DEVELOPMENT AND PROCESS OPTIMIZATION OF SPRAY DRIED POWDER FROM ENZYMATICALLY EXTRACTED RIPE PALM (Borassus flabellifer) JUICE

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ABSTRACT
Ripe Palm (Borassus flabellifer) juice contains high sugars that make it difficult to store for a longer period, which limits its use for spray drying. The present work explores the feasibility and optimization of spray drying to make powder from enzymatically extracted ripe palm juice using maltodextrin and gum Arabic as wall materials. Various parameters such as moisture, water activity, solubility, ascorbic acid, colour change, and yield were optimized using response surface method with the central composite design. A mixture of maltodextrin and gum Arabic at a ratio of 3:1 (w/w) combined with lactose, and spray drying at an inlet temperature of 140°C resulted in the optimum powder quantity and quality. The palm powder yield was maximum (63.5±0.29 %) with acceptable solubility (31.6±0.33 secs), colour change (ΔE=18.37±0.03), ascorbic acid content (54±0.0003 µg/ml), moisture content (3.3±0.61), and water activity (0.29±0.05). The optimized conditions can be replicated on an industrial scale for the production of palm powder.

Keywords: Palm fruit, Fruit juice, Spray drying, Encapsulation, Quality assessment

INTRODUCTION
Palm or Palmyra (Borassus flabellifer) is a tropical fruit well known for its pulpy seeds and sweet sap. The fruit is also known as palmyra palm, doubt palm, tala palm, toddy palm, wine palm, or palmyra palm (Borassus flabellifer). The ripen fruit pulp has medicinal uses in curing some inflammatory conditions of the skin and treatment of nausea, vomiting, and worm infestation (Arunachalam et al., 2011). Palm pulp is rich in sugars, vitamins (A, B, and C), carotenoids, and flavonoids (Vijayakumari et al., 2014; Rout et al., 2014). The pulp is extracted by mechanical methods (Vijayakumari et al., 2014). The pulps and juice recovery can be increased by enzyme-assisted extraction processes (Rout et al., 2014; Vivek et al., 2018). However, due to high sugar content, palm pulp, and juice ferment quickly, even at ambient conditions (Vijayakumari et al., 2014). Hence, storing of palm juice for a longer period is a challenging task. Converting the palm juice to powder can be an option to address the problem. The juice can be spray-dried to fruit powder under optimized conditions (Shishir et al., 2017; Vivek et al., 2021). The juice is atomized and sprayed on to hot air that dries the moisture of the liquid feed and forms powder (Krishnaiah et al., 2014; Vivek et al., 2021). However, the simple sugars present in the fruit juice melt at a higher temperature and make the powder sticky and hygroscopic. These problems can be addressed by adding wall-coating material that encloses the simple sugars and other nutrients present in the fruit juice (Chegini et al. 2007; Gharshallahu et al. 2007; Phisut et al., 2012; Vivek et al., 2020; Vivek et al., 2021). In the present work, enzymatically extracted palm juice (Mohanty et al., 2018) was used for making powder. Maltodextrin and Gum Arabic were added as wall-material to address the problem of the stickiness of the final product. The spray drying process was optimized for additive concentration in the feed and inlet air temperature of the spray dryer. The feed rate and air aspiration rate of the spray dryer were kept constant. The palm powder so obtained had acceptable physicochemical properties. Results suggest that the process can be scaled up at the industrial level for the production of palm powder. This can open up avenues for developing processes and products for commercial use of the palm juice, which in turn can improve the economic condition and livelihood of the palm cultivators.

MATERIALS AND METHODS
Feed preparation
Ripe Palm is a seasonal fruit and is available only during the rainy season in tropical regions (Chaurasiya et al., 2014). Ripe palms (Borassus flabellifer), each of 900-1000g, were obtained from the local market (Fig.1a). Palm was cleaned with water and was peeled off. The seeds and the fibrous pulp were extracted manually. The fiber of the fruit is non-digestible and may block the nozzle of the spray dryer. Hence, separated from the pulp using a stainless steel scraper. The pulp (Fig.1b), so recovered, was pasteurized for 10 min at 90°C. Palm juice was extracted from the pulp using Cellulase and Pectinase enzymes (Mohanty et al., 2018; Vivek et al., 2019). The enzymatic extraction process had juice yield of 87.9%. The extracted juice had a total solid content of 12.9% with TSS of 12.8° Brix. The total ascorbic acid content of the juice was 57±0.0003 µg/ml. The juice had protein and sugar contents of 1.36 and 95±0.52 mg/ml, respectively (Mohanty et al., 2018).

