

# Supplementary Data

## 1. Supplementary methods

### 1.1. Optimization of oil loaded powders using multilevel category design

The multilevel category design was conducted based on the experimental results with the data already obtained. Design Expert® 11(Stat-Ease Inc, Minneapolis, MN, USA) was used for experimental design and statistical evaluation. The experiments were designed by excluding PVP, Gelatin A, and Gelatin B as absorbents. This is due to the fact that when the above absorbents and hydrogenated lecithin and PEG40 glycerol monostearate were used as surfactants, the powders were not formed. As a categoric factor, two factors were used as independent variables. Five kinds of levels (MC, HPMC,  $\alpha$ -CD,  $\beta$ -CD,  $\gamma$ -CD) were used for the type of absorber ( $X_1$ ). The type of surfactant ( $X_2$ ) was carried out using three levels (Poloxamer 188, hydrogenated lecithin, PEG40 glycerol monostearate). The evaluation of each formulation is based on the particle size of the second emulsion (SE,  $Y_1$ ), particle size of reconstituted emulsion (RE,  $Y_2$ ), moisture ( $Y_3$ ), free oil ( $Y_4$ ), encapsulated oil (EE,  $Y_5$ ), total oil ( $Y_6$ ) and morphology score ( $Y_7$ ) (Table S1).

**Table 1.** Factors and responses used in multilevel category design.

Categoric factor	Factors	Levels					
		1	2	3	4	5	
	$X_1$ : Absorbents	MC	HPMC	$\alpha$ -CD	$\beta$ -CD	$\gamma$ -CD	
Response	$X_2$ : Surfactants	Poloxamer 188	Hydrogenated Lecithin		PEG40 glycerol monostearate		
	$Y_1$	$Y_2$	$Y_3$	$Y_4$	$Y_5$	$Y_6$	$Y_7$
	SE (nm)	RE (nm)	Moisture (%)	Free oil (g/100g)	EE (g/100g)	Total oil (g/100g)	Morphology score
Goals	Minimize	Minimize	Minimize	Minimize	Maximize	Maximize	Maximize

Forty-five experimental compositions were run and observed responses were as like Table S2.

**Table 2.** The experimental composition and observed responses through multilevel category design.

Run	Factors		Responses						
	$X_1$	$X_2$	$Y_1$	$Y_2$	$Y_3$	$Y_4$	$Y_5$	$Y_6$	$Y_7$
	Absorbents	Surfactants	SE (nm)	RE (nm)	Moisture (%)	Free oil (g/100g)	EE (g/100g)	Total oil (g/100g)	Morphology score
1	$\beta$ -CD	Poloxamer 188	268.95	374.75	4.1	39.35	9.66	59.37	2
2	$\beta$ -CD	H.Lecithin	237.4	330.2	3.75	48.04	10.86	43.78	7
3	HPMC	P.monostearate	285.97	405.6	4.75	52.36	10.22	56.26	5
4	$\gamma$ -CD	H.Lecithin	280.57	246.2	4	49.55	10.18	36.96	10
5	$\alpha$ -CD	P.monostearate	540.1	847.7	6.45	56.63	9.18	59.69	3
6	$\alpha$ -CD	Poloxamer 188	250.8	360.4	3.55	38.87	13.74	58.33	1
7	$\alpha$ -CD	H.Lecithin	257	216.57	3.75	52.59	10.27	52.45	1
8	HPMC	H.Lecithin	336.93	472.97	2.85	47.8	11.36	30.49	2
9	$\gamma$ -CD	Poloxamer 188	258.95	293.35	4.98	37.96	8.66	56.02	1
10	$\alpha$ -CD	P.monostearate	500.64	789.39	5.25	51.2	8.92	55.85	3
11	$\alpha$ -CD	P.monostearate	579.56	906.01	7.65	62.06	9.44	63.53	3
12	HPMC	P.monostearate	283.96	396.46	2.84	51.92	9.6	54.32	5
13	HPMC	H.Lecithin	299.11	457.02	2.78	47.443	7.72	22.59	2
14	MC	P.monostearate	284.87	342.13	5.9	67.78	11.77	71.43	5
15	HPMC	H.Lecithin	374.75	488.92	2.92	48.17	15	38.39	2
16	MC	H.Lecithin	296.47	472.73	2.9	58.04	17.33	56.04	4
17	$\alpha$ -CD	H.Lecithin	248.68	214.09	3.54	51.62	7.63	50.66	1

