CHAPTER IV

RESULTS AND DISCUSSION

1. Preparation of Curcuminoid Microcapsules by Spray-Drying Techniques

The experiment was carried out by coating the curcuminoid extract with three types of polymer, employing curcuminoids: polymer in the ratios of 1:1, 1:2 and 1:3 (Table 6). The resulting spray-dried microcapsules were assessed their properties, which included the percent yield, percent content and percent entrapment of curcuminoids in microcapsules, the morphology and particle size, bulk and tapped densities, percent moisture content, chemical stability of curcuminoid microcapsules during storage, and chemical stability of curcuminoid microcapsules contained in skin-care preparations.

2. Analysis of Curcuminoid Microcapsules

2.1. Yield of microcapsules

The percent yield was calculated as the ratio of the mass of microcapsules obtained at the end of the process and the mass of initial solid substances added, including curcuminoid extract and polymer, multiplying by 100. The compositions of microcapsules and the percent yields were shown in table 6.

Table 6. The compositions of microcapsules and the percent yields.

Sam no.	Sample Description				Actual wt. of microcapsules (g.)	Obtained wt. of microcapsules (g.)	% Yield
	Polymer	Plasticizer	Drug: Polymer	%Solid content			
1	PM	PG + GTA	1:1	1	10.19	None	-
2	PM	PG + GTA	1:1	2	20.04	None	-
3	PM	PG + GTA	1:2	1	10.59	None	-
4	PM	PG + GTA	1:2	2	20.57	None	-
5	PM	PG + GTA	1:3	1	10.49	None	-
6	PM	PG + GTA	1:3	2	20.37	None	-
7	PM	PG	1:1	1	10.86	3.47	32.0
8	PM	PG	1:1	2	20.67	8.34	40.3
9	PM	PG	1:2	1	10.63	5.14	48.4
10	PM	PG	1:2	2	20.56	7.05	34.3
11	PM	PG	1:3	1	10.35	6.17	59.6
12	PM	PG	1:3	2	20.52	8.71	42.4
13	PM	PG + PEG400	1:1	1	10.27	3.04	29.6
14	PM	PG + PEG400	1:1	2	20.12	4.65	23.1
15	PM	PG + PEG400	1:2	1	10.51	4.29	40.8
16	PM	PG + PEG400	1:2	2	20.73	10.40	50.2
17	PM	PG + PEG400	1:3	1	10.42	4.52	43.4
18	PM	PG + PEG400	1:3	2	20.33	9.82	48.3
19	PVA	PG + GTA	1:1	1	10.83	None	-
20	PVA	PG + GTA	1:1	2	20.43	None	-
21	PVA	PG + GTA	1:2	1	10.25	None	-
22	PVA	PG + GTA	1:2	2	20.13	None	-
23	PVA	PG + GTA	1:3	1	10.79	None	-
24	PVA	PG + GTA	1:3	2	20.95	None	-
25	PVA	PG	1:1	1	10.76	None	-
26	PVA	PG	1:1	2	20.28	None	-
27	PVA	PG	1:2	1	10.67	None	-
28	PVA	PG	1:2	2	20.61	None	-
29	PVA	PG	1:3	1	10.53	None	-
30	PVA	PG	1:3	2	20.44	None	-
31	PVA	PG + PEG400	1:1	1	10.26	None	-
32	PVA	PG + PEG400	1:1	2	20.47	None	-
33	PVA	PG + PEG400	1:2	1	10.10	None	-
34	PVA	PG + PEG400	1:2	2	20.76	None	-
35	PVA	PG + PEG400	1:3	1	10.60	None	-
36	PVA	PG + PEG400	1:3	2	20.38	None	-

Table 6. (Continued)