Figure 1 (a) Ripe Palm fruit and (b) Extracted pulp for experiments

Spray drying of palm powder
The palm juice (100ml) was mixed with 25-35g of maltodextrin (DE 13-17, Sigma-Aldrich, India) and 10-20g of gum arabic at different proportions to get proper encapsulation of fruit matrix during spray drying. Food grade gum arabic was obtained from the Indian Institute of Natural Resins and Gums, Ranchi, India. Lactose (15g, HiMedia, India) was also added to increase the solid content of the juice and lower the glass transition temperature during spray drying (Angel et al., 2009; Vivek et al., 2021). A lab-scale spray dryer (LSD-48, JISL, Mumbai, India) was used for the spray drying experiments. The inlet air temperature for the spray drying was varied between 130 to 150°C for various combinations of additives. On adding carrier wall materials at different proportions to the enzymatically extracted palm juice at different proportions, the total solid content increased to 23-48%. The feed was fed to the spray dryer with a feed rate of 20
ml/min (Muzaffar and Kumar, 2015). Spray drying was done at a fixed air pressure of 4 bar with an aspiration rate of 45% as per the instrument operating manual. The spray-dried powder was collected in the cyclone and collecting jar. The powder was stored in airtight glass jars and was analyzed for various physical and chemical properties. The process parameters were optimized.

Quality analysis of palm powder and reconstituted juice

The experimental responses such as powder yield, moisture, water activity, solubility, colour change, and ascorbic acid content were determined following standard protocols described below.

Powder yield

The powder yield was calculated as the ratio of the weight of solid content of powder to the weight of the solid content of the feed (Cynthia et al., 2015). The yield percentage was calculated as

\[ P_y = \left( \frac{Q_p}{Q_t} \right) \times 100 \]

Where \( P_y \) is powder yield in %, \( Q_p \) is solid content of powder in grams, \( Q_t \) is solid content of the feed in grams

Ascorbic acid content

Ascorbic acid (Vitamin C) contents of extracted and reconstituted juices were measured by the titrimetric method (Joana et al., 2015). The direct titration of ascorbic acid with the dye 2,6-dichlorophenolindophenol gave qualitative measurements of vitamin C contents of the samples. The oxidative reaction of metaphosphoric-acetic acid with 2,6-dichlorophenolindophenol solution converts the ascorbic acid to dehydroascorbic acid, which is visually indicated by the titration method.

Solubility time

Solubility time was measured following the standard method suggested by Muzaffar and Kumar (2015). The time required to dissolve 2.5 g of powder completely in 100 mL of distilled water at 25°C was recorded and statistically analyzed.

Moisture content

The moisture content of the spray-dried palm powder was determined based on the AOAC method (Horwitz, 2000). Two grams of Palm powder was kept inside a hot air oven at a temperature of 105°C until a constant weight was obtained. Triplicates of the sample were examined to get a consistent result.

Water activity

The water activity of the palm powder was measured to evaluate the microbial growth during storage by placing 5 g of powder in the Water activity meter (Rotronic, Switzerland) following the standard protocol (Muzaffar and Kumar, 2015).

Reconstitution of Palm juice

Reconstituted palm juice was prepared by dissolving palm powder in distilled water at 25°C. The fruit powder was rehydrated to the same moisture content as the enzymatically extracted palm juice. To achieve the natural juice TSS of 12.8±0.5 °Brix, the palm powder was reconstituted at a ratio of 1:3:10 (Rodríguez-Hernández et al., 2005).

Colour difference of reconstituted juice

Fresh palm juice reflects yellow colour. On exposure to high heat through spray drying, the colour of the powder changes. The colour of the extracted and reconstituted juices were measured using a colourimeter (Colorflex EZ, HunterLab, USA). The instrument was standardized following standard protocol, and the colour values were represented in terms of brightness/darkness (L’), redness/greenness (a’), and yellowness/blueness (b’) (Ogbonna et al., 2013). The colour difference (\( \Delta E \)) of the samples was calculated by

\[ \Delta E = \sqrt{\left( \Delta L^* \right)^2 + \left( \Delta a^* \right)^2 + \left( \Delta b^* \right)^2} \]

Statistical Analysis

The spray drying and quality analysis experiments were designed using the response surface method (RSM) with central composite design (CCD) in Design-Expert® (Ver. 7.0.0) (Sagı et al., 2014, Lee et al., 2006). The variations in the responses due to independent factors were estimated by taking five center points (Bazaria and Kumar, 2018; Shishir et al., 2016). The experimental data were statistically analyzed, and regression models were developed. Additive concentration (\( X_1 \)) and inlet temperature (\( X_2 \)) were taken as independent variables. In the case of mixed additive treatments, maltodextrin concentration (\( X_3 \)), gum Arabic concentration (\( X_4 \)), and inlet temperature (\( X_5 \)) were taken as independent variables. Powder yield (\( Y_1 \)), powder moisture (\( Y_2 \)), water activity (\( Y_3 \)), solubility (\( Y_4 \)), ascorbic acid content (\( Y_5 \)), and colour change (\( Y_6 \)) of spray-dried palm powder samples were measured as dependent variables or responses and are shown in Table 1 (a), (b) and (c). These values were related to the coded variables (\( X_i \), where \( i = 1, 2, 3, \) and 4) by a second-degree polynomial equation (Lee et al., 2006; Singh et al., 2012) as below:

\[ Y = b_0 + \sum b_iX_i + \sum b_{ij}X_i^2 + \sum b_{ij}X_iX_j \]

Where \( Y \) is the response, \( X_i \) and \( X_j \) are the levels of variables, \( b_i \) is the constant, \( b_i \) is the linear coefficient, \( b_{ij} \) is the quadratic term, and \( b_{ij} \) is the coefficient of the interaction terms. Analysis of variance (ANOVA) was performed, and regression coefficients for linear, quadratic, and interaction terms were determined. Contour graphs were drawn for moisture content, water activity, solubility, ascorbic acid content, colour difference, and powder yield using the regression models and coefficients. The coefficients of determination and regression, and their significances for each treatment are shown in Table 2 (a), (b) and (c).

Table 1(a) The central composite experimental design (in the coded level of two variables) for maltodextrin assisted spray drying of palm juice

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maltodextrin, g (X1)</td>
<td>Powder Yield, % (Y1)</td>
</tr>
<tr>
<td></td>
<td>Inlet Temp, °C (X2)</td>
<td></td>
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<tr>
<td></td>
<td>Coded</td>
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<td>2</td>
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<td>30</td>
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<td>3</td>
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<td>4</td>
<td>-1.4</td>
<td>22.9</td>
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<td>5</td>
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</tr>
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<td>6</td>
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<td>7</td>
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RESULTS AND DISCUSSION

Effect of spray drying with maltodextrin on response variables

Powder yield

The linear terms of the independent variable had a significant effect on powder yield at p<0.001. Spray-dried powder yield was higher with increased additive concentration and higher inlet temperature. The interaction terms showed an insignificant effect on powder yield, whereas the quadratic term of additive concentration had a significant effect (p<0.05) on the yield. The presence of additives in palm juice is contributing to the higher yield of palm powder (Goula et al., 2010, Vivek et al., 2020). Response surfaces of powder yield are shown in Fig. 2(a). An optimized spray-dried powder yield of 59.55±0.55 % (w/w) was achieved with 25grams of maltodextrin and inlet temperature of 148°C. The data fits the equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2a).

Moisture content

The moisture content plays a crucial role in controlling microbial growth and extending the shelf life of the powder. The effect of spray drying with maltodextrin on the moisture content of the palm powder is shown in Table 2(a). The linear terms for additive concentration and temperature showed a significant difference at p<0.05. The moisture content of the palm powder decreased with an increase in inlet temperature and additive concentration. This may be due to the exposure of the juice to high temperature during drying. Similar results were observed for watermelon, cactus pear, and orange (Rodríguez-Hernández et al., 2005; Quek et al. 2007). The interaction terms showed a significant difference at p<0.05. While the quadratic term of additives concentration showed a significant difference at p<0.01. The response surfaces of process variables and their interactions for moisture content are shown in Fig. 2(b). The data fits the equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2a).

Water activity

The linear terms, i.e., additive concentration and temperature, showed significant differences at p<0.001. The water activity of the powder decreased with an increase in inlet temperature and additive concentration. This may be due to the decrease in moisture content and the influence of encapsulating and anti-caking agents. No significant decrease in water activity was observed for the interaction terms. The quadratic term for additive concentration had a significant difference at p<0.05. Similar results were observed for pineapple juice with maltodextrin as a wall material (Goula et al., 2010). The response surfaces of process variables
and their interactions for water activity are shown in Fig. 2(c). The data fits the
equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2a).

**Solubility time**

The spray-dried palm powder has more solubility time. The linear terms for
independent factors showed significant differences at \( p < 0.01 \). The increased
solubility time might be due to the presence of a high amount of additives that
makes it difficult to get soluble in water (Rodríguez-Hernández et al., 2005).
The interaction terms showed insignificant differences, whereas the quadratic
term for additive concentration shows a significance at \( p < 0.01 \). The effects of
independent variables on solubility are shown in Fig. 2(d). The data fits the
equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2a).

**Ascorbic acid content**

The linear terms for additive concentration (\( p < 0.01 \)) and inlet temperature
\( (p < 0.001) \) had a significant effect on ascorbic acid content. Ascorbic acid content
decreased with an increase in the drying temperature. Palm powder made with
25g of maltodextrin and spray-dried at 140°C inlet temperature had the maximum
ascorbic acid content. The high ascorbic acid content of the powder could be due
to efficient encapsulation by maltodextrin that protects it from degradation at a
higher temperature. Similar results have been reported for spray-dried guava and
passion fruit powders (Joana et al., 2015; Bazarias et al., 2018). The interaction
and the quadratic terms of the independent variables had insignificant effects on
the response. The response surface for ascorbic acid content is shown in Fig. 2(e).

**Effect of spray drying with gum arabic on response variables**

**Powder yield**

There was a significant effect (\( p < 0.001 \)) of linear terms of additive concentration
on the yield of powder. The response surface plots (Fig. 3 (a)) indicates increased
powder yield at increased additive concentration and inlet temperature. The
higher amount of gum arabic additive encapsulates the palm powder more
effectively at higher temperatures resulting in higher yield. Similar results have
been reported for spray-dried pineapple and mulberry powders (Fazaeil et al.,
2012; Jittanit et al., 2010; Vivek et al., 2020). The data fits the equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2b). The optimized value of powder yield was 65.23±0.17 % (w/w) at 140°C inlet
temperature with 10 grams of gum Arabic additive having the desirability of
greater than 0.8.

**Moisture content**

The linear terms, i.e., additive concentration and temperature, had significant
effects on the moisture content of the powder at \( p < 0.01 \). The moisture content of
powder decreased with an increase in temperature and carrier concentration. At
higher temperatures, moisture removal was more. Similar results have been
reported for mulberry and pomegranate powders with gum arabica (Fazaeil et al.,
2012). The response surfaces of process variables and their interactions are
illustrated in Fig. 3 (b). The data fits the equation extremely well with the highest
R², Adj. R² and Predicted R² (Table 2b).

**Water activity**

As the moisture content of the spray-dried palm powder decreased with gum
arabica as an additive, the water activity also decreased. The linear term (\( p <
0.01 \)) and quadratic term (\( p < 0.05 \)) of additive concentration had a significant
difference (Table 2b). The anti-caking agent, magnesium carbonate, and gum
arabica decreased the availability of water in the palm powder. It also lowers the
hygroscopicity of the powder. Gum arabic encapsulates the powder particles and
stabilizes it (Yossef et al., 2011). The optimized value of the water activity of the
palm powder with gum Arabic was 0.25±0.014. The response surfaces of water
activity are illustrated in Fig. 3 (c). The data fits the equation extremely well with the highest R², Adj. R² and Predicted R² (Table 2b).

**Colour of reconstituted palm juice**

The spray-dried palm powder was used to make reconstituted juice and was
compared with the palm juice. The physicochemical properties of the
reconstituted juice are given in Table 3. The linear terms of additive
concentration and inlet temperature showed significant differences at \( p < 0.01 \) on
the colour of the reconstituted juice. The interaction and quadratic term of
additive concentration had an insignificant effect on the response, whereas the
quadratic term for temperature had a significant effect at \( p < 0.01 \). The colour
difference between original and reconstituted juices decreased with increased
maltodextrin in the feed. This may be due to proper encapsulation of palm
powder during spray drying that preserves natural colour pigments in the process.
The additive is of a lighter colour, which also may have added to the reason for
colour difference (Rodríguez-Hernández et al., 2005; Goula et al., 2010;
Bazarias et al., 2018). The response surfaces for Colour difference is shown in
Fig. 2(f). The data fits the equation extremely well with the highest R², Adj. R²
and Predicted R² (Table 2a).

The powder obtained under optimum conditions using maltodextrin had a
moisture content of 4.1±0.15 % (db), water activity of 0.33±0.011, solubility time of
46.09±0.06 seconds, and Ascorbic Acid content (50±0.0026 μg of AA/ml). The
reconstituted juice had a colour change (ΔE) of 15.92±0.02.

<p>| Table 2(a) Coefficients of regression, R² values for the different Responses for Maltodextrin aided spray drying of palm juice |</p>
<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Moisture Activity</th>
<th>Water Activity</th>
<th>Solubility</th>
<th>Ascorbic Acid</th>
<th>Colour change</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>b₀</td>
<td>4.28</td>
<td>0.28</td>
<td>46.5</td>
<td>52.20</td>
<td>15.5</td>
<td>58.9</td>
</tr>
<tr>
<td>b₁</td>
<td>-0.16*</td>
<td>-0.029**</td>
<td>-4.51**</td>
<td>1.13**</td>
<td>-0.71</td>
<td>2.22***</td>
</tr>
<tr>
<td>b₂</td>
<td>-0.19**</td>
<td>0.86</td>
<td>4.07**</td>
<td>-3.02***</td>
<td>-1.09**</td>
<td>2.66***</td>
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<tr>
<td>b₃</td>
<td>-0.16**</td>
<td>-0.012</td>
<td>4.50</td>
<td>-0.94</td>
<td>0.70</td>
<td>-0.50</td>
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<tr>
<td>b₄</td>
<td>0.22**</td>
<td>0.012</td>
<td>-0.91</td>
<td>0.34</td>
<td>0.61</td>
<td>0.46</td>
</tr>
<tr>
<td>b₅</td>
<td>-0.93</td>
<td>-0.113</td>
<td>-6.53</td>
<td>0.34</td>
<td>0.86**</td>
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<tr>
<td>b₆</td>
<td>0.89</td>
<td>0.923</td>
<td>0.909</td>
<td>0.963</td>
<td>0.883</td>
<td>0.989</td>
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<tr>
<td>R²</td>
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<td>0.84</td>
<td>0.93</td>
<td>0.80</td>
<td>0.98</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
<td>0.75</td>
<td>0.75</td>
<td>0.93</td>
</tr>
<tr>
<td>Predicted R²</td>
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<td>0.78</td>
<td>0.78</td>
<td>0.75</td>
<td>0.75</td>
<td>0.93</td>
</tr>
</tbody>
</table>

b represents the coefficients of equations different responses with b₀ the constant term; b₁, and b₂ the linear effects (1, and 2 respectively the concentration, temperature); b₃, b₄, b₅ are the quadratic effects; and b₆ is the interactions.

*Significant at \( p \leq 0.05 \), **Significant at \( p \leq 0.01 \), ***Significant at \( p \leq 0.001 \)
The response surfaces of this option presence of a higher occurrence of more additive, the ascorbic Largo gum powder yield even at a higher temperature. The response surfaces for this parameter is shown in Fig. 3(f). There was a high colour difference when a higher amount of gum arabic was added to the feed. This may be due to the effect of the natural brown colour of the additive (Gabas et al., 2007; Vivek et al., 2020). The quadratic terms of additive concentration and inlet temperature for this parameter had significance differences (p<0.05), indicating changes in powder colour at a higher temperature in the presence of gum arabic. The data fits the equation extremely well with the highest R², Adj R² and Predicted R² (Table 2b).

Colour of the reconstituted juice

The fruit powder was reconstituted, and the colour was measured. The other physicochemical properties of the reconstituted juice are given in Table 3. The linear term, i.e., additive concentration had a significant effect (p<0.01) on the colour difference of the reconstituted juice. These additives encapsulate ascorbic acid and other antioxidants present in the fruit juice matrix (Qucek et al., 2007; Jittanit et al., 2010; Vivek et al., 2020). The data fits the equation extremely well with the highest R², Adj R² and Predicted R² (Table 2b).