18	$\beta$ -CD	H.Lecithin	227.26	292.03	3.26	46.6	8.84	40.85	7
19	MC	Poloxamer 188	488.85	600.85	5.1	48.28	10.85	66.42	3
20	$\beta$ -CD	Poloxamer 188	255.55	219.15	3.11	37.75	8.3	57.08	2
21	$\gamma$ -CD	P.monostearate	339.23	712.2	5.5	65.68	7.73	67.51	5
22	$\gamma$ -CD	P.monostearate	315.2	639.59	4.65	63.99	7.2	65.48	5
23	$\alpha$ -CD	H.Lecithin	265.32	219.05	3.96	53.56	12.91	54.24	1
24	$\gamma$ -CD	H.Lecithin	262.76	226.28	3.86	48.92	7.23	32.7	10
25	$\gamma$ -CD	P.monostearate	363.26	784.81	6.35	67.37	8.26	69.54	5
26	MC	Poloxamer 188	458.05	524.25	4.4	46.86	7.03	65.09	3
27	MC	Poloxamer 188	519.65	677.45	5.8	49.7	14.67	67.75	3
28	$\beta$ -CD	Poloxamer 188	282.35	530.35	5.09	40.95	11.02	61.66	2
29	$\beta$ -CD	P.monostearate	354.87	847.7	3.8	56.63	9.18	59.69	4
30	$\gamma$ -CD	Poloxamer 188	251.65	274.35	3.78	34.99	5.38	50.13	1
31	MC	P.monostearate	279.81	331.19	4.2	67.36	10.94	66.91	5
32	HPMC	Poloxamer 188	396.85	483.95	3.5	36.66	10.3	56.41	3
33	$\beta$ -CD	P.monostearate	351.58	789.39	3.23	51.2	8.92	55.85	4
34	HPMC	Poloxamer 188	393.85	418.65	3.36	33.4	9.64	53.94	3
35	MC	H.Lecithin	273.66	455.7	2.76	56.51	13.47	53.14	4
36	HPMC	P.monostearate	287.98	414.74	6.66	52.8	10.84	58.2	5
37	$\beta$ -CD	H.Lecithin	247.54	368.37	4.24	49.48	12.88	46.71	7
38	$\gamma$ -CD	Poloxamer 188	266.25	312.35	6.18	40.93	11.94	61.91	1
39	$\alpha$ -CD	Poloxamer 188	241.9	310.1	3.34	36.66	11.76	55.32	1
40	$\gamma$ -CD	H.Lecithin	298.38	266.12	4.14	50.18	13.13	41.22	10
41	$\beta$ -CD	P.monostearate	358.16	906.01	4.37	62.06	9.44	63.53	4
42	MC	H.Lecithin	319.28	489.76	3.04	59.57	21.19	58.94	4
43	HPMC	Poloxamer 188	399.85	549.25	3.64	39.92	10.96	58.88	3
44	MC	P.monostearate	289.93	353.07	7.6	68.2	12.6	75.95	5
45	$\alpha$ -CD	Poloxamer 188	259.7	410.7	3.76	41.08	15.72	61.34	1