Sam no.	Sample Description				Actual wt. of microcapsules (g.)	Obtained wt. of microcapsules (g.)	% Yield
	Polymer	Plasticizer	Drug: Polymer	%Solid content			
37	EC	PG + GTA	1:1	1	10.74	3.11	29.0
38	EC	PG + GTA	1:1	2	20.37	7.28	35.7
39	EC	PG + GTA	1:2	1	10.32	4.11	39.8
40	EC	PG + GTA	1:2	2	20.88	6.03	28.9
41	EC	PG + GTA	1:3	1	10.08	3.49	34.6
42	EC	PG + GTA	1:3	2	20.31	2.53	12.5
43	EC	PG	1:1	1	10.66	4.19	39.3
44	EC	PG	1:1	2	20.68	7.17	34.7
45	EC	PG	1:2	1	10.29	3.97	38.6
46	EC	PG	1:2	2	20.17	8.33	41.3
47	EC	PG	1:3	1	10.04	2.85	28.4
48	EC	PG	1:3	2	20.01	8.33	41.6
49	EC	PG + PEG400	1:1	1	10.32	3.33	32.3
50	EC	PG + PEG400	1:1	2	20.83	5.78	27.7
51	EC	PG + PEG400	1:2	1	10.48	5.37	51.2
52	EC	PG + PEG400	1:2	2	20.16	8.30	41.2
53	EC	PG + PEG400	1:3	1	10.14	2.88	28.4
54	EC	PG + PEG400	1:3	2	20.97	4.11	19.6

Table 6 indicated that, under the spray-drying conditions setting air inlet temperature of 120°C, aspirator rate of 28 m^3/hr, pump rate of 5 mL/min, and rotameter of 30 mm, the PVA-coated curcuminoid microcapsules could not be collected due to the adherence of the microcapsules on the inner surface of the separating cyclone. The microcapsules were glutinous in appearance which could be attributed to the influences of low minimum film formation temperature (MFT) of PVA. The MFT is the minimum temperature above which a continuous film is formed during drying (ISO 2115/DIN 53787). PVA aqueous dispersion (Kollicoat®SR 30 D) used had a low MFT and could bring about the tackiness during the coating process (Dashevsky et al., 2005). The spray-dried microcapsules were fine particles with light weight, in which, some were lost with the exhausted air and some were adhered on the inner surface of the separating cyclone.

From table 6, it was found that the PM-coated microcapsules plasticized with the combination of PG/GTA (formulation no. 1-6) could not provide any microcapsules mass in the collector chamber due to the adherence of the microcapsules on the inner surface of the separating cyclone.

Table 6 also showed that the percent yield of the PM-coated microcapules plasticized with PG (formulation no.7-12) at 1% solid content were higher along with the increase of polymer. However, this was not happened for the same formulation of 2% solid content. The percent yield of this formulation ranged from 32.0-59.6%.

The ranges of percent yield of the PM-coated microcapsules plasticized with the combination of PG/PEG400 (formulation no.13-18), EC-coated microcapsules plasticized with the combination of PG/GTA (formulation no.37-42), EC-coated microcapsules plasticized with PG (formulation no.43-48), and EC-coated microcapsules plasticized with the combination of PG/PEG400 (formulation no.49-54) were 23.1-50.2%, 12.5-39.8%, 28.4-41.6%, and 19.6-51.2%, respectively.

The highest percent yield was 59.6% for PM-coated microcapsules plasticized with PG, spray-dried at 1:3 curcuminoids: polymer ratio and 1% solid content and this formulation also found to have highest average percent yield of 42.8%. The lowest percent yield was 12.5% for EC-coated microcapsules plasticized with the combination of PG/GTA, spray-dried at 1:3 curcuminoids: polymer ratio and 2% solid content and this formulation also found to have the lowest average percent yield of 30.1%. Therefore, it could be concluded that the formulation no.7-12 which employed PM and PG as the wall material were superior to other formulations in percent yields.

The overall results revealed that the average percent yield of PM-coated microcapsules was higher than that of EC-coated microcapsules. The reason could be because PM possesses more intermolecular forces caused by strongly polar groups of –COOH and –COO-, which are regularly distributed along the chain and this promotes the cohesion of the polymer. During spray-drying process, PM molecules with more cohesive strength tended to stick together and compact resulted in the certain heavy mass and fell into the collector chamber. Though EC contains strongly polar groups of –OH, it also has rigid ring structure chain backbone which could limit the flexibility and the compactness (Banker, 1966 and Heng et al., 2003).

It was remarked that, with the same polymer, feed formulations which employed only PG as a plasticizer gave higher yield percentage than those with additional of GTA and PEG400. Moreover, the feed formulations with the additional PEG400 were found to have higher percentage of yield than those with the additional GTA.

During the spray-drying process, there were some difficulties encountered in the process which included sticking, fluctuating of inlet temperature, and low yield. Thus, processing variables must be well controlled to avoid these problems. The optimization of spray-drying process involved the evaluation of parameter concerning both spray-dryer and feed formulation.

2. HPLC Analysis

2.1. Analytical Method Development

The analysis for the chromatogram of the curcuminoid microcapsules was determined by preparation of working standard solution of 1.00, 2.50, 5.00, 7.50, 10.00 μg/mL using HPLC for analysis and the conditions as followed

HPLC Condition:

Mobile Phase:	Glacial acetic acid 2%: Acetonitrile (60 : 40)
Column:	Inersil ODS (C18, 5 μm, 4.6 mm x 15 cm)
Flow Rate:	2.0 mL/min
Detector:	UV 425 nm
Temperature:	Room temperature
Injection Volume:	20 μL
Run Time:	19 min

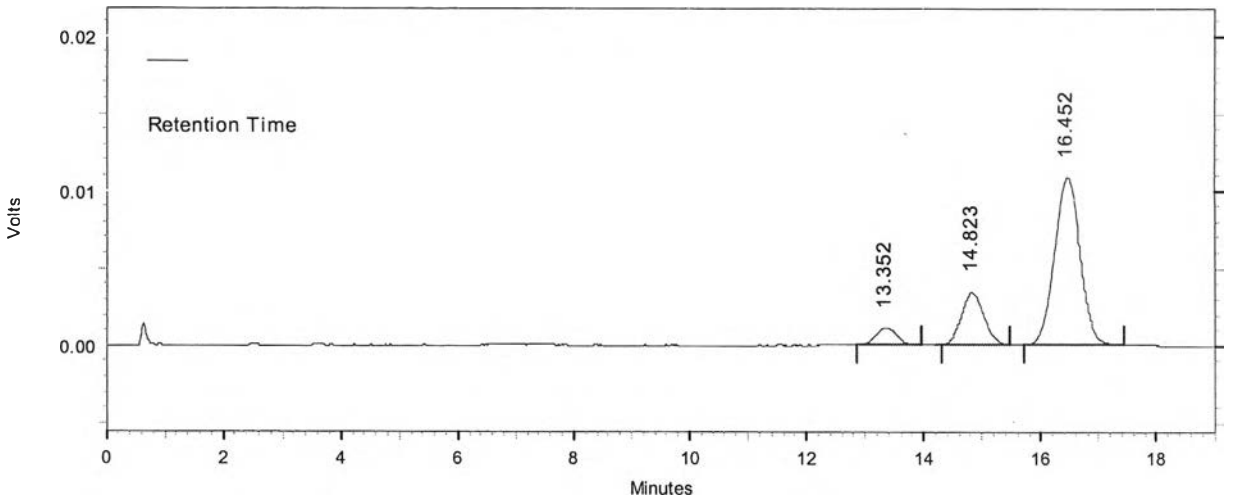


Figure 9. Chromatogram of working standard of curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin.

Retention time of Bisdesmethoxycurcumin = 13.352 min

Retention time of Desmethoxycurcumin = 14.823 min

Retention time of Curcumin = 16.452 min

Curcuminoids standard :

Bisdesmethoxycurcumin 4.43%

Desmethoxycurcumin 23.63%

Curcumin 71.5%

Table 7. Peak area of curcuminoid working standard (standard curve).

Sample	Conc. (μg/mL)	Peak Area		
		Bisdesmethoxy curcumin	Desmethoxy curcumin	Curcumin
Std 1	0.990	2193	10034	34056
Std 2	2.475	6141	21803	80609
Std 3	4.950	13469	45347	164043
Std 4	7.426	21221	68461	246238
Std 5	9.901	29049	92001	330262

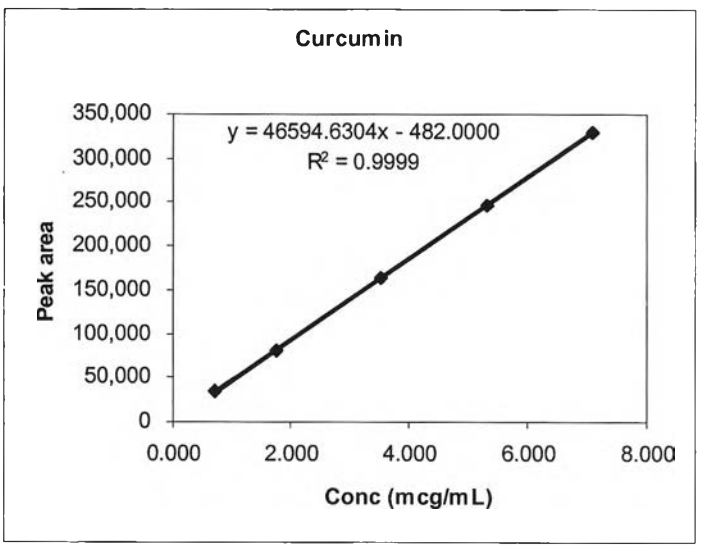


Figure 10. Standard curve of curcumin.

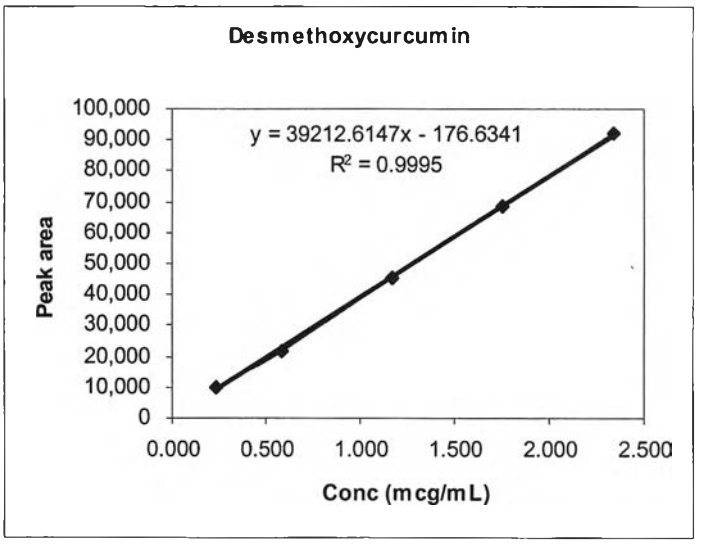


Figure 11. Standard curve of desmethoxycurcumin.

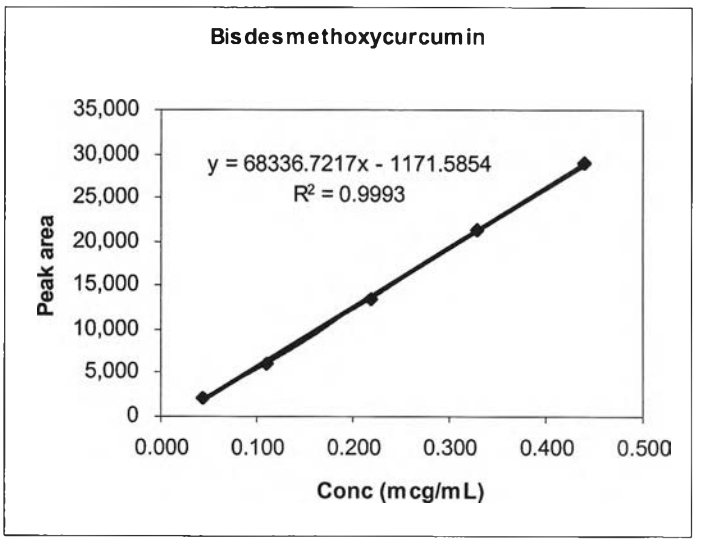


Figure 12. Standard curve of bisdesmethoxycurcumin.

2.2. Analytical Method Validation of Curcumin, Desmethoxycurcumin, and Bisdesmethoxycurcumin of Microencapsulated Curcