Journal of Engineering Science and Technology
Vol. 18, No. 1 (2023) 112 - 135

OPTIMISATION OF SPRAY DRYING OPERATING CONDITIONS OF TOMATO SLURRY USING RESPONSE SURFACE METHODOLOGY

S. M. ANISUZZAMAN[1,2,*],
COLLIN G. JOSEPH[3], OLIVIA MAYANG ENDU[2]

[1]Energy Research Unit (ERU), Universiti Malaysia Sabah,
88400 Kota Kinabalu, Sabah, Malaysia
2Chemical Engineering Programme, Faculty of Engineering,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
3Industrial Chemistry Programme, Faculty of Science and Natural Resources,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
*Corresponding Author: anis_zaman@ums.edu.my

Abstract

Tomato fruits and tomato-based products are one of the most consumed foods globally due to its high nutritional value. However tropical temperature is not conducive for the cultivation of tomatoes which leads to post harvest losses. The development of spray-dried tomato powder is therefore crucial to extend the value and usability of these perishable produces. The main objective of this study is to determine the optimum condition for spray drying in order to obtain spray-dried tomato powders with the highest product yield, lowest moisture content, and the best retention of red-orange colour content. This study presents the effectiveness of spray drying of different fruit juices, the effect of selected spray drying parameters on the tomato powder production and its optimisation. The studied factors were the inlet air temperature (ºC), the concentration of different carrier agents (%, w/w), and the feed flow rate (g/min). Meanwhile the response variables were the moisture content, product yield, and the red-orange colour retention of tomato powder. Suitable articles related to the spray-dried fruit powders and tomato powders were taken for analysis and comparison. Based on the analysed trend, it was observed that the most significant factors were the inlet air temperature (ºC), and the concentration of carrier agents, whilst feed flow rate showed less significant effects on the spray-dried tomato slurry. On the other hand, response surface methodology (RSM) was applied to show the interaction of multiple factors and to conduct an optimisation study for the spray drying condition for tomato powder. The optimum value of inlet air temperature and the concentration of carrier agents for spray-dried tomato pomace powders were found to be 123.20°C and 9.40% w/w with the addition of gum Arabic (GA), 180.44°C and 16.42% w/w with the addition of inulin, respectively. Meanwhile, the optimal value of inlet air temperature, feed flow rate, and atomization speed for the spray-dried tomato pulp powder was found to be 220°C, 276 g/min, and 25000 rpm, respectively.

Keywords: Carrier agents, Gum Arabic, Inulin, Maltodextrin, Optimization, Response surface methodology, Spray drying.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is cultivated around the world in subtropical and temperate regions [1]. It is one of the most globally-consumed vegetables as it is a key component of the Mediterranean diet [2]. The significance of nutrition in tomatoes is clearly illustrated by their numerous compounds that promote health, in which vitamins, bioactive substances, carotenoids, and phenolic compounds are detected [3-6]. In addition, processed tomatoes such as soup, paste, concentrate, juice, and ketchup are also prepared for the global and local market [7]. There is also potential for instant tomato powder to be used as a natural additive in cooking, meat industry, and other products.

According to Swetha and Banothu [8], high quality tomatoes have a firm, uniform and shiny colour with a good appearance, and the absence of any bruises. However, due to a short shelf-life, tomato fruit is highly perishable and subjected to the natural physiological process, incidence, and severity of external injury during the process of harvesting, handling and storing, which includes the risk of microbiological and parasitic diseases [8, 9].

On the other hand, tomato is limited by post-harvest losses, which constrains the volumes of good quality product reaching consumers, despite its nutritional, economic and health importance [10]. The main reason for postharvest losses was due to the limited shelf life of this tropical produce. An alternative to overcome these shortcomings is to explore the viability of preparing tomato powder using spray-drying techniques.

The drying process is one of the conventional methods that have been improved over time for the convenience of the food industry. The most fundamental drying methods include solar drying, convective drying, spray drying, lyophilization, infrared, microwave, radiofrequency drying, osmotic dehydration, and as well as reaction engineering approach (REA) [11-16]. A frequently used process for converting powder from liquid state phase is spray drying [17-22]. To break the substance into smaller droplets in the range of 10-200 μm, it is required for solutions or slurries to pass through a spray or atomizer. The factors that influence the consistency of spray-dried microcapsules are the processing index of the spray drier and the properties or constitution of the feed solution [16]. The most popular microencapsulation process is the spray drying technique, which proved to be an efficient technology for preserving bioactive compounds and probiotics [23].

Medina-Torres et al. [24] noted that with this technique, water suspensions are normally converted into powdered microparticles consisting of a wall material known as 'shell' and a core material known as 'encapsulated material'. However, sensitive compounds such as lycopene, β-carotene, anthocyanins, vitamin C, colours, and flavours are influenced by the high temperature used during the drying process [25, 26].

During the drying of tomato powder, it is reported that the powder recovery in spray drying of fruit and vegetables is challenging because of the presence of sugars of low molecular weight, such as glucose and fructose [27]. In fact, these low molecular weight sugars are high in hygroscopicity, thermoplasticity, and contain low glass transition temperature (T_g) which causes the powders to become sticky inside the drying chamber. Stickiness is therefore the key challenge of higher fruit and vegetable powder production. Therefore, several steps have been taken to solve this concern, such as introducing high molecular weight of carrier agents to improve the temperature of the feed mixture's T_g, using low humidness and temperature drying conditions, and changing the properties surfaces of atomized droplets by adding proteins such as whey, casein and soy protein [28]. On the other hand, the resulting spray-dried juice powders could lose their original colour due to the high concentration of carrier agents and high drying temperature.

Therefore, the aim of this study was to investigate the effect of carrier agent's concentration used in the production of tomato powders and to identify the optimal processing parameters of spray drying in order to create a microencapsulated powder of tomato slurry with the highest product yield, the lower moisture content, and the best red-orange colour retention. This study estimated the range of drying temperature and feed flow rate that will be suitable to produce tomato powders. Besides, this study also demonstrated the best concentration of carrier agents and the commonly used type of carrier agents to produce good quality tomato powders. The desired characteristics of tomato powders which can be manipulated by adjusting the spray drying conditions were also presented in this study.

2. Methodology

The experimental data of the spray-dried tomato powders and other fruits powder were compiled from past researchers [29, 30]. The obtained properties of spray-dried powders were recorded in the form of numerical data consisting of the inlet air temperature, type of carrier agent, concentration of carrier agent, and feed flow rate. The compiled numerical data of factors were shown in the form of coded values (+1), (0), and (-1) for clear classification of maximum and minimum value. Graphical data was also included to show the relationship between the spray drying conditions and the properties of tomato powders produced. The graphical data in the form of contour plot, three-dimensional plot, or linear plot was mostly re-run based on the experimental data obtained from literature and analysed using the design software 8.0.6 by applying the response surface methodology (RSM) for the extracted data.

Optimisation of spray drying condition

To apply the optimisation of spray drying by using RSM, two articles related to spray-dried tomato powders were chosen for data extraction [29, 30]. The experimental data obtained by the authors were used for RSM optimisation. Table 1 and Table 2 show the ranges of the process variables and their coded levels for the experimental design for tomato pomace powder [29] and tomato pulp powder [30], respectively.

Table 1. Experimental conditions for the experimental design of tomato pomace powder.

Level	-1	0	+1
X_1 (°C)	110.00	155.00	200.00
X_2 (%, w/w)	5.00	20.00	35.00
X_3 (g/min)	127.00	201.50	276.00

where X_1 = inlet air temperature (°C); X_2 = concentration of different carrier agents (%,w/w); and X_3 = feed flow rate (g/min).

Table 2. Experimental conditions for the experimental design of tomato pulp powder.

Level	-1	0	+1
$\boldsymbol{X_1}$ (°C)	200.00	210.00	220.00
$\boldsymbol{X_3}$(g/min)	127.00	201.50	276.00
$\boldsymbol{X_4}$ (rpm)	25000.00	30000.00	35000.00

where X_1 = inlet air temperature (°C); X_3 = feed flow rate (g/min); and X_4= atomisation speed (rpm).