Table 2(b) Coefficients of regression, R² values for the different Responses for Gum Arabic aided spray drying of palm juice

<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Moisture</th>
<th>Water Activity</th>
<th>Solubility</th>
<th>Ascorbic Acid</th>
<th>Colour change</th>
<th>Yield</th>
</tr>
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<tbody>
<tr>
<td>b₀</td>
<td>3.69</td>
<td>0.28</td>
<td>37.62</td>
<td>56.34</td>
<td>27.02</td>
<td>67.78</td>
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<tr>
<td>b₁</td>
<td>-0.31**</td>
<td>0.013**</td>
<td>3.01**</td>
<td>2.05**</td>
<td>2.78***</td>
<td>2.84***</td>
</tr>
<tr>
<td>b₂</td>
<td>-0.16**</td>
<td>0.577</td>
<td>0.61</td>
<td>0.52</td>
<td>0.74</td>
<td>0.46</td>
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<tr>
<td>b₃</td>
<td>-0.083</td>
<td>0.25</td>
<td>0.93</td>
<td>-0.63</td>
<td>-0.075</td>
<td>-0.10</td>
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<tr>
<td>b₄</td>
<td>0.20</td>
<td>-0.48³</td>
<td>1.51⁻</td>
<td>-0.77⁻</td>
<td>-1.00⁻</td>
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<td>b₅</td>
<td>-0.045</td>
<td>-0.98</td>
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<td>R²</td>
<td>0.92</td>
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<td>0.84</td>
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<td>Adjusted R²</td>
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<tr>
<td>Predicted R²</td>
<td>0.76</td>
<td>0.62</td>
<td>0.76</td>
<td>0.68</td>
<td>0.86</td>
<td>0.67</td>
</tr>
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b Represents the coefficients of equations different responses with b₀ the constant term, b₁, and b₂ the linear effects (1 and 2 respectively the concentration, temperature); b₃, b₄, and b₅ are the quadratic effects; and b₆ is the interactions.

Moisture content

The linear term of the equation, such as gum Arabic (p<0.05), maltodextrin (p<0.01), and temperature (p<0.001), had significant effects on powder yield. The powder yield increased with an increase in the additive concentrations and temperature (Fig. 4(a)). Efficient encapsulation by the additives plays an important role in increasing powder yield even at a higher temperature (Muzaffar et al., 2018; Vivek et al., 2020). The solid contents of both the additives also contributed to a higher yield of palm powder. The quadratic terms of gum arabic (p<0.001) and temperature (p<0.01) had significant effects on powder yield. The spray drying process was optimized at 140°C of inlet temperature, 30 grams of maltodextrin, and 10 grams of gum arabic with product desirability of 1. Under the optimized conditions, the powder yield was 63.5±0.29 % (w/w). The data fitted the equation extremely well with the highest R², Adj R² and Predicted R² (Table 2c).

Water activity

The linear terms, i.e., maltodextrin (p<0.001), gum Arabic (p<0.01), and inlet temperature (p<0.01), had significant effects on water activity of the spray-dried cake. These additive concentrations had a significant effect on the ascorbic acid content of the powder, with the highest R², Adj R², and Predicted R² (Table 2b). The data fits the equation extremely well with the highest R², Adj R², and Predicted R² (Table 2b).

Effect of spray drying with combined maltodextrin and gum arabic on response variables

Powder yield

All the linear terms of the equation, such as gum Arabic (p<0.05), maltodextrin (p<0.01), and temperature (p<0.001), had significant effects on powder yield. The powder yield increased with an increase in the additive concentrations and temperature (Fig. 4(a)). Efficient encapsulation by the additives plays an important role in increasing powder yield even at a higher temperature (Muzaffar et al., 2018; Vivek et al., 2020). The solid contents of both the additives also contributed to a higher yield of palm powder. The quadratic terms of gum arabic (p<0.001) and temperature (p<0.01) had significant effects on powder yield. The spray drying process was optimized at 140°C of inlet temperature, 30 grams of maltodextrin, and 10 grams of gum arabic with product desirability of 1. Under the optimized conditions, the powder yield was 63.5±0.29 % (w/w). The data fitted the equation extremely well with the highest R², Adj R² and Predicted R² (Table 2c).
powder. The response surface plots (Fig. 4 (c)) indicate a decreased water activity with an increased concentration of combined additives and inlet temperature. This is due to the decreased moisture content of the spray-dried palm powder. Similar results were observed by Largo et al. (2015) and Quek et al. (2007) for spray-dried powders of watermelon, sugarcane, and cactus pear fruits with a lower water activity (< 0.5). The data fits the equation extremely well with the highest $R^2$, Adj. $R^2$ and Predicted $R^2$ (Table 2c).

![Figure 3](image-url)

**Figure 3** Response surfaces of Gum Arabic aided spray drying representing the effect of Additive Concentration and Inlet Temperature on (a) Powder Yield (b) Moisture Content (c) Water activity (d) Solubility Time (e) Ascorbic Acid Content (f) Colour Change

**Solubility time**

Significance differences were observed for linear terms of gum arabica ($p<0.01$), inlet temperature ($p<0.01$), and maltodextrin ($p<0.05$) on solubility time. The response surface of solubility is shown in Fig. 4(d). The solubility time of the powder increased as the additive concentration increased. However, maltodextrin had a lesser effect on the solubility time of the powder than gum Arabic. The interaction terms of maltodextrin-inlet temperature ($p<0.05$), maltodextrin-gum Arabic ($p<0.01$), and gum Arabic-inlet temperature ($p<0.001$) had significant effects on solubility time. With a higher concentration of additives, the powder had higher solubility time. This may be due to the lower water-soluble and hygroscopic properties of the additives. Similar results were observed during spray-drying sugarcane juice. The solubility time increased with inlet temperature and additive concentration (Largo et al., 2015 and Nishad et al., 2019). The data fits the equation extremely well with the highest $R^2$, Adj. $R^2$ and Predicted $R^2$ (Table 2c).

**Ascorbic acid content**

Linear terms of maltodextrin ($p<0.01$) and temperature ($p<0.01$) had significant effects on ascorbic acid content. However, gum Arabic had no significant effect on the ascorbic acid content when used in combination with maltodextrin. The response surface plots (Fig. 4(e)) indicates an increase of ascorbic acid content with increased additive concentration. The combination of both the additives improved the encapsulation of fruit matrix that protected the ascorbic acid in the powder even at a higher temperature (Muzaffar et al., 2018). The ascorbic acid data fits the equation extremely well with the highest $R^2$, Adj. $R^2$ and Predicted $R^2$ (Table 2c). The optimum value of ascorbic acid content while spray-drying with combined additives was 54±0.0003 µg of AA/ml. This value was much higher than that obtained with individual additive.

### Table 2c

<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Moisture</th>
<th>Water activity</th>
<th>Solubility</th>
<th>Ascorbic Acid</th>
<th>Colour</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>3.68</td>
<td>0.32</td>
<td>34.88</td>
<td>-0.66</td>
<td>0.48</td>
<td>1.69</td>
</tr>
<tr>
<td>$b_1$</td>
<td>-0.11***</td>
<td>-0.023***</td>
<td>-0.20</td>
<td>-0.66 ***</td>
<td>-0.06</td>
<td>0.48</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.054***</td>
<td>0.021***</td>
<td>0.53</td>
<td>0.12</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>$b_3$</td>
<td>0.027***</td>
<td>-0.021***</td>
<td>0.33</td>
<td>-0.96 ***</td>
<td>-0.18</td>
<td></td>
</tr>
<tr>
<td>$b_{12}$</td>
<td>0.058***</td>
<td>-0.75</td>
<td>0.68</td>
<td>0.50</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>$b_{13}$</td>
<td>0.037**</td>
<td>-0.75</td>
<td>0.33</td>
<td>0.41</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>$b_{23}$</td>
<td>0.050***</td>
<td>-0.75</td>
<td>0.83***</td>
<td>-0.024</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>$b_7$</td>
<td>-0.13***</td>
<td>0.036</td>
<td>-1.28</td>
<td>0.38</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>$b_8$</td>
<td>-0.031*</td>
<td>-0.339</td>
<td>-0.014</td>
<td>-0.43</td>
<td>-0.71</td>
<td></td>
</tr>
<tr>
<td>$b_9$</td>
<td>0.883</td>
<td>-0.732</td>
<td>-0.33</td>
<td>-0.29</td>
<td>-0.30</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.96</td>
<td>0.913</td>
<td>0.908</td>
<td>0.867</td>
<td>0.891</td>
<td></td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.93</td>
<td>0.83</td>
<td>0.94</td>
<td>0.74</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Predicted $R^2$</td>
<td>0.78</td>
<td>0.62</td>
<td>0.82</td>
<td>0.66</td>
<td>0.65</td>
<td></td>
</tr>
</tbody>
</table>

b Represents the coefficients of equations different responses with $b_0$ the constant term; $b_1$, $b_2$, and $b_3$ the linear effects (1, 2, and 3 respectively the maltodextrin weight, gum arabic weight and temperature); $b_{12}$, $b_{13}$, $b_{23}$ are the quadratic effects; and $b_{12}$, $b_{13}$, $b_{23}$ are different interactions.

*Significant at $p \leq 0.05$, **Significant at $p \leq 0.01$, ***Significant at $p \leq 0.001$.

