

[4] M.D. Azhar, S.A. Hashib, U.K. Ibrahim, A.N. Rahman, Development of carrier material for food applications in spray drying technology: an overview, Mater. Today: Proc. 47 (2021) 1371–1375.

[5] C.A. Michalska, K. Lech, The effect of carrier quantity and drying method on the physical properties of apple juice powders, Bever 4 (2018) 2, https://doi.org/10.3390/beverages4010002.

[6] S. Linnenkugel, A.H. Paterson, L.M. Huffman, J.E. Bronlund, Prediction of the glass transition temperature of low molecular weight components and polysaccharide mixture, J. Food Eng. 292 (2021) 345.

[7] S.M. Jafari, S. Masoudi, A. Bahrami, Taguchi approach production of spray-dried whey powder enriched with nanoencapsulated vitamin D3, Dry, Technol. 37 (16) (2019) 2059–2071.

[8] J.K.M. Lee, F.S. Taip, Z. Abdullah, Effectiveness of additives in spray drying performance: a review, Food Res. 2 (6) (2018) 486–499.

[9] Q.D. Nguyen, T.T. Dang, T.V.L. Nguyen, T.T.D. Nguyen, N.N. Nguyen, Microencapsulation of roselle (Hibiscus sabdariffa L.) anthocyanins: effects of different carriers on selected physicochemical properties and antioxidant activities of spray-dried and freeze-dried powder, Int. J. Food Prop. 25 (1) (2022) 39–374.

[10] K. Sarabandi, S.H. Peighambardoust, A.R.S. Mahoonak, S.P. Samaei, Effect of different carriers on microstructure and physical characteristics of spray dried apple juice concentrate concentrate, JFST 55 (8) (2018) 3098–3109.

[11] K. Samborska, P. Gajek, A. Kamińska-Dwórznicka, Spray drying of honey: the effect of drying agents on powder properties, Pol. J. Food Nutr. Sci. 65 (2) (2015) 109–118.

[12] T. Qadri, H.R. Naik, S.Z. Hussain, T. Ahad, F. Shafi, F.M.K. Sharma, Comparative evaluation of apple juice concentrate and spray dried apple powder for nutritional, antioxidant and rheological behaviour, Qual. Assur. Saf. Foods 14 (2) (2022) 74–85.

[1][3]] T. Qadri, H.R. Naik, S.Z. Hussain, B. Naseer, T. Bhat, Vijaykumar, F.J. Wani, Spray dried apple powder: qualitative, rheological, structural characterization and its sorption isotherm, LWT (Lebensm.-Wiss. & Technol.) 165 (2022), 113694.

[14] AOAC. Official, Method of Analysis, eighteenth ed., Association of Official Analytical Chemists. AOAC Press, Gaithersburg, 2012.

[15] P.S. Kumar, D.A. Keran, S. Pushpavalli, K.N. Shiva, S. Uma, Effect of cellulose and gum derivatives on physicochemical, microstructural and prebiotic properties of foam-mat dried red banana powder, Int. J. Biol. Macromol. 218 (2022) 44–56.

[16] S. Santhalakshmy, S.J. Don Bosco, S. Francis, M. Sabeena, Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder, Powder Technol. 274 (2015) 37–43, https://doi.org/10.1016/j.powtec.2015.01.016.

[17] F. Hasan, A. Nazir, B. Sobti, H. Tariq, R. Karim, A.H. Al-Marzouqi, A. Kamal-Eldin, Dehydration of date fruit (*Pheonix dactylifera* L.) for the production of natural sweet powder, NFSJ 27 (2022) 13–20.

[18] M.M. Camacho, M.A. Silva-Espinoza, N. Martínez-Navarrete, Flowability, rehydration behaviour and bioactive compounds of an orange powder product as affected by particle size, Food Bioprocess Technol. 15 (3) (2022) 683–692.

[19] J. Wang, Z. Huang, J. Xia, Application of powdered bio-composites in the field of self-compacting concrete: a review, Construct. Build. Mater. 346 (2022), 128318.

[20] P. Mishra, S. Mishra, C.L. Mahanta, Effect of maltodextrin concentration and inlet temperature during spray drying on physicochemical and antioxidant properties of amla (Emblica officinalis) juice powder, Food Bioprod. Process. 92 (3) (2014) 252–258.

[21] T.A. Bhat, S.Z. Hussain, S.M. Wani, M.A. Rather, M. Reshi, B. Naseer, A. Khalil, The Impact of Different Drying Methods on Antioxidant Activity, Polyphenols, Vitamin C and Rehydration Characteristics of Kiwifruit, Food Biosci., 2022, 101821.

[22] V.S. Ipar, R.S. Singhal, P.V. Devarajan, An innovative approach using microencapsulated turmeric oleoresin to develop ready-to-use turmeric milk powder with enhanced oral bioavailability, Food Chem. 373 (2022) (2022), 131400.

[23] K. Muzaffar, B.N. Dar, P. Kumar, Assessment of nutritional, physicochemical, antioxidant, structural and rheological properties of spray dried tamarind pulp powder, J. Food Meas. Char. 11 (2) (2017) 746–757.

[24] P. Barajas-Alvarez, M. Gonzalez-Avila, H. Espinosa-Andrews, Microencapsulation of Lactobacillus rhamnosus HN001 by spray drying and its evaluation under gastrointestinal and storage conditions, LWT (Lebensm.-Wiss. & Technol.) 153 (2022), 112485.

[25] K. Maroof, R.F. Lee, L.F. Siow, S.H. Gan, Microencapsulation of propolis by spray drying: a review, Dry. Technol. 40 (6) (2022) 1083–1102.

[26] C.M. Nayak, C.T. Ramachandra, U. Nidoni, S. Hiregoudar, J. Ram, N.M. Naik, Influence of processing conditions on quality of Indian small grey donkey milk powder by spray drying, JFST (2022) 1–8.

[27] K. Thirugnanasambandham, V. Sivakumar, Influence of process conditions on the physicochemical properties of pomegranate juice in spray drying process: modelling and optimization, J. Saudi Soc. Agricul. Sci. 16 (2022) 4.

[28] M.A. Bednarska, E. Janiszewska-Turak, The influence of spray drying parameters and carrier material on the physico-chemical properties and quality of chokeberry juice powder, JFST 57 (2020) 564–577.

[29] P.T. Quoc, Effect of different carrier agents on physicochemical properties of spray-dried pineapple (*Ananas comosus* Merr.) powder, J. Kor. Chem. Soc. 64 (2020) 5.

[30] C.D.S. Araújo, W.C. Vimercati, L.L. Macedo, S.H. Saraiva, L.J.Q. Teixeira, da Costa, C.J. Pimenta, Encapsulation of phenolic and antioxidant compounds from spent coffee grounds using spray-drying and freeze-drying and characterization of dried powders, JFST 87 (9) (2022) 4056–4067.

[31] D. Seth, H.N. Mishra, S.C. Deka, Functional and reconstitution properties of spray-dried sweetened yogurt powder as influenced by processing conditions, Int. J. Food Prop. 20 (7) (2017) 1603–1611.

[32] K. Pant, M. Thakur, H.K. Chopra, V. Nanda, Encapsulated bee propolis powder: drying process optimization and physicochemical characterization, LWT (Lebensm.-Wiss. & Technol.) 155 (2022), 112956.

[33] E.H.J. Kim, X.D. Chen, D. Pearce, Effect of surface composition on the flowability of industrial spray-dried dairy powders, Colloids Surf. B Biointerfaces 46 (2005) 182–187.

[34] G. İzli, G. Yildiz, S.E. Berk, Quality retention in pumpkin powder dried by combined microwave-convective drying, JFST 59 (4) (2022) 1558–1569.

[35] I. Flfoul, J. Burgain, C. Perroud, C. Gaiani, J. Scher, H. Attia, J. Petit, Impact of spray-drying conditions on physicochemical properties and rehydration ability of skim dromedary and cow's milk powders, Dry. Technol. 40 (3) (2022) 665–667.

[36] T.A. Tran, V.H. Nguyen, Effects of spray-drying temperatures and carriers on physical and antioxidant properties of lemongrass leaf extract powder, Bever 4 (84) (2018).

[37] V. Souza, A. Mesquita, C. Veríssimo, C. Grosso, A. Converti, M.I. Maciel, Microencapsulation by spray drying of a functional product with mixed juice of acerola and ciriguela fruits containing three probiotic lactobacilli, Dry, Technol. 40 (6) (2022) 1185–1195.

[38] A.M. Goula, T.D. Karapantsios, D. S Achilias, K.G. Adamopoulos, Water sorption isotherms and glass transition temperature of spray dried tomato pulp, J. Food Eng. 85 (1) (2008) 73–83.

[39] C.C. Ferrari, S.P.M. Germer, I.D. Alvim, F.Z. Vissotto, J.M. de Aguirre, Influence of carrier agents on the physicochemical properties of blackberry powder produced by spray drying, Int. J. Food Sci. Technol. 47 (6) (2012) 1237–1245.

[40] D. Arepally, T.K. Goswami, Effect of inlet air temperature and gum Arabic concentration on encapsulation of probiotics by spray drying, LWT (Lebensm.-Wiss. & Technol.) 99 (2019) 583–593.

[41] S. Jokić, N. Nastić, S. Vidović, I. Flanjak, K. Aladić, J. Vladić, An approach to value cocoa bean by-product based on subcritical water extraction and spray drying using different carriers, Sustainability 12 (6) (2020).

[42] X. Zhang, Y. Li, J. Li, H. Liang, Y. Chen, B. Li, S. Liu, Edible oil powders based on spray-dried Pickering emulsion stabilized by soy protein/cellulose nanofibrils, LWT (Lebensm.-Wiss. & Technol.) 154 (2022), 112605.

[43] M. Fazaeli, Z. Emam-Djomeh, A.K. Ashtari, M. Omid, Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder, Food Bioproc. Prod. 90 (4) (2012) 667–675.

[44] P. Solt, J. Konnerth, W. Gindl-Altmutter, W. Kantner, J. Moser, R. Mitter, H.W. Van Herwijnen, Technological performance of formaldehyde-free adhesive alternatives for particleboard industry, Int. J. Adhesion Adhes. 94 (2019) 99–131.

[45] S. Srivastava, M. Bansal, D. Jain, Y. Srivastava, Encapsulation for efficient spray drying of fruit juices with bioactive retention, J. Food Meas. Char. 2022 (2022) 1–23.

[46] S. Moghbeli, S.M. Jafari, Y. Maghsoudlou, D. Dehnad, Influence of pectin-whey protein complexes and surfactant on the yield and microstructural properties of date powder produced by spray drying, J. Food Eng. 242 (2019) 124–132.

[47] V. Lobo, A. Patil, A. Phatak, N. Chandra, Free radicals, antioxidants and functional foods: impact on human health, Pharmacol. Rev. 4 (8) (2010) 118.

[48] M.R.I. Shishir, W. Chen, Trends of spray drying: a critical review on drying of fruit and vegetable juices, Trends Food Sci. Technol. 65 (2017) 49–67.

[49] P. Arya, P. Kumar, Characterization of spray dried diosgenin from fenugreek using binary blend of carrier agents, Appl. Food Res. 2 (1) (2022), 100054.

[50] A. Saha, N. Jindal, Process optimization for the preparation of bael (Aegle marmelos correa) fruit powder by spray drying, Int. J. Food Sci. Nutr. 3 (4) (2018) 44–51.

[51] D. Santos, A.C. Maurício, V. Sencadas, J.D. Santos, M.H. Fernandes, P.S. Gomes, Spray Drying: an Overview, New Ed., Biomater. Physic. Chem.-, 2018, pp. 9–35.

[52] A. Kaur, A.K. Bansal, Optimization of particle properties of nanocrystalline solid dispersion based dry powder for inhalation of voriconazole, J. Pharmaceut. Sci. 111 (9) (2022) 2592–2605.

[53] A.D.T. Phan, O. Adiamo, S. Akter, M.E. Netzel, D. Cozzolino, Y. Sultanbawa, Effects of drying methods and maltodextrin on vitamin C and quality of *Terminalia ferdinandiana* fruit powder, an emerging Australian functional food ingredient, J. Sci. Food Agric. 101 (12) (2021) 5132–5141.

[54] O. López-Fernández, B.M. Bohrer, P.E. Munekata, R. Domínguez, M. Pateiro, J.M. Lorenzo, Improving oxidative stability of foods with apple-derived polyphenols, Compr. Rev. Food Sci. Food Saf. 21 (1) (2022) 296–320.

[55] U.S. Speth, D. König, S. Burg, M. Gosau, R.E. Friedrich, Evaluation of the sense of taste and smell in patients with Neurofibromatosis Type 1, Journal of Stomatology, Oral and Maxillofacial Surgery 124 (1) (2023) 101271.

[56] S. Soares, A. Sousa, N. Mateus, V. De-Freitas, Effect of condensed tannins addition on the astringency of red wines, Chem. Senses 37 (2012) (2012) 191–198.

[57] Y. Soleimanian, I. Sanou, S.L. Turgeon, D. Canizares, S. Khalloufi, Natural plant fibers obtained from agricultural residue used as an ingredient in food matrixes or packaging materials: a review, Compr. Rev. Food Sci. Food Saf. 21 (1) (2022) 371–415.

[58] A.M. Hajmohammadi, M. Pirouzifard, M. Shahedi, M. Alizadeh, Enrichment of a fruit-based beverage in dietary fiber using basil seed: effect of Carboxymethyl cellulose and Gum Tragacanth on stability, LWT (Lebensm.-Wiss. & Technol.) 74 (2016) 84–91.

[59] C.R. Spehar, R.L.B. Santos, Quinoa BRS Piabiru: alternativa para diversificar os sistemas de produção de grãos, Pesqui. Agropecuária Bras. 37 (2002) 889–893.

[60] Y. Suhag, G.A. Nayik, I.K. Karabagias, V. Nanda, Development and characterization of a nutritionally rich spray-dried honey powder, Foods 10 (2021) (2021) 162.

[61] C.K.D. Wellala, J. Bi, X. Liu, J. Liu, J. Lyu, M. Zhou, K. Marszałek, U. Trych, Effect of high-pressure homogenization combined with juice ratio on water-soluble pectin characteristics, functional properties and bioactive compounds in mixed juices, Innovat. Food Sci. Emerg. Technol. 60 (2020), 102279.