The data obtained from the past researchers were rerun by using the Box-Behken and D-optimal depending on the number of factors to be studied. The order of the experiments was fully randomised. The experimental data were analysed by multiple regressions using the least-squares method. Hence, second order polynomial equation was used to demonstrate the variables' responses as a function of the independent variables.

$$Y_k = \beta_{k0} + \sum_{i=j}^{n} \beta_{ki} X_i + \sum_{i=j}^{n-1} \sum_{j=i+1}^{n} \beta_{kij} X_i X_j + \sum_{i=1}^{n} \beta_{kii} X_i^2 \qquad (1)$$

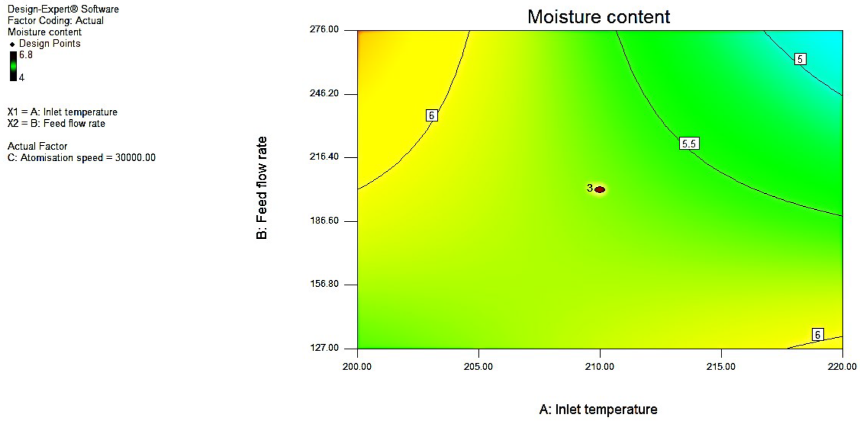
where Y_k is the response variables; β_{k0} , β_{kii} , and β_{kij} are the regression coefficients for the linear terms, quadratic terms, and two-factorial interaction terms, respectively.

The test of statistical significance was performed on the total error criteria by using a confidence level of 95%. The significance terms in the model were analysed by using the analysis of variance (ANOVA) for each response variable. Then, the adequacy of the model was measured by calculating the R^2 and adjusted-R^2. Meanwhile, the optimisation of spray drying conditions was conducted by setting the desired goals for both independent and response variables. Then, the designed variables with the highest desirability were chosen as the optimum condition for the spray drying condition of tomato slurry. The response variables were either minimised or maximised, while the independent variables were kept within range.

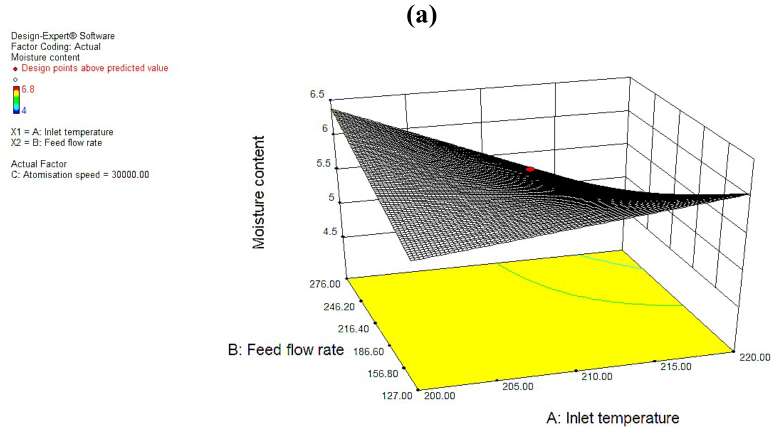
3. Results and Discussion

3.1. Effect of inlet temperature on moisture content

In this study, the experimental data was obtained from Sousa et al. [30] to study the effect of inlet air temperature on the moisture content of spray-dried tomato powder. Figure 1 shows the effect of inlet temperature and feeds flow rate on the moisture content. In Fig. 1(a), the blue-turquoise zone indicated the lowest value of moisture content, and the yellow-orange zone indicated the highest value of moisture content, whilst the green zone indicated the median value of moisture content. From Fig. 1, it was shown that the moisture content decreased with the highest value of inlet air temperature at a high feed flow rate but also increased with the highest value of inlet air temperature at a low feed flow rate. However, Sousa et al. [30] stated the moisture content reduced with the increase in inlet air temperature and decrease in feed flow rate due to the higher drying rate. High inlet temperature reduced moisture content because the drying rate increased [21]. According to Zanoni et al. [31], a temperature rise increases the heat diffusion into the droplets. Consequently, the shrinkage of the powder also increases and leads to the reduction of diffusion. According to Goula et al. [21], the rate of heat transfer into the particles will be greater when the temperature difference between the drying medium and the particles is greater as it provides the driving force for the removal of moisture from the particle.



(a)



(b)

Data adapted from: Sousa et al. [30]

Fig. 1. Effect of inlet temperature and feed flow rate on the moisture content (a) Contour plot of moisture content surface design (b) Three-dimensional surface plot of moisture content.

Meanwhile, Pui et al. [17] in their study of spray-dried cempedak (*Artocarpus integer*) fruit powder also observed the same trend of analysis with the study of spray-dried tomato powder. The researchers found that the inlet air temperature influenced more significantly on the moisture content compared to maltodextrin (MD) concentration. They also stated that the higher rate of heat transfers to particles had provided a better driving force for moisture removal resulting in the production of powders with less moisture content.

3.2. Effect of carrier agents on moisture content

The data of the effect of MD and gum Arabic (GA) on the moisture content of spray-dried powder was taken from the study of spray-dried acai (*Euterpe oleracea mart*) powder. Based on the experimental data from Tonon et al. [32], it was demonstrated that both of the carrier agents had efficiently reduced the moisture content of the powder because the moisture content was in the desirable range of 3 to 5%, but the most significant reduction was shown by MD and GA with a higher dextrose equivalent (DE). The researchers mentioned that MD with a lower DE had a great binding property compared to MD with higher DE which led to greater moisture retention. This finding was also supported by Bicudo et al. [33] who reported that moisture content of the jucara (*Euterpe edulis* M.*)* pulp powder produced with MD was significantly higher than that produced with GA and gelatin because it was difficult for water molecules to diffuse through the larger MD molecules during the spray-dring process [21, 33].

On the other hand, these findings were in contradiction with a study by Du et al. [34] who stated that MD was better in reducing the moisture content compared to GA as GA is a complex heteropolysaccharide with a highly ramified structure, containing shorter chains and more hydrophilic groups compared to MD. However, although GA is a polysaccharide that is highly hydrophilic but the GA is also consisting of amino acids at the peripheral of the branched structure. Hence, its functionality in reducing the moisture content may be determined by proteoglycans rather than that of pure polysaccharides [33]. Therefore, it can be concluded that GA is better in reducing the moisture content of spray-dried powders compared to MD.

A different trend of analysis was studied by Goula et al. [21] in regards to the different DE MD as it was observed that higher DE MD reduced the drying rate of the tomato powder. It is stated that the high-DE MD takes a longer time to develop stickiness and reach a state of non-adhesion slower than low-DE MD, hence the sticky phase lasted longer than that of low-DE MD. Stickiness resulted in an agglomeration of powder which then led to the reduction of surface area and thereby provided small surface contact with the heating medium and small surface for moisture to escape. Therefore, according to Goula et al. [21], low-DE MD was better in spray drying of tomato slurry.

Fazaeli et al. [35] also found the same trend of analysis in the spray drying of black mulberry juice powder in which they found that high-DE MD caused an increase in powder moisture content which was attributed to the lower molecular weight of MD with high-DE and therefore contain shorter chains and more hydrophilic. On the other hand, Goula et al. [21] also found that the increase in MD concentration increased the moisture content because it became difficult for the water molecules to diffuse past the larger MD molecules as mentioned previously.

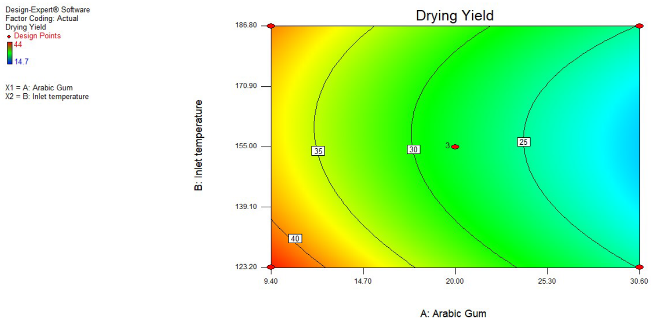
However, the result was in contradiction with the spray drying of watermelon powder by Quek et al. [36] in which the increase of the concentration of MD decreases the moisture content of the watermelon powder. The difference in the study might be attributed to the lower temperatures used during the drying process in the drying chamber as Goula et al. [21] used the dehumidified air as the drying medium. When the drying temperature is lower than the T_g of the feed, then stickiness will occur due to agglomeration caused by high moisture content [37]. Meanwhile, Fazaeli et al. [35] investigating the spray drying of fruit powder had also reported that the increased concentration of low-DE MD and GA reduced the moisture content of the spray-dried black mulberry juice powder significantly [38-41]. Hence, it is expected that the increase in both the MD and GA with lower DE will reduce the moisture content of the tomato powder.

