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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 with an inlet temperature of 140ºC 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, doub palm, tala palm, toddy palm, wine palm, and ice apple. 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 pulp 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; Gharsallaoui *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 90ºC. 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 12.8º 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**).

(a) (b)

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^{0}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

$$P_y = \left(\frac{Q_p}{Q_f}\right) * 100$$

Where P_y is powder yield in %, Q_p is solid content of powder in grams, Q_f 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 (**Ioana *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 25ºC 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 105ºC 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 25^0C. 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 ^{0}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 (ΔE) of the samples was calculated by

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

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) (**Sagu *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_1), gum Arabic concentration (X_2), and inlet temperature (X_3) 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:

$$Y = b_0 + \Sigma b_i X_i + \Sigma b_{ii} {X_i}^2 + \Sigma b_{ij} X_i X_j$$

Where Y is the response, X_i and X_j are the levels of variables, b_0 is the constant, b_i is the linear coefficient, b_{ii} is the quadric 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

Sl No	Independent Variables				Dependent Variables					
	Maltodextrin,g (X1)		Inlet Temp., ^{0}C (X2)		Powder Yield,% (Y1)	Moisture, %(Y2)	Water Activity (Y3)	Solubility, secs (Y4)	Ascorbic Acid (µg /ml) (Y5)	Juice Colour, ΔE (Y6)
	Coded	Actual	Coded	Actual						
1	0	30	1.4	152	63	3.8	0.295	40.0	50.0	15.5
2	0	30	0	145	59	4.2	0.275	42.5	52.5	15.0
3	-1	25	1	150	60	4.1	0.345	42.0	50.0	16.0
4	-1.4	22.9	0	145	57	4.1	0.345	52.5	50.75	17.5
5	-1	25	-1	140	54	4.1	0.310	42.5	55.25	20.0
6	1	35	-1	140	60	4.15	0.275	25.0	59.0	17.5
7	0	30	0	145	59	4.5	0.284	50.0	52.0	15.7
8	0	30	0	145	58.5	4.4	0.295	47.5	52.0	16.0
9	1	35	1	150	64	3.5	0.261	42.5	50.0	16.32
10	0	30	0	145	59	4.2	0.268	42.5	52.5	15.5
11	1.4	37	0	145	62.5	3.6	0.265	39.0	54.5	15.0
12	0	30	-1.4	138	55	4.4	0.261	29.0	57.0	18.0
13	0	30	0	145	59	4.1	0.295	50.0	52.0	15.3

Table 1(b) The central composite experimental design (in coded level of two variables) for gum arabic assisted spray drying of palm juice

Sl No	Independent Variables				Dependent Variables					
	Gum arabic, g (X1)		Inlet Temp., ^{0}C (X2)		Powder Yield,% (Y1)	Moisture, %(Y2)	Water Activity (Y3)	Solubility, secs (Y4)	Ascorbic Acid (µg /ml) (Y5)	Juice Colour, ΔE (Y6)
	Coded	Actual	Coded	Actual						
1	0	15	1.4	142	68.4	3.30	0.265	37.2	57.6	26.4
2	1	20	-1	130	69.2	3.35	0.270	42.0	57.6	27.5
3	1	20	1	140	70.0	3.30	0.290	45.0	56.3	28.4
4	0	15	0	135	65.1	3.80	0.275	38.5	54.9	25.1
5	-1	10	-1	130	64.5	4.12	0.251	37.2	52.6	21.6
6	-1	10	1	140	65.7	3.74	0.262	36.5	53.8	22.8
7	1.4	22	0	135	72.4	3.20	0.280	43.3	58.2	28.8
8	-1.4	7.9	0	135	62.7	4.10	0.241	35.7	51.9	21.2
9	0	15	-1.4	128	67.2	3.90	0.278	35.4	54.6	23.7
10	0	15	0	135	68.4	3.50	0.283	36.7	55.9	27.5
11	0	15	0	135	69.5	3.70	0.291	37.2	57.2	26.9
12	0	15	0	135	68.4	3.65	0.279	37.4	56.1	28.1
13	0	15	0	135	67.5	3.81	0.275	38.3	57.6	27.5