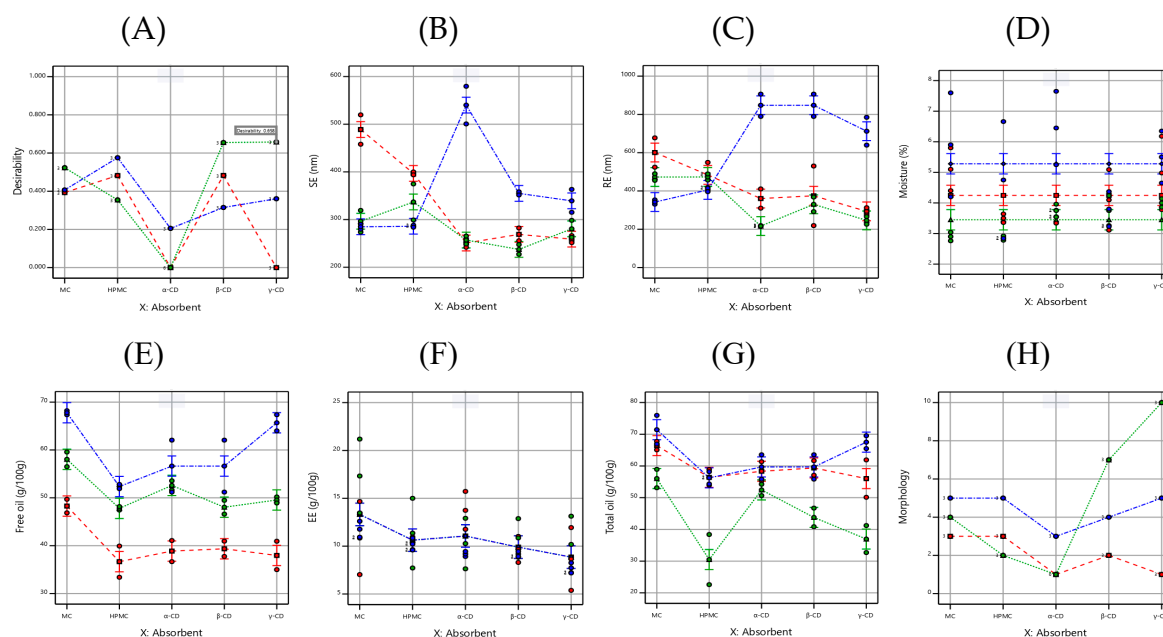
In summary, model p-value and statistical analysis were successfully carried out (Table S3).

**Table 3.** Summary of model p-value and statistical analysis.

Response	Model p-value	R <sup>2</sup>	Adjusted R <sup>2</sup>	Predicted R <sup>2</sup>	Adeq Precision	Importance
Y1: SE	<0.0001	0.9658	0.9498	0.9230	26.47	+++++
Y2: RE	<0.0001	0.9426	0.9157	0.8707	18.58	+++++
Y3: Moisture	0.0001	0.3453	0.3141	0.2484	6.64	+
Y4: Free Oil	<0.0001	0.9525	0.9303	0.8931	21.20	+++
Y5: EE	0.0160	0.2574	0.1832	0.0602	5.01	++
Y6: Total oil	<0.0001	0.9218	0.8853	0.8241	18.71	+++
Y7: Morphology score	-	1	1	1	1	+++++

\*The morphology score is R<sup>2</sup>, which is 1 because the results of three experiments were assigned the same score.

The p-values < 0.0500 indicate model terms are significant. R<sup>2</sup> values close to 1 indicate satisfactory analytical quality. It is recommended that the difference between adjusted R<sup>2</sup> and predicted R<sup>2</sup> is less than 0.2. Adeq precision measures the signal to noise ratio. A ratio greater than 4 is desirable. This means that this model can be used to navigate the design space. The degree of importance was determined by reflecting R<sup>2</sup> and Adeq precision.



**Figure 1.** Effect of factors on responses. (A), Desirability; (B),  $Y_1$  (SE, nm); (C),  $Y_2$  (RE, nm); (D),  $Y_3$  (Moisture, %); (E),  $Y_4$  (Free oil, g/100g); (F),  $Y_5$  (Encapsulated oil, g/100g); (G),  $Y_6$  (Total oil, g/100g); (H),  $Y_7$  (Morphology score). The desirability value is calculated by reflecting the goal and importance for all the responses. The higher the value, the more the characteristics are similar to the target characteristics. Desirability value was calculated by reflecting the results of several responses according to the degree of importance. As a result, the P18 formulation (Desirability value: 0.658) was selected as the best formulation because the highest value was obtained. **Note.** (---■---) Poloxamer 188, (---▲---) Hydrogenated Lecithin, (---◆---) PEG40 glycerol monostearate.