3.3. Effect of feed flow rate on moisture content

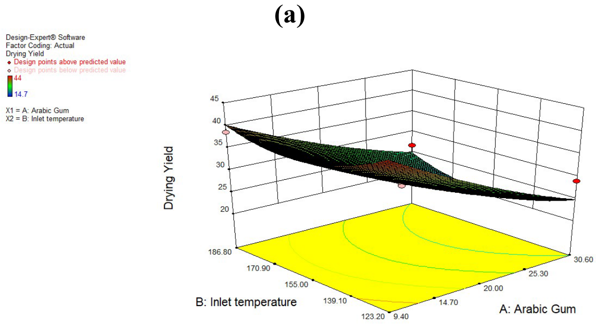
By referring to Fig. 1, it was observed that the moisture content of tomato powder was reduced with the decrease in feed flow rate. According to Sousa et al. [30], the reduction in moisture content was attributed to the decreased amount of water introduced to the drier when the feed flow rate was low and which increased the drying rate of the tomato pulp. The same pattern of analysis of spray-dried tomato powder was also observed by Goula et al. [21] in which a low drying feed flow rate had caused the product sojourn time or the time in the drying chamber to increase. Hence, it improved the circulation effects and led to the reduction of moisture content [42, 43]. Therefore, it can be concluded that a low feed flow rate was better in reducing the moisture content of spray-dried tomato powder.

3.4. Effect of inlet temperature on product yield

Figure 2 shows the effect of inlet temperature and GA on the moisture content. This was done based on the experimental results obtained from Corrêa-Filhoet al. [29]. There were two forms of data included such as the contour plot and the three-dimensional surface plot to demonstrate a clear trend of results. It was noticed that the inlet air temperature had increased the drying yield constantly while the low concentration of GA had increased the drying yield significantly. Similarly, the blue-turquoise zone indicated the lowest value of drying yield, the orange-yellow zone indicated the highest value of drying yield, and the green zone indicated the median value of the obtained drying yield.



(a)



(b)

Data adapted from: Corrêa-Filhoet al. [29].

Fig. 2. Effect of inlet temperature and GA on the product yield (a) Contour plot of drying yield surface design (b) Three-dimensional surface plot of product yield

3.5. Effect of carrier agents on product yield

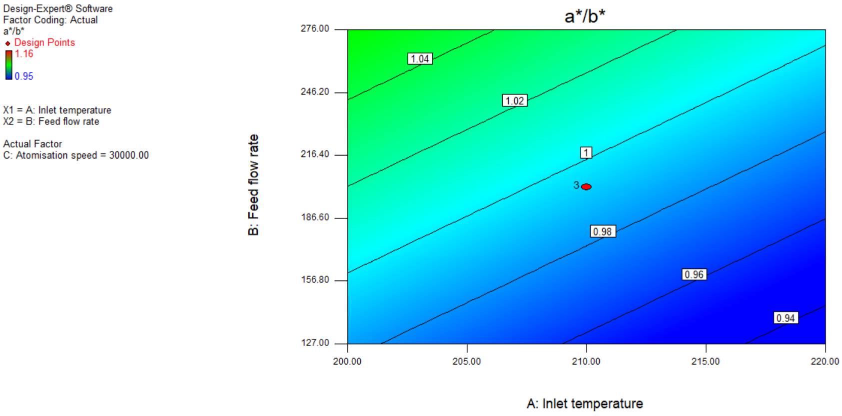
Based on the experimental data adapted from Corrêa-Filhoet al. [29], the highest drying yield of tomato pomace extracted with GA was found to be slightly lower than inulin as a carrier agent which was 44.0% and 49.5%, respectively. However, the highest yield was obtained by GA at the concentration of 9% indicated the high efficiency of GA as the carrier agent compared to inulin at the concentration of 22%. The losses in the recovery of the powders in the spray drying process may be due to the deposition of the powder on the wall of the drying chamber or cyclone [29]. Meanwhile, Souza et al. [45] found that the addition of MD was highly efficient in reducing the moisture content of the tomato concentrate. Therefore, the degree of the stickiness of the tomato concentrate can be efficiently reduced with the addition of MD and thereby can increase the production yield [17, 35, 40]. Pui et al. [17] had stated that a film around the solids in the feed was formed when the spray-dryer feed was added with MD, which in turn produces a flour-like powder that was non-hygroscopic and free-flowing. The same researcher reported that the linear effects of MD concentration were significant on process yield along with the inlet temperature ($p \leq 0.05$). Therefore, it is expected that the addition of MD will also aid in increasing the tomato powder yield with the increase in MD concentration. In general, both MD and GA can be used to spray dry tomato powder efficiently. However, in a study by Yousefi et al. [47], the drying yield was observed to increase more with the addition of GA compared to MD. It was because the waxy starch of MD caused the powders to have a crystalline configuration and hence the deposition on the wall increased, creating a lower dryer yield. Comparing the efficiency of five different carrier agents on the spray-dried persimmon pulp powders also found the same pattern of result in which product yield increased more with GA compared to MD [34]. The researcher stated that it was because of the higher T_g of GA as their molecules are larger than the MD. Unfortunately, there is no direct study on the effect of MD and GA on the spray-dried tomato powder available in literatures. Hence, by considering the experimental data obtained by Du et al. [34] and Yousefi et al. [47], it can be concluded that GA is better in producing a higher yield of tomato powder compared to MD.

3.6. Effect of feed flow rate on product yield

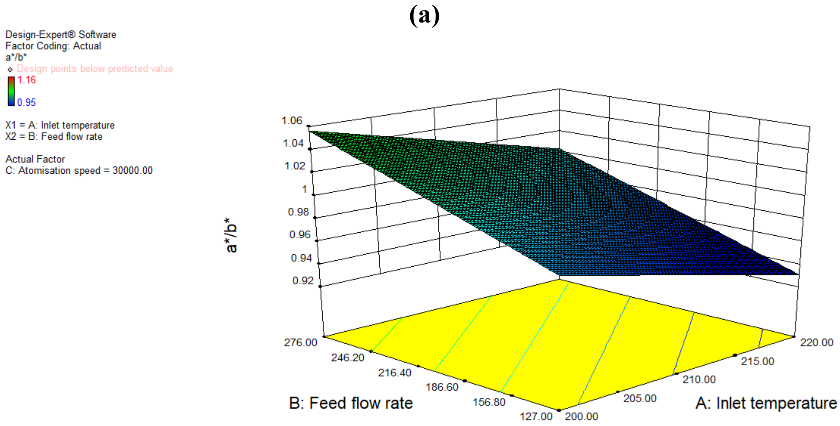
It was found that a lower feed flow rate helped to reduce the moisture content of tomato powders more efficiently. Hence, it is expected that the lower feed flow rates the higher is the drying yield of tomato powders in this study because the correlation of drying yield is directly proportional to the moisture content [42,43]. According to Bazaria and Kumar [43], the feed flow rate had affected the powder yield negatively which was attributed to the slow heat and mass transfer rate. Hence, it can be concluded that a low feed flow rate will help in maximising the powder recovery.

3.7. Effect of inlet air temperature on colour retention

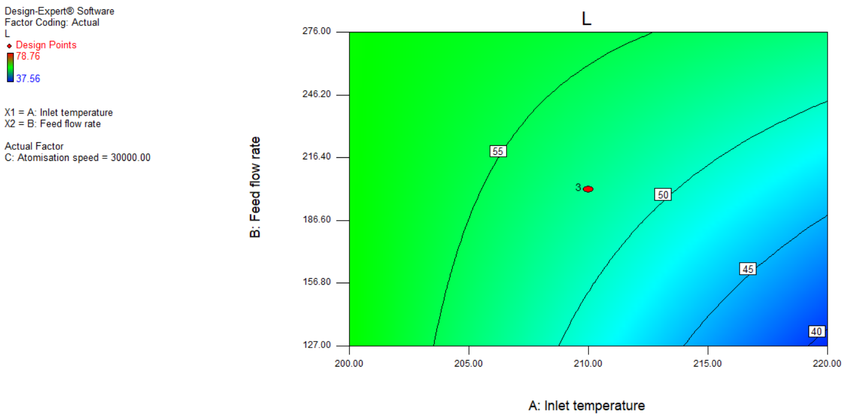
Figure 3 shows the effect of inlet temperature and feed flow rate on the colour retention**.** The blue-turquoise zone indicates the lowest value of hue angle, the orange-yellow zone indicates the highest value of hue angle, and the green zone indicates the median value of the obtained hue angle. As Fig. 3 shows, the hue angle increased with the decreased inlet temperature and increased feed flow rate. It was desirable for the hue angle to increase as the lightness value decreased when the hue angle increased. Meanwhile, the lightness value decreased when the inlet temperature increased, and no significant effect was shown by the feed flow rate as the lightness value stayed constantly in the green zone. Therefore, it can be concluded that high inlet temperature increased the hue angle and decreased the lightness value while feed flow rate had no significant effect on the colour retention.