Table 1(c) The central composite experimental design (in coded level of two variables) for combined additive assisted spray drying of palm juice

Sl No	Independent Variables						Dependent Variables					
	Maltodextrin (g) (X1)		Gum Arabic (g) (X2)		Inlet Temp. (^{0}C) (X3)		Powder Yield % (Y1)	Moisture % (Y2)	Water Activity (Y3)	Solubility, secs (Y4)	Ascorbic Acid (µg /ml) (Y5)	Juice Colour, ΔE (Y6)
	Coded	Actual	Coded	Actual	Coded	Actual						
1	0	27.5	0	12.5	1.68	147	67.2	3.75	0.29	34.7	54.00	20.51
2	0	27.5	0	12.5	0	130	64.8	3.7	0.32	35.4	57.32	22.18
3	1.68	31.7	0	12.5	0	130	65.8	3.1	0.28	31.3	56.70	20.49
4	0	27.5	1.68	16.7	0	130	60.3	3.7	0.30	36.2	55.12	21.83
5	-1	25.0	-1	10.0	1	140	56.5	3.56	0.35	32.8	56.00	18.22
6	1	30.0	1	15.0	1	140	67.2	3.6	0.23	35.5	55.60	23.12
7	1	30.0	-1	10.0	1	140	62.7	3.35	0.28	31.5	54.60	19.10
8	1	30.0	1	15.0	-1	120	58.5	3.45	0.30	32.4	57.20	23.24
9	0	27.5	0	12.5	-1.68	113	56.1	3.6	0.35	33.7	57.14	21.56
10	0	27.5	0	12.5	0	130	64.5	3.7	0.34	34.6	56.50	21.69
11	-1.68	23.3	0	12.5	0	130	62.1	3.48	0.33	31.74	58.23	19.62
12	0	27.5	0	12.5	0	130	66.5	3.69	0.31	34.9	57.69	20.96
13	0	27.5	-1.68	8.3	0	130	57.5	3.45	0.38	34.0	55.20	17.90
14	-1	25.0	1	15.0	-1	120	57.2	3.56	0.35	32.3	58.23	19.89
15	1	30.0	-1	10.0	-1	120	61.2	3.31	0.34	31.9	55.30	19.26
16	-1	25.0	1	12.0	1	140	63.8	3.67	0.31	33.9	55.81	21.40
17	0	27.5	0	12.5	0	130	62.5	3.68	0.31	34.9	56.39	22.00
18	-1	25.0	-1	10.0	-1	120	55.2	3.74	0.37	34.3	59.13	20.13
19	0	27.5	0	12.5	0	130	65.9	3.61	0.34	34.6	56.38	22.48
20	0	27.5	0	12.5	0	130	66.5	3.7	0.31	34.8	55.62	23.15

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^{0}C. The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (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 R^2, Adj. R^2 and Predicted R^2 (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 R^2, Adj. R^2 and Predicted R^2 (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 R^2, Adj. R^2 and Predicted R^2 (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 (**Ioana *et al.*, 2015; Bazaria *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). The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (Table 2a).

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; Bazaria *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 R^2, Adj. R^2 and Predicted R^2 (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.

Table 2(a) Coefficients of regression, R^2 values for the different Responses for Maltodextrin aided spray drying of palm juice

Regression Coefficient	Moisture	Water Activity	Solubility	Ascorbic Acid	Colour change	Yield
b_0	4.28	0.28	46.5	52.20	15.5	58.9
b_1	-0.16^{*}	-0.029^{***}	-4.51^{**}	1.13^{**}	-0.71	2.22^{***}
b_2	-0.19^{*}	0.86	4.07^{**}	-3.02^{***}	-1.09^{**}	2.66^{***}
b_{12}	-0.16^{*}	-0.012	4.50	-0.94	0.70	-0.50
b_1^2	0.22^{**}	0.012^{*}	-0.91	0.34	0.61	0.46^{*}
b_2^2	-0.093	-0.113	-6.53	0.34	0.86^{*}	0.081
R^2	0.89	0.923	0.909	0.963	0.883	0.989
Adjusted R^2	0.81	0.87	0.84	0.93	0.80	0.98
Predicted R^2	0.78	0.78	0.78	0.75	0.75	0.93

b represents the coefficients of equations different responses with b_0 the constant term; b_1, and b_2 the linear effects (1, and 2 respectively the concentration, temperature); b_1^2, b_2^2 are the quadratic effects; and b_{12} is the interactions.
* Significant at $p \leq 0.05$, ** Significant at $p \leq 0.01$, *** Significant at $p \leq 0.001$.

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 (**Fazaeli *et al.*, 2012; Jittanit *et al.*, 2010, Vivek *et al*., 2020**). The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (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 (**Fazaeli *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 R^2, Adj. R^2 and Predicted R^2 (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 quadrative 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 (**Yousefi *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 R^2, Adj. R^2 and Predicted R^2 (Table 2b).

Solubility time

The linear term for additive concentration had a significant effect on the solubility of the powder at *$p< 0.01$*. Gum arabic decreases the solubility of the spray-dried palm powder. The solubility time of powder increased with an increase in additive concentration (Fig. 3(d)). This increase in solubility time of the powder may be attributed to the lower soluble properties of Gum arabic. Similar results have been reported for pineapple and watermelon powder spray dried with gum Arabic (**Quek *et al.*, 2007 and Gabas *et al.*, 2007**). The interaction terms and quadratic term for additive concentration *($p< 0.05$)* show a positive effect on solubility time, confirming the results. The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (Table 2b).

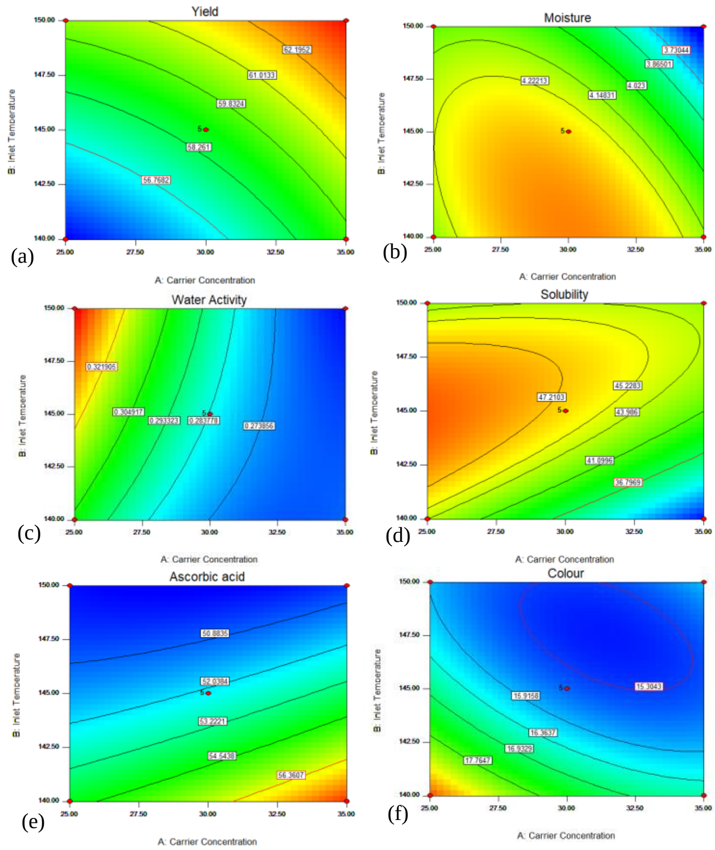

Figure 2 Response surfaces of Maltodextrin aided spray drying representing the effect of Additive Concentration and Inlet Temperature on (a) Powder Yield (b) Moisture Content (c) Water activity (d) Solubility Time (e) Ascorbic Acid Content (f) Colour Change