### Table 3

<table>
<thead>
<tr>
<th>Properties</th>
<th>Optimized juice</th>
<th>Reconstituted juice from MD aided SD Powder</th>
<th>Reconstituted juice from GA aided SD Powder</th>
<th>Reconstituted juice from MD and GA aided SD Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>87.1 ± 1.09</td>
<td>88.2 ± 0.12</td>
<td>87.23 ± 0.24</td>
<td>89.2 ± 1.25</td>
</tr>
<tr>
<td>Total solid (%)</td>
<td>12.9 ± 0.17</td>
<td>12.71 ± 0.63</td>
<td>12.82 ± 0.22</td>
<td>12.90 ± 0.23</td>
</tr>
<tr>
<td>Total soluble solid (Brix)</td>
<td>12.8 ± 0.0514</td>
<td>12.54 ± 0.23</td>
<td>12.6 ± 0.41</td>
<td>12.7 ± 0.66</td>
</tr>
<tr>
<td>Total dissolved solids (ppm)</td>
<td>259.4 ± 108</td>
<td>345.52 ± 0.61</td>
<td>350.23 ± 0.52</td>
<td>356.2 ± 0.114</td>
</tr>
<tr>
<td>pH</td>
<td>3.5 ± 0.031</td>
<td>4.5 ± 0.111</td>
<td>4.2 ± 0.155</td>
<td>4.2 ± 0.021</td>
</tr>
<tr>
<td>Ascorbic acid (µg of AA/ml)</td>
<td>57 ± 0.0003</td>
<td>51 ± 0.0026</td>
<td>55 ± 0.0024</td>
<td>54 ± 0.005</td>
</tr>
<tr>
<td>Protein (mg/ml)</td>
<td>1.36 ± 0.23</td>
<td>1.33 ± 0.05</td>
<td>1.31 ± 0.25</td>
<td>1.31 ± 0.12</td>
</tr>
<tr>
<td>Fat%</td>
<td>0.45 ± 0.13</td>
<td>0.42 ± 0.04</td>
<td>0.45 ± 0.11</td>
<td>0.41 ± 0.25</td>
</tr>
<tr>
<td>Sugar (mg/ml)</td>
<td>95 ± 0.52</td>
<td>85.52 ± 0.51</td>
<td>82.15 ± 0.33</td>
<td>88.3 ± 0.41</td>
</tr>
<tr>
<td>Yield (%)</td>
<td>87.9 ± 0.66</td>
<td>55.01 ± 0.55</td>
<td>68.56 ± 0.44</td>
<td>63.5 ± 0.29</td>
</tr>
<tr>
<td>Colour difference (ΔE)</td>
<td>8.41 ± 0.03</td>
<td>16.52 ± 0.23</td>
<td>27.34 ± 0.59</td>
<td>18.37 ± 0.03</td>
</tr>
</tbody>
</table>

*Control Sample: Enzymatically extracted juice before spray drying; MD: Maltodextrin; SD: Spray dried; GA: Gum Arabic. Data represented as mean ± standard deviation, sample size = 3. Values in the same column, followed by superscripted letters (a-d) are significantly different ($p \leq 0.05$) as determined by DUNCAN Test.
The linear terms of combined additives showed a significant ($p<0.001$) effect on the colour difference of the reconstituted palm juice. The interaction terms of maltodextrin-gum Arabic ($p<0.01$) and the quadratic terms of these additives ($p<0.05$) had significant effects on the colour difference of reconstituted juice. Fig. 4(f) shows the response surfaces of colour difference. The presence of these additives increases the colour difference of the reconstituted juices from the extracted palm juice. These additives impart their colour to the final palm powder and the reconstituted juice. Similar results have been reported for spray-dried pineapple powder and cactus pear (Ferreira et al., 2005; Gabas et al., 2007). The colour difference data fits the equation extremely well with the highest $R^2$, Adj. $R^2$ and Predicted $R^2$ (Table 2c). The optimum value of the colour difference (AE) with combined additives was 18.37$±$0.03. Other physicochemical properties of the reconstituted juice (Table 3) were similar to the enzymatically extracted palm juice.

Under optimized condition, the spray-dried palm powder with combined additives had a moisture content of 3.3$±$0.61 % (db), ascorbic acid content of 54$±$0.0003 µg of AA/ml, water activity of 0.29$±$0.05, and solubility time of 31.6$±$0.33 seconds. The Palm powder (Fig. 5) obtained was less hygroscopic and had better solubility in water.