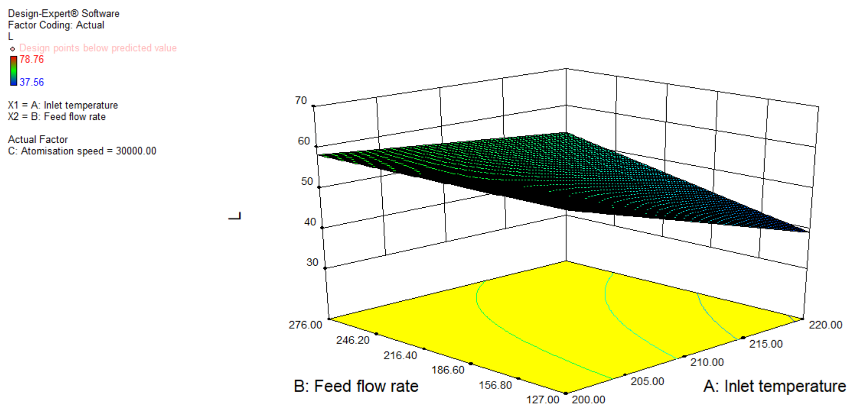
(a)



(b)



(c)



(d)

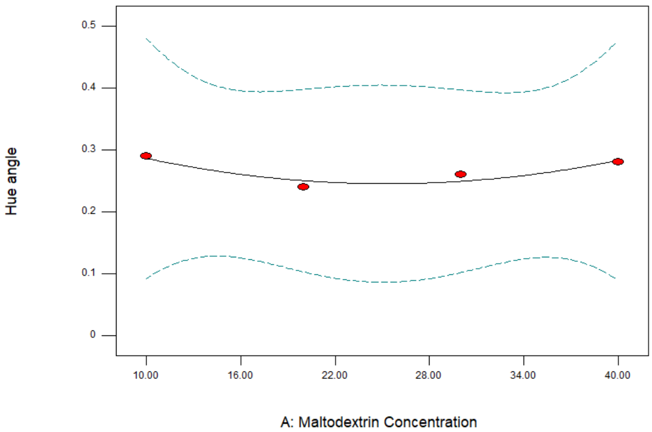
Data adapted from: Sousa et al. [30]

Fig. 3. Effect of inlet temperature and feed flow rate on the colour retention (a) Contour plot of hue angle surface design (b) Three-dimensional surface plot of hue angle (c) Contour plot of lightness value surface design (d) Three-dimensional surface plot lightness value.

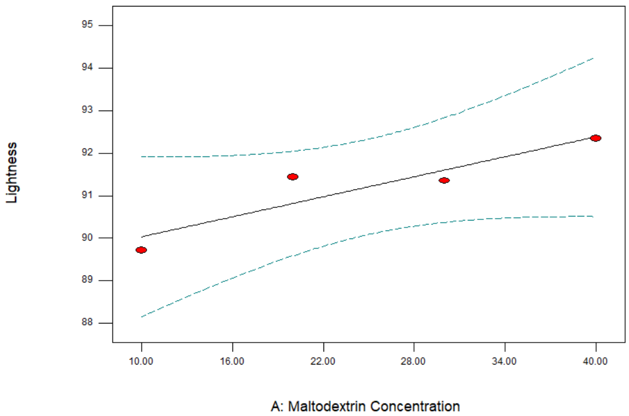
Quek et al. [36] observed the same pattern of result in which an increase in inlet temperature had caused the lightness of the powder to decrease. It can be attributed to the fact that the colour of the powders was darkened when the inlet temperature was high. Furthermore, it was found that the hue angles increased along with the increase in the inlet air temperature but suddenly decreased when the inlet air temperature was in the highest value. The degradation of red colour was mainly due to the destruction of lycopene and β-carotene at higher temperatures [36]. Tomato is similar to watermelon in which red-orange colour is contributed by the high content of lycopene and β-carotene. Therefore, the characteristic of the red colour in spray-dried watermelon powder is identical to the spray-dried tomato powders. On the other hand, several researchers also found a decrease in powder lightness due to the high temperature [40, 42, 46].

3.8. Effect of carrier agents on colour retention

There is no data available to study the effect of MD and GA with different DE on the colour changes of tomato powder. Therefore, a study by Chang et al. [40] on the spray drying of enzyme-liquefied papaya (*Carica papaya* L.) was used for review since papaya also contains a high amount of carotenoid. The study on the spray drying of papaya powder was taken as both tomato fruits and papaya fruits have strong colour pigment concentrations like red-orange and orange-yellowish colour respectively. In addition, the effect of feed flow rate showed the same pattern of results on the spray drying of fruits powders as a higher feed flow rate increased the volume of the feed and decreased the surface area exposed to heat, thus, decreasing the tendency for the colour pigment to become lighter. Moreover, papaya fruits also contain a high concentration of lycopene that gives orange-yellow pigmentation to papaya fruit and red-orange colour to tomato fruits. It was observed from Figs. 4 (a) and (b) that the increase in MD had caused the colour retention of the reconstituted powders to decrease. Movahhed and Mohebbi, [42] stated that the loss of colour pigment in fruit powders was mainly attributed to the increase in capsulation of particles in which the pigments are covered by the carrier agent. Meanwhile, Yousefi et al. [47] stated that the total colour difference of pomegranate (*Punica granatum* L.) powder decreased as the concentration of the main carrier increased but the range of concentration was between 8 to 12% which was not too high. It showed the efficiency of carrier agents in the preservation of colour when used in optimum value. The colouring agent in the pomegranate may be absorbed by the carrier agent and hence was protected from severe drying exposure during the formation of particles in the drying chamber [47].



(a)



(b)

Data adapted from: Chang et al. [40]

Fig. 4. Effect of MD concentration on (a) the hue angle (b) the lightness value.

Meanwhile, Du et al. [34] mentioned that changes in colour lightness can be due to the sensitive colour pigment retention ability of different carriers during drying and the colour-diluting effect of the carriers. Similar to tomato fruits, fresh persimmon fruits also have a favourable orange-red colour due to the high concentration of carotenoids. It was found that the addition of GA increased the lightness of persimmon powder more than MD. It was because MD retained polyphenol better than GA [33]. This finding is also supported by Yousefi et al. [47] in which the addition of GA showed the highest value of total colour difference. Besides, it might also have related to the morphology of the powders produced [34]. Meanwhile, MD with a high-DE increased the agglomeration of the powder during the drying and therefore the surface area was not exposed too much to the oxygen and heating medium, leading to lower thermal degradation and oxidation which can affect the colour pigment [47].

3.9. Effect of feed flow rate on colour retention

Sousa et al. [30] stated that the feed flow rate affected less significantly the colour properties. Another study in spray-dried fruit powders also stated that the feed flow rate showed no significant effect on the powder colour of spray-dried beetroot juice [43]. It was concluded based on the good fit of the experimental data (R^2 and R^2_{Adj}) analysed from the experiment. It was observed that the decrease in the feed flow rate tends to increase the powder lightness which indicated that a low feed flow rate leads to weak colour retention [30]. This finding was supported by Movahhed and Mohebbi, [42] in which the lightness of powder tended to reduce with the increase of feed flow rate. It was highly related to the increase of size particle due to the high feed flow rate in which volume to surface ratio increased and protected the colour pigment. This statement was also supported by Souza et al. [48] in which a low feed flow rate had reduced the particle size.

3.10. Optimisation of spray drying condition of tomato pomace powder

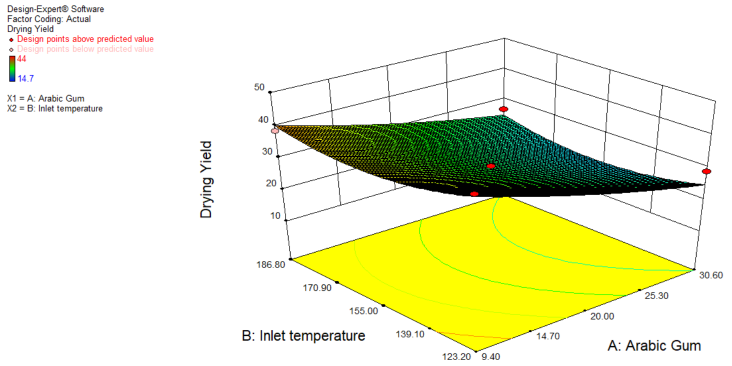
From the experimental data adapted from Corrêa-Filhoet al. [29], the studied factors mentioned was the inlet air temperature, X_1 (°C) and the concentration of a different type of carrier agents, GA X_{2GA} (% w/w), Inulin X_{2INU} (% w/w). Inulin is a protein derivatives carrier agent. In this section, inulin was mentioned instead of MD because the optimisation was conducted based on two studies which were the spray drying of tomato powder and the spray drying tomato pulp powder in which the spray drying of tomato powder did not study the properties of MD as carrier agent whilst the spray drying of tomato pulp powder did not study on carrier agents. Meanwhile, the responding variable was the product yield, (%). For the experimental design, there were a total of 11 runs designed by the RSM model in which; the highest level and the lowest level for the GA concentration was 30.6% (+1) and 9.4% (-1) respectively; the highest level and the lowest level for the inulin concentration was 22.1% (+1) and 7.9% (-1) respectively; the highest level and the lowest level for inlet temperature was 186.8°C (+1) and 123.2°C (-1) respectively.

From the analysed data, the final fitted equation of quadratic model for the product yield with the addition of GA and inulin shown in Table 3.