Ascorbic acid content

The linear term for additive concentration had a significant effect on the ascorbic acid content of the palm powder at *p< 0.01*. The response surfaces of this parameter are shown in Fig. 3(e). Ascorbic acid content increased with an increase in additive concentration. In the presence of more additive, the ascorbic acid is encapsulated well and less effected on exposure to a higher temperature. The quadratic term for additive concentration also had a significant difference at p< 0.05, suggesting less degradation Ascorbic acid in the presence of a higher amount of additive. These additives encapsulate ascorbic acid and other antioxidants present in the fruit juice matrix (**Quek *et al.*, 2007, Jittanit *et al.*, 2010, Vivek *et al.*, 2020**). The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (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. The response surface 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 R^2, Adj. R^2 and Predicted R^2 (Table 2b). The optimized value of the colour difference (ΔE) was 23.08±0.08.

The Palm juice powder with gum Arabic additive had a moisture content of 3.69±0.22 % (db), water activity of 0.25±0.014, Ascorbic Acid content of 54±0.0015 μg of AA/ml with solubility time of 35.7±0.03 seconds.

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

Regression Coefficient	Moisture	Water Activity	Solubility	Ascorbic Acid	Colour change	Yield
b_0	3.69	0.28	37.62	56.34	27.02	67.78
b_1	-0.31***	0.013**	3.01**	2.05**	2.78***	2.84***
b_2	-0.16**	0.577	0.61	0.52	0.74	0.46
b_{12}	-0.083	0.25	0.93	-0.63	-0.075	-0.10
b_1^2	0.020	-0.48*	1.51*	-0.77*	-1.00*	-0.20
b_2^2	-0.045	-0.98	-0.091	-0.25	-0.97*	-0.071
R^2	0.92	0.80	0.87	0.84	0.93	0.82
Adjusted R^2	0.86	0.65	0.78	0.73	0.88	0.70
Predicted R^2	0.76	0.62	0.76	0.68	0.86	0.67

b Represents the coefficients of equations different responses with b_0 the constant term; b_1, and b_2 the linear effects (1, and 2 respectively the concentration, temperature); b_1^2, b_2^2 are the quadratic effects; and b_{12} is the interactions.
* Significant at $p \le 0.05$, ** Significant at $p \le 0.01$, *** Significant at $p \le 0.001$.

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^{0}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 R^2, Adj. R^2 and Predicted R^2 (Table 2c).

Moisture content

Maltodextrin and gum Arabic was used for spray drying of palm juice. Fig. 4 (b) shows the graphs of the response surfaces of moisture content. The linear terms of both the additives and inlet temperature (p<0.01) had significant effects on the moisture content of the powder. The moisture content of palm powder decreased with an increase in additives concentration. The combined effect of two additives helped in better microencapsulation of the fruit juice matrix. The interaction terms of the combined effect of gum arabic concentration-inlet temperature had a significant effect on the moisture content of the powder at p<0.01, whereas the interaction terms of maltodextrin concentration-inlet temperature, had a significant effect at p<0.05. Gum arabic was more effective in decreasing the moisture content of the palm powder than maltodextrin. The quadratic terms of maltodextrin concentration *(p<0.001)* and gum arabic concentration *(p<0.05)* had significant effects on the moisture content of the powder. The presence of a higher amount of maltodextrin and gum Arabic in palm juice reduces the moisture content of palm powder at a higher temperature. This may be due to the anti-hygroscopic property of these additives. Similar results have been reported for spray-dried sugarcane and mulberry powders (**Largo *et al.*, 2015; Fazaeli *et al.*, 2012**). The data fits the equation extremely well with the highest R^2, Adj. R^2 and Predicted R^2 (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 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).

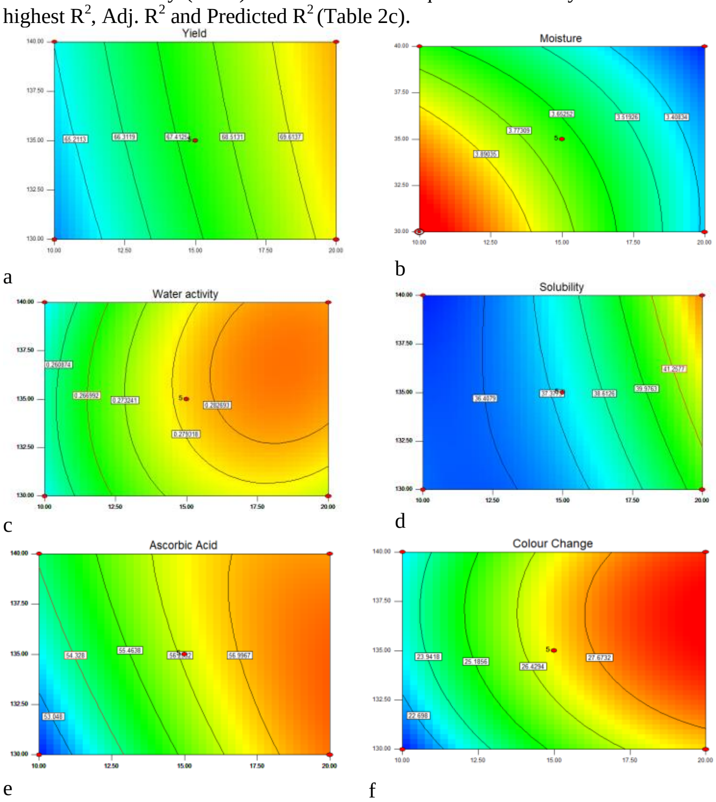

Figure 3 Response surfaces of Gum Arabic aided spray drying representing the effect of Additive Concentration and Inlet Temperature on (a) Powder Yield (b) Moisture Content (c) Water activity (d) Solubility Time (e) Ascorbic Acid Content (f) Colour Change

Solubility time

Significance differences were observed for linear terms of gum arabic (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 2(c) Coefficients of regression, R^2 values for the different Responses for the combined effect of additives on spray drying of palm juice

Regression Coefficient	Moisture	Water activity	Solubility	Ascorbic Acid	Colour	Yield
b_0	3.68	0.32	34.88	56.64	22.07	65.15
b_1	-0.11^{***}	-0.023^{***}	-0.20^{*}	-0.66^{**}	0.48	1.69^{**}
b_2	0.054^{***}	-0.021^{**}	0.53^{**}	0.12	1.29^{***}	1.16^{*}
b_3	0.027^{**}	-0.021^{**}	0.33^{**}	-0.96^{**}	-0.18	2.69^{***}
b_{12}	0.058^{**}	-0.75	0.68^{**}	0.50	0.63^{*}	-0.94
b_{13}	0.033^{*}	-0.75	0.33^{*}	0.41	0.015	0.29
b_{23}	0.050^{**}	-0.75	0.83^{***}	-0.024	0.43	1.56
b_1^2	-0.13^{***}	0.036	-1.28^{***}	0.38	-0.64^{*}	-0.62
b_2^2	-0.031^{*}	-0.339	-0.014	-0.43	-0.71^{*}	-2.41^{***}
b_3^2	0.883	-0.732	-0.33^{**}	-0.29	-0.30	-1.44^{**}
R^2	0.96	0.913	0.968	0.867	0.891	0.925
Adjusted R^2	0.93	0.83	0.94	0.74	0.79	0.85
Predicted R^2	0.78	0.62	0.82	0.66	0.65	0.69

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_1^2, b_2^2 , b_3^2 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 Comparative Studies of physicochemical properties of the control and reconstituted juices

Properties	Optimized juice (Control Sample)	Reconstituted juice from MD aided SD Powder	Reconstituted juice from GA aided SD Powder	Reconstituted juice from MD and GA aided SD Powder
Moisture content (%)	87.1 ± 1.09 ^{c}	88.2 ± 0.12 ^{a}	87.23 ± 0.24 ^{c}	89.2 ± 1.25 ^{d}
Total solid (%)	12.9 ± 0.17 ^{b}	12.71 ± 0.63 ^{d}	12.82 ± 0.22 ^{b}	12.90 ± 0.23 ^{a}
Total soluble solid (Brix)	12.8 ± 0.0513 ^{a}	12.54 ± 0.23 ^{b}	12.6 ± 0.41 ^{a}	12.7 ± 0.66 ^{b}
Total dissolved solids (ppm)	259.4 ± 0.108 ^{c}	345.52 ± 0.61 ^{b}	350.23 ± 0.52 ^{a}	356.2 ± 0.114 ^{b}
pH	3.5 ± 0.031 ^{a}	4.5 ± 0.011 ^{a}	4.2 ± 0.015 ^{c}	4.2 ± 0.021 ^{b}
Ascorbic acid (µg of AA/ml)	57 ± 0.0003 ^{d}	51 ± 0.0026 ^{c}	55 ± 0.024 ^{a}	54 ± 0.005 ^{a}
Protein (mg/ml)	1.36 ± 0.23 ^{d}	1.33 ± 0.05 ^{a}	1.31 ± 0.25 ^{b}	1.31 ± 0.12 ^{c}
Fat%	0.45 ± 0.13 ^{c}	0.42 ± 0.04 ^{d}	0.45 ± 0.11 ^{d}	0.41 ± 0.25 ^{a}
Sugar (mg/ml)	95 ± 0.52 ^{a}	85.52 ± 0.51 ^{c}	82.15 ± 0.33 ^{b}	88.3 ± 0.41 ^{d}
Yield (%)	87.9 ± 0.66 ^{d}	55.01 ± 0.55 ^{b}	68.56 ± 0.44 ^{d}	63.5 ± 0.29 ^{b}
Colour difference (ΔE)	8.41± 0.03 ^{c}	16.52 ± 0.23 ^{d}	27.34 ± 0.59 ^{a}	18.37± 0.03 ^{c}

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.

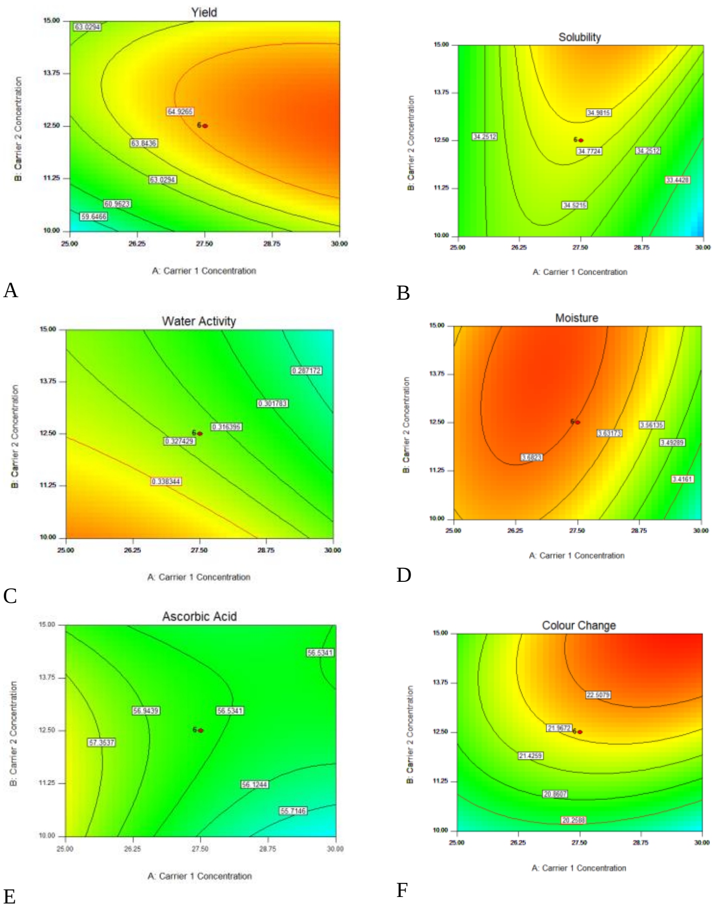

Figure 4 Response surfaces of Combined aided spray drying representing effect of Additive Concentration and Inlet Temperature on (a) Powder Yield (b) Moisture Content (c) Water activity (d) Solubility Time (e) Ascorbic Acid Content (f) Colour Change

Colour of the reconstituted juice

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 (**Rodríguez-Hernández *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 (ΔE) 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.

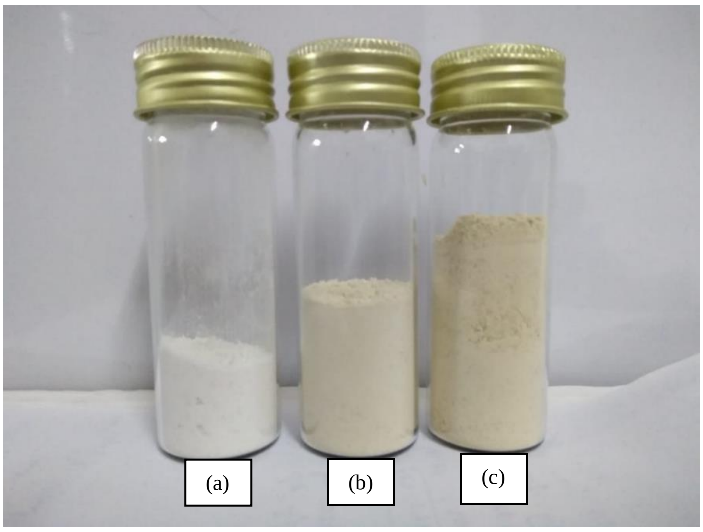

Figure 5 Palm Powder obtained from different Spray drying conditions (a) Maltodextrin aided spray-dried palm powder (b) Gum Arabic aided spray-dried palm powder (c) Combined Additive aided spray-dried palm powder

CONCLUSION

Palm (*Borassus flabellifer*) is a seasonal fruit rich in nutrients and antioxidants. As extraction of palm pulp and juice is difficult, preservation and value-addition have not been taken up commercially. Palm juice was enzymatically extracted for this work. Again due to the high sugar content of the juice, shelf life is very less. Palm fruit powder could be a suitable alternative. In this work, spray-drying of the juice with multiple additives such as maltodextrin and gum Arabic, in combination, was explored. The additive concentration and inlet temperature of spray-drying were optimized for quality parameters of the powder and reconstituted juice using the central composite design of the response surface method. Spray-drying of enzymatically extracted palm juice was optimized at an inlet temperature of 140ºC and with a combination of additives (maltodextrin and gum Arabic) at a ratio of 3:1. Palm powder obtained from these optimized spray-drying parameters had better yield, quality, and stability. Palm powder with gum Arabic had better quality than that with maltodextrin under optimum operating conditions. However, the palm powder with combined maltodextrin and gum Arabic had the best quality as compared to individual additive. The optimized palm powder 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 reconstituted palm juice had similar physicochemical properties as those with enzymatically extracted palm juice. These optimized parameters for spray drying of palm juice can be adopted in the industrial scale for making palm powder.

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