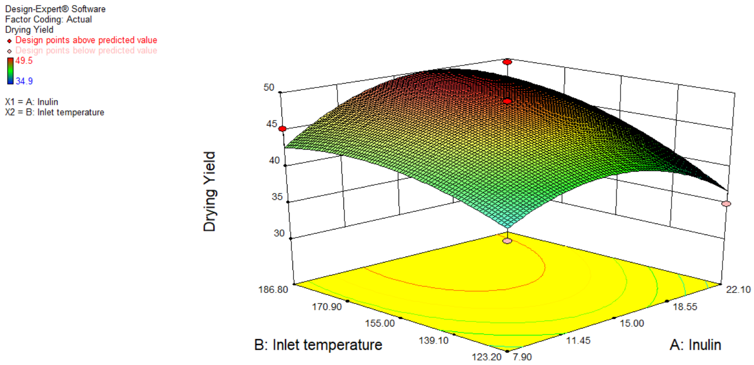
Table 3. Regression coefficients of second-order polynomial equations for each carrier agents.

Carrier agent	Equation	R^2	R^2_{Adj}
GA	$Drying\ yield = +158.78913 - 1.56470X_{2GA} - 1.35931X_1 + 2.29916E - 003X_{2GA}X_1$ $4.15869E - 003X_1^2$ (2)	0.9333	0.8665
Inulin	$Drying\ yield = -25.95988 + 1.68168X_{2INU} + 0.67662X_1 + 7.64018E - 003X_{2INU}X_1$ $2.19265E - 003X_1^2$ (3)	0.8716	0.7433

A good fit to the data was indicated by high values of R^2 and R^2_{Adj}. Hence, the model designed by the RSM was adequate to study the effect of inlet air temperature and carrier agent on the drying yield of spray-dried tomato pomace. Figure 5 shows that the drying yield was most affected by the inlet air temperature and the carrier agents. The figures indicate that the drying yield increased by increasing the inlet air temperature and decreasing the carrier agent concentration.



(a)



(b)

Data adapted from: Corrêa-Filho et al. [29]

Fig. 5. Plots of the drying yield of spray-dried tomato pomace powder response surface (a) Drying yield of tomato pomace powder obtained when added with GA (b) Drying yield of tomato powder obtained when added with inulin.

3.11. Optimisation of spray drying condition with the addition of GA

The formulation of optimisation was developed based on the obtained responses. For drying yield, the obtained value was within 14.7-44%. For an efficient product yield, a drying yield of 50% and above would be better as stated by Bhandari et al. [27]. However, the authors obtained only 44% as the highest drying yield with the addition of GA. Therefore, the optimisation process took 44% as the most desirable yield in the study. Table 4 shows the criteria used in numerical optimisation. From the optimisation, the suggested spray drying condition can be seen in Table 5. It was suggested by taking the highest desirability of solutions into account. The highest desirability was found to be 97.60%.

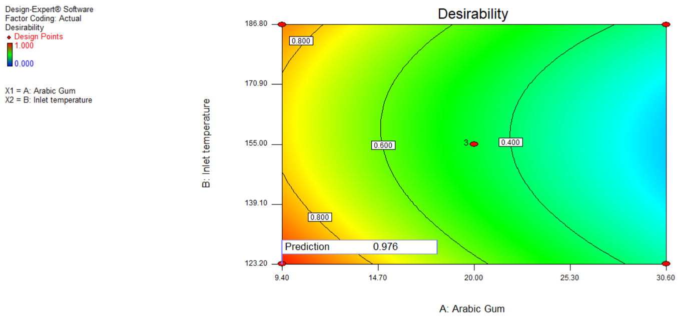
Table 4. The criteria used in numerical optimisation.

Response	Target	In range	
		Low	High
Drying yield	**Maximum**	14.7	44

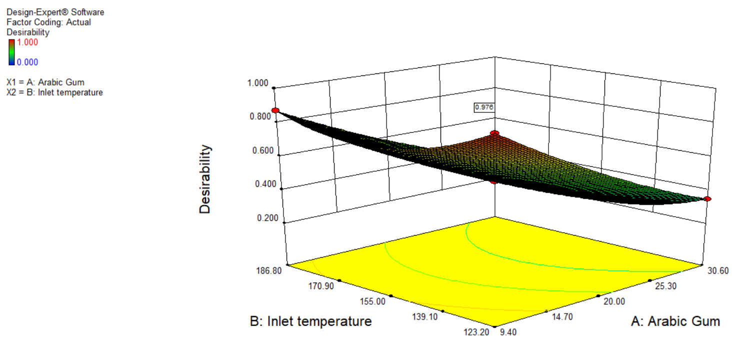
Table 5. The suggested formulation of spray dying.

Component	Suggested formulation
Inlet air temperature, ºC	123.20
GA concentration, % w/w	9.40

Figure 6 shows that the inlet temperature gave a constant effect on the drying yield, which indicated that the range of the inlet temperature chosen by the authors was adequate enough to produce powders with high productivity. Meanwhile, the optimum concentration value of GA was found to be at the minimum value, which was aligned with many studies that reported the drying yield would increase with the decrease of GA concentration.



(a)



(b)

Fig. 6. The optimisation of spray-dried tomato pomace (GA) (a) Contour plot of drying yield (b) Three-dimensional surface plot of drying yield.

3.12. Optimisation of spray drying condition with the addition of inulin

The formulation of optimisation was developed based on the obtained responses. As mentioned previously, drying yield at 50% and above was efficient. However, the authors obtained only 49.5% as the highest drying yield with the addition of inulin. Therefore, the optimisation process took 49.5% as the most desirable yield in the study.

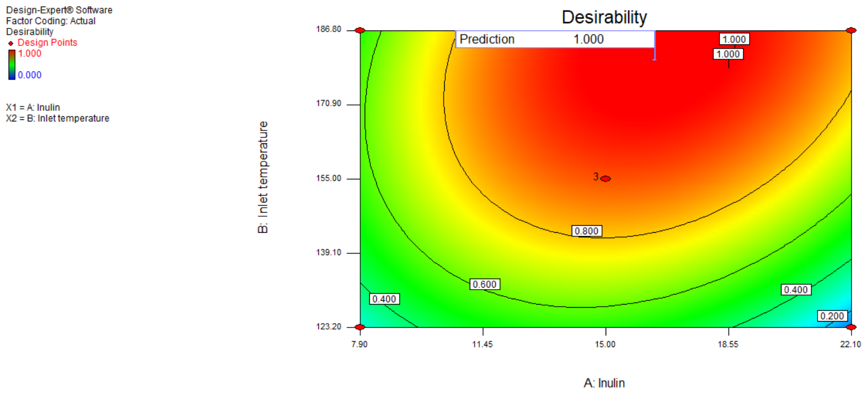
Table 6 shows the criteria used in numerical optimisation. From the optimisation, the suggested spray drying condition can be seen in Table 7. It was suggested by taking the highest desirability of solutions into account. The highest desirability was found to be 100%. Figure 7 shows the optimisation of spray-dried tomato pomace with the addition of inulin.

Table 6. The criteria used in numerical optimisation.

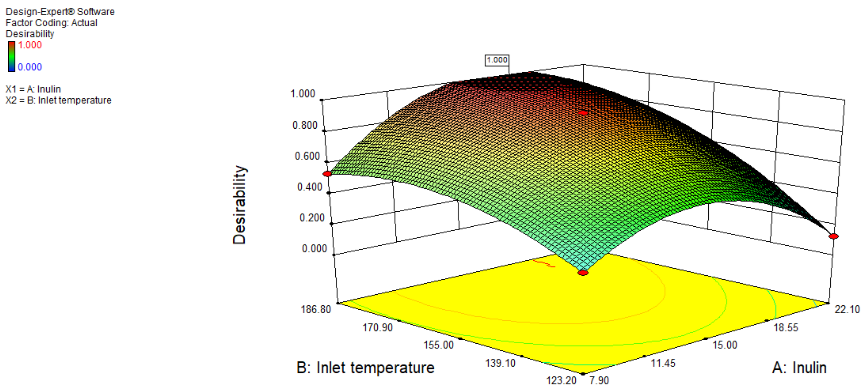
Response	Target	In range	
		Low	High
Drying yield	Maximum	34.9	49.5

Table 7. The suggested formulation of spray drying.

Component	Suggested formulation
Inlet air temperature, °C	180.44
Inulin concentration, % w/w	16.42



(a)



(b)

Fig. 7. The optimisation of spray-dried tomato pomace (inulin) (a) Contour plot of drying yield (b) Three-dimensional surface plot of drying yield.

Figure 7 shows that the inlet temperature gave a constant effect on the drying yield, which indicated that the range of the inlet temperature chosen by the authors was adequate enough to produce powders with high productivity. Meanwhile, the optimum concentration value of inulin was found to be at the median value.

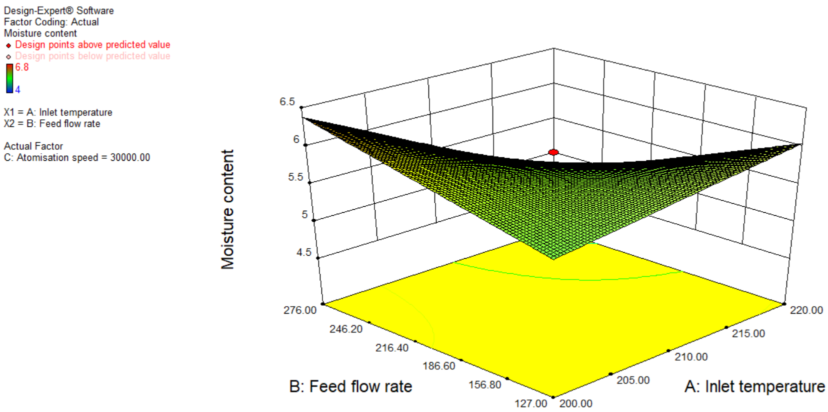
3.13. Optimisation of spray drying condition of tomato pulp powder

From the analysed data, the final fitted equation of quadratic model for the moisture content is shown in Eq. (4).

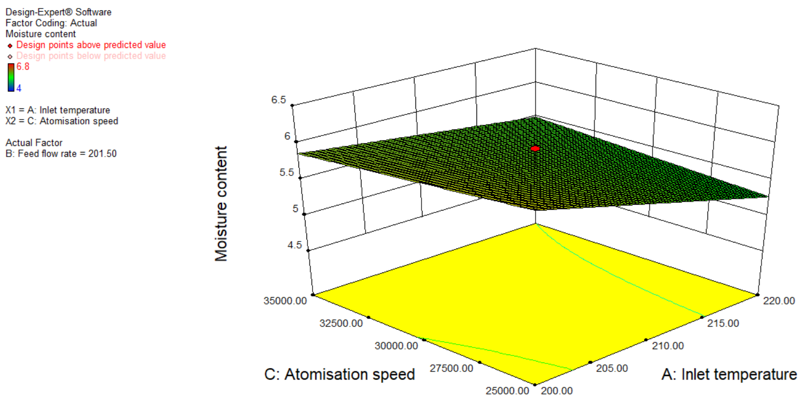
$$Moisture\ content = 1.12603 + 0.038144X_1 + 0.12981X_2 - 6.06074E - 004X_3 - 6.97987E - 004X_1X_2 + 2.40000E - 006X_1X_3 + 4.96644E - 007X_2X_3 \quad (4)$$

The R^2 and the R^2_{Adj} for the equation (4) was 0.65 and 0.12 respectively. It shows that the RSM model was not adequate enough to demonstrate the relationship between the manipulated variables and the response variables.

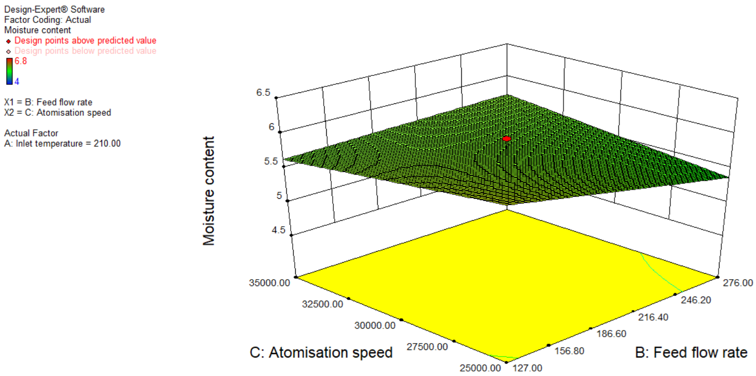
Figure 8 shows that the moisture content was most affected by the inlet air temperature, feed flow rate, and atomisation speed. In these plots, the moisture content decreased by increasing the inlet air temperature and the feed flow rate and decreasing the atomisation speed.



(a)



(b)



(c)

Data adapted from: Sousa et al. [30]

Fig. 8. Plots of the moisture content of spray-dried tomato powder response surface. (a) Moisture content of tomato powder obtained when X_4=0; (b) Moisture content of tomato powder obtained when X_3=0; (c) Moisture content of tomato powder obtained when X_1 =0.

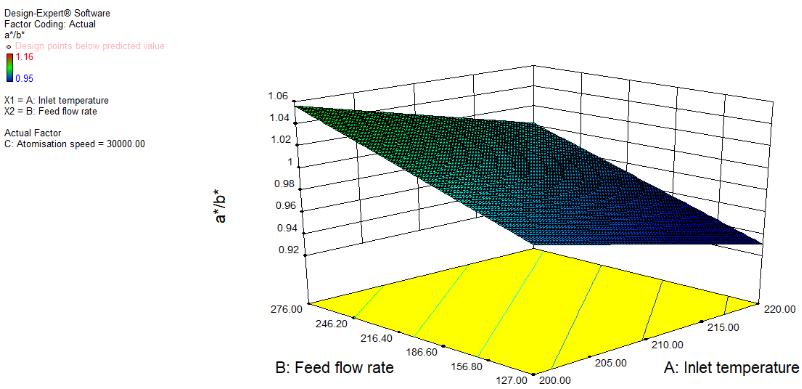
From the analysed data, the final fitted of linear model for the colour retention was

$$Hue\ angle = 1.60434 - 2.62500E - 003X_1 + 4.86577E - 004X_2 - 5.25000E - 006X_3 \quad (5)$$

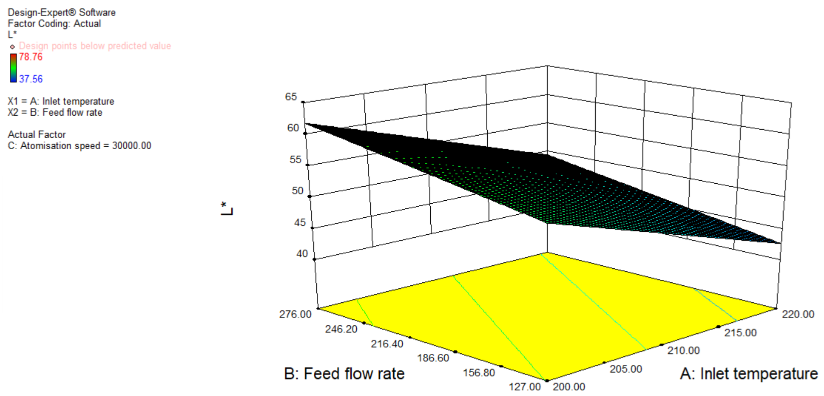
$$Lightness\ value = 206.15640 - 0.61275X_1 + 0.46376X_2 - 1.15200E - 003X_3 \quad (6)$$

The R^2 and the R^2_{Adj} for the equation (5) was 0.65 and 0.50 respectively; the equation (6) was 0.50 and 0.28 respectively. It showed that the model was not adequate enough to show the effect of manipulated variables on the response variables.

Figure 9 shows that the colour retention was most affected by the inlet air temperature, and the feed flow rate. In these plots, the hue angle decreased by decreasing the inlet air temperature and the feed flow rate. Meanwhile, the lightness value was also decreasing with the increase of inlet air temperature and the decrease of feed flow rate.



(a)



(b)

Data adapted from: Sousa et al. [24]

Fig. 9. Plots of the colour retention of spray-dried tomato powder response surface (a) Hue angle of tomato powder obtained when X_4=0; (b) Lightness value of tomato powder obtained when X_4=0.

The formulation of optimisation was developed based on the obtained responses. Table 8 shows the criteria used in numerical optimisation. From the optimisation, the suggested spray drying condition can be seen in Table 9. It was suggested by taking the highest desirability of solutions into account. The highest desirability was found to be 56.70%.

Table 8. The criteria used in numerical optimisation.

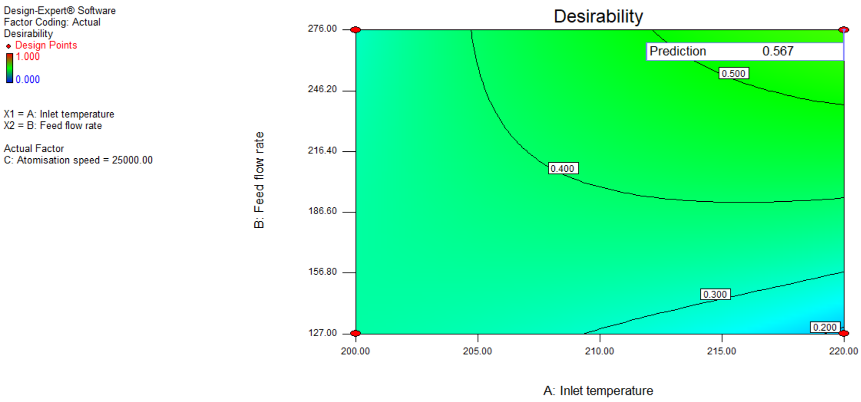
Response	Target	In range	
		Low	High
Moisture content, %	Minimum	4	6.8
Hue angle, °	Maximum	0.95	1.16
Lightness value	Minimum	37.56	78.76

Table 9. The suggested formulation of spray drying.

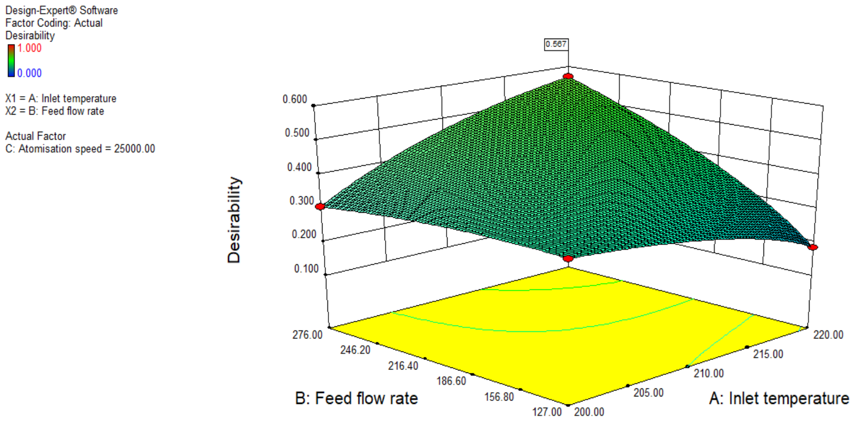
Component	Suggested formulation
Inlet air temperature, °C	220
Feed flow rate, g/min	276
Atomisation speed, rpm	25000

Figure 10 shows that a high inlet temperature was suitable to produce powders with low moisture content and high colour retention. Meanwhile, the optimum concentration value of feed flow rate was found to be at the maximum value, which was not aligned with many studies that reported the low feed flow rate was suitable to produce powders with low moisture content. However, it was in alignment with the studies that reported that a high feed flow rate would give better colour retention despite its negative effect on the moisture content.

Moisture content decreased as inlet temperature increased due to the higher drying rate. Besides, it decreased the most with the addition of low-DE MD and high concentrations of GA due to their structural properties. Next, a low feed flow rate was better in reducing the moisture content of the spray-dried powders. Therefore, it was expected that in the spray drying of tomato powders, the moisture content will decrease along with the increase in inlet temperature, and decrease in feed flow rate with low-DE MD and high concentration of GA. On the other hand, product yield increased as the inlet temperature increased because the tendency for the powders to stick on the drying chamber reduced which was attributed to the high heat and mass transfer. As mentioned previously, a low feed flow rate reduced moisture content and thereby increased the drying yield of spray-dried powders. Therefore, it was expected that in the spray drying of tomato powder, product yield will increase with the increase in inlet temperature, and decrease in feed flow rate with an efficient addition of MD and GA.



(a)



(b)

Fig. 10. The optimisation of spray-dried tomato pulp (a) Contour plot of moisture content and colour retention (b) Three-dimensional surface plot of moisture content and colour retention.

Furthermore, colour retention is highly related to lycopene retention in which degradation of colour pigment indicates the degradation of the lycopene content. It was stated in the studies that high inlet temperature and low feed flow rate had reduced the colour and lycopene retention due to the high drying rate that led to the exposure of thermal degradation and oxidation. Previously, it was reported that MD was better in retaining the lycopene content compared to the GA due to the morphology of the powders produced by using the MD. However, due to the dilution effect, it had also increased the lightness value of the spray-dried powders which had decreased when the temperature increased. Therefore, it is expected that the low heat temperature and high feed flow rate will decrease the colour retention of tomato powders along with the addition of MD.

Eventually, it was noted that an increase in both MD and GA concentration had reduced the moisture content due to the high solids ratio in the feed and increased the drying yield but at the same time decreased the nutrients contained in the spray-dried fruit powders due to the dilution effect of the carrier agents. Therefore, it is expected that a high concentration of carrier agents is good to reduce the moisture content and increase the drying yield of the spray-dried tomato powder but not the retention of the colour pigment. Considering the different effects brought by the spray drying conditions, it is important to ensure that the spray drying condition is in optimum conditions to produce powders with the best quality and high productivity. The optimisation of spray drying condition can be conducted by applying the RSM. Many researchers had applied the method in their studies, and it had helped them to design the experimental matrix which in turn reduced the time taken needed for experiments. Meanwhile, the RSM had also aided in optimising by analysing the trend of results obtained from past researchers. After setting the goal target for each response, it had provided solutions with high desirability. Hence, a solution with the highest desirability was considered as the optimum spray drying condition for tomato powder.

4. Conclusions

Moisture content reduced significantly whilst drying yield increased significantly with a high inlet air temperature and low feed flow rate with the optimal addition of MD and GA concentration. Meanwhile, red-orange colour retention of tomato powders was best obtained at a low inlet air temperature, high feed flow rate, and the optimal addition of MD and GA concentration. Furthermore, the concentration of the carrier agents should not be too high or too low as it can affect the moisture content and the nutrient content retention of the powders differently. Lastly, in terms of feed flow rate, it was expected that a low feed flow rate is beneficial to decrease the moisture content of the tomato slurry during the drying process and increase the powder recovery. However, a high feed flow rate helped to retain the colour pigment of spray-dried tomato powders. Therefore, it is important to identify the optimum condition of the spray drying process to maintain the quality of the tomatoes. The optimum value of inlet air temperature and the concentration of carrier agents for spray-dried tomato pomace powders were found to be 123.20°C and 9.40% w/w with the addition of GA, 180.44°C and 16.42% w/w with the addition of inulin, respectively. Meanwhile, the optimal value of inlet air temperature, feed flow rate, and atomization speed for the spray-dried tomato pulp powder were found to be 220°C, 276 g/min, and 25000 rpm, respectively. These optimum values were designed by the RSM model with the highest desirability to produce tomato powders with the highest drying yield, and the lowest moisture content along with the best red-orange colour retention.

Acknowledgments

The authors would like to acknowledge the financial support given by the Centre for Research Management of Universiti Malaysia Sabah (UMS), under the SDN Grant Scheme, with code DN21100- Phase 1/2021 to undertake this project.

References

1. Blanca, J.; Cañizares, J.; Cordero, L.; Pascual, L.; Diez, M.J.; and Nuez, F. (2012). Variation revealed by SNP genotyping and morphology provides insight into the origin of the tomato. *PloS ONE*, 7(10), 1-17.
2. Patil, V.; Chauhan, A.K.; and Singh, R.P. (2014). Optimization of the spray-drying process for developing guava powder using response surface methodology. *Powder Technology*, 253, 230-236.
3. Li, T.; Yang, X.; Yu, Y.; Si, X.; Zhai, X.; Zhang, H.; Dong, W.; Gao, C.; and Xu, C. (2018). Domestication of wild tomato is accelerated by genome editing. *Nature Biotechnology*, 36, 1160-1163.
4. Raiola, A.; Rigano, M.M.; Calafiore, R.; Frusciante, L.; and Barone, A. (2014). Enhancing the health-promoting effects of tomato fruit for biofortified food. *Mediators of Inflmmation,* 2014, 1-16.
5. Viuda-Martos, M.; Sanchez-Zapata, E.; Sayas-Barberá, E.; Sendra, E.; Pérez-Álvarez, J.A.; and Fernández-López, J. (2014). Tomato and tomato byproducts. Human health benefits of lycopene and its application to meat products: a review. *Critical Reviews in Food Science and Nutrition*, 54(8), 1032-1049.
6. Martínez-Huélamo, M.; Vallverdú-Queralt, A.; Lecce, G.D.; Valderas-Martínez, P.; Tulipani, S.; Jáuregui, O., Escribano-Ferrer, E.; Estruch, R; Illan, M.; and Lamuela-Raventós, R.M. (2016). Bioavailability of tomato polyphenols is enhanced by processing and fat addition: Evidence from a randomized feeding trial. *Molecular Nutrition & Food Research*, 60(7), 1578-1589.
7. Gutierrez, V.E.E. (2018). *An overview of recent studies of tomato (Solanum lycopersium spp) from a social, biochemical and genetic perpective on quality parameters.* Introductory Paper, Faculty of Landscape Architecture, Horticulture and Crop Production Science, Swedish University of Agricultural Sciences.
8. Swetha, K.; and Banothu, L. (2018). Alternative technologies for tomato post-harvest quality preservation. *Journal of Pharmacognosy and Phytochemistry,* 7(6), 1678-1682.
9. Kader, A.A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. *Acta Horticulturae,* 682, 2169-2176.
10. Gharib, H.M.; Abajy, M.Y.; and Omaren, A. (2020). Investigating the effect of some fluoroquinolones on C-reactive protein levels and ACh-Induced blood pressure reduction deviations after aging of diabetes in STZ-Induced diabetic wistar rats. *Research Journal of Pharmacy and Technology,* 13(12), 5993-5998.
11. Adak, N.; Heybeli, N.; and Ertekin, C. (2017). Infrared drying of strawberry. *Food Chemistry,* 219, 109-116.
12. Haque, M.; and Adhikari, B. (2015). *Drying and denaturation of proteins in spray drying process. A.S. Mujumdar (Ed.),* Handbook of Industrial Drying, Taylor & Francis Group LLC, Boca Raton, FL.

13. Ziaforoughi, A.; and Esfahani, J.A. (2016). A salient reduction of energy consumption and drying time in a novel PV-solar collectorassisted intermittent infrared dryer. *Solar Energy,* 136, 428-436.
14. Uyar, R.; Bedane, T.F.; Erdogdu, F.; Koray Palazoglu, T.; Farag, K.W.; and Marra, F. (2015). Radio-frequency thawing of food products – A computational study. *Journal of Food Engineering,* 146, 163-171.
15. Compaore, A.; Dissa, A.O.; Rogaume, Y.; Putranto, A.; Chen, X.D.; Mangindaan, D.; Zoulalian, A.; Rémond, R.; and Tiendrebeogo, E. (2017). Application of the reaction engineering approach (REA) for modelling of the convective drying of onion. *Drying Technology,* 35(4), 500-508.
16. Hii, C.L.; Ong, S.P.; Yap, J.Y.; Putranto, A.; and Mangindaan, D. (2021). Hybrid drying of food and bioproducts: a review. *Drying Technology,* 39(11), 1554-1576.
17. Pui, L.P.; Karim, R.; Yusof, Y.A.; Wong, C.W.; and Ghazali, H.M. (2020). Optimization of spray-drying parameters for the production of 'Cempedak' (*Artocarpus integer*) fruit powder. *Journal of Food Measurement and Characterization*, 14(6), 3238-3249.
18. Shishir, M.R.I.; and Chen, W. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. *Trends in Food Science and Technology*, 65, 49-67.
19. Goula, A.M.; Adamopoulos, K.G.; and Kazakis, N.A. (2004). Influence of spray drying conditions on tomato powder properties. *Drying Technology,* 22(5), 1129-1151.
20. Goula, A.M.; and Adamopoulos, K.G. (2005). Stability of lycopene during spray drying of tomato pulp. *LWT - Food Science and Technology,* 38(5), 479-487.
21. Goula, A.M.; and Adamopoulos, K.G. (2008). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: I. Drying kinetics and product recovery. *Drying Technology*, 26(6), 714-725.
22. Hu, L.; Zhang, J.; Hu, Q.; Gao, N.; Wang, S.; Sun, Y.; and Yang, X. (2016). Microencapsulation of brucea javanica oil: Characterization, stability and optimization of spray drying conditions. *Journal of Drug Delivery Science and Technology*, 36, 46-54.
23. Guiné, R.P.F. (2018). The drying of foods and its effect on the physical-chemical, sensorial and nutritional properties. *International Journal of Food Engineering*, 4(2), 93-100.
24. Medina-Torres, L.; Santiago-Adame, R.; Calderas, F.; Gallegos-Infante, J.A.; González-Laredo, R.F.; Rocha-Guzmán, N.E.; Núñez-Ramírez, D.M.; Bernad-Bernad, M.J.; and Manero, O. (2016). Microencapsulation by spray drying of laurel infusions (*Litsea glaucescens*) with maltodextrin. *Industrial Crops and Products*, 90, 1-8.
25. Ozkan, G.; Franco, P.; Marco, I.D.; Xiao, J.; and Capanoglu, E. (2019). A review of microencapsulation methods for food antioxidants: Principles, advantages, drawbacks and applications. *Food Chemistry*, 272, 494-506.
26. Zhu, M.; Chen, G.; Zhou, S.; Tu, Y.; Wang, Y.; Dong, T.; and Hu, Z. (2014). A new tomato NAC (N AM/A TAF1/2/C UC2) transcription factor, SlNAC4, functions as a positive regulator of fruit ripening and carotenoid accumulation. *Plant and Cell Physiology*, 55(1), 119-135.

27. Bhandari, B.R.; Datta, N.; and Howes, T. (1997). Problems associated with spray drying of sugar-rich foods. *Drying Technology*, 15(2), 37-41.
28. Muzaffar, K.; Nayik, G.A., and Kumar, P. (2015). Stickiness problem associated with spray drying of sugar and acid rich foods : A mini review. *Journal of Nutrition & Food Sciences,* S12:003, 1-3.
29. Corrêa-Filho, L.C.; Lourenço, S.C.; Duarte, D.F.; Moldão-Martins, M.; and Alves, V.D. (2019). Microencapsulation of tomato (*Solanum lycopersicum* L.) pomace ethanolic extract by spray drying: Optimization of process conditions. *Applied Sciences,* 9(3), 1-15.
30. Sousa, A.S., Borges, S.V.; Magalhães, N.F.; Ricardo H.V.; and Azededo A.D. (2008). Spray-dried tomato powder : reconstitution properties and colour. *Brazilian Archives of Biology and Technology*, 51, 807-814.
31. Zanoni, B.; Peri, C.; Nani, R.; and Lavelli, V. (1998). Oxidative heat damage of tomato halves as affected by drying. *Food research international,* 31(5), 395-401.
32. Tonon, R.V.; Freitas, S.S.; and Hubinger, M.D. (2011). Spray drying of açai (*Euterpe oleraceae mart*) juice: Effect of inlet air temperature and type of carrier agent. *Journal of Food Processing and Preservation*, 35, 691-700.
33. Bicudo, M.O.P.; Jó, J.; Oliveira, G.A.D.; Chaimsohn, F.P.; Sierakowski, M.R.; Freitas, R.A.D.; and Ribani, R.H (2015). Microencapsulation of jucara (*Euterpe edulis* M.) pulp by spray drying using different carriers and drying temperatures. *Drying Technology,* 33(2), 153-161.
34. Du, J.; Ge, Z.Z.; Xu, Z.; Zou, B.; Zhang, Y.; and Li, C.M. (2014). Comparison of the efficiency of five different drying carriers on the spray drying of persimmon pulp powders. *Drying Technology,* 32(10), 1157-1166.
35. Fazaeli, M.; Emam-Djomeh, Z.; Ashtari, A.K; and Omid, M. (2012). Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder. *Food and Bioproducts Processing*, 90(4), 667-675.
36. Quek, S.Y.; Chok, N.K.; and Swedlund, P. (2007). The physicochemical properties of spray-dried watermelon powders. *Chemical Engineering and Processing: Process Intensification,* 46(5), 386-392.
37. Papadakis, S.E.; Gardeli, C.; and Tzia, C. (2006). Spray drying of raisin juice concentrate. *Drying Technology,* 24(2), 173-180.
38. Abadio, F.D.B.; Domingues, A.M.; Borges, S.V.; and Oliveira, V.M. (2004). Physical properties of powdered pineapple (*Ananas comosus*) juice-effect of malt dextrin concentration and atomization speed. *Journal of Food Engineering*, 64(3), 285-287.
39. Chang, L.S.; Karim, R., Abdulkarim, S.M.; and Ghazali, H.M. (2018). Production and characterization of enayme-treated spray-dried soursoup (*Annona muricata L.*) powder. *Journal of Food Process Engineerting,* 41, 1-12.
40. Chang, L.S., Tan, Y.L.; and Pui, L.P. (2020). Production of spray-dried enzyme-liquefied papaya (*Carica papaya* L .) powder. *Brazilian Journal of Food Technology*, 23, 1-16.
41. Wong, C.W.; Pui, L.P.; and Ng, J.M.L. (2015). Production of spray-dried Sarawak pineapple (*Ananas comosus*) powder from enzyme liquefied puree. *International Food Research Journal,* 22(4), 1631-1636.

42. Movahhed, M.K.; and Mohebbi, M. (2016). Spray drying and process optimization of carrot – celery juice. *Journal of Food Processing and Preservation,* 40, 212-225.
43. Bazaria, B.; and Kumar, P. (2018). Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM). *Journal of the Saudi Society of Agricultural Sciences*, 17(4), 408-415.
44. Mohammed, N.K.; Tan, C.P.; Manap, Y.A.; Muhialdin, B.J.; and Hussin, A.S.M. (2020). Spray Drying for the Encapsulation of Oils-A Review. *Molecules,* 25(17), 1-16.
45. Souza, A.L.R.; Hidalgo-Chávez, D.W.; Pontes, S.M.; Gomes, F.S.; Cabral, L.M.C.; and Tonon, R.V. (2018). Microencapsulation by spray drying of a lycopene-rich tomato concentrate: Characterization and stability. *LWT - Food Science and Technology*, 91, 286-292.
46. Sukri, N.; Hashib, S.A.; Rahman, N.A.; Hasfalina, C.M.; and Abdulsalam, M. (2018). Effect of maltodextrin concentration and slurry temperature on pineapple powder using ultrasonic spray dryer. *Journal of Food Science*, 2, 582-586.
47. Yousefi, S.; Emam-Djomeh, Z.; and Mousavi, S.M. (2011). Effect of carrier type and spray drying on the physicochemical properties of powdered and reconstituted pomegranate juice (*Punica granatum* L.). *Journal of Food Science and Technology,* 48(6), 677-684.
48. Souza, A.S.; Borges, S.V.; Magalhães, N.F.; Ricardo, H.V.; Cereda, M.P.; and Daiuto, E.R. (2009). Influence of spray drying conditions on the physical properties of dried pulp tomato. *Food Science and Technology International,* 29(2), 291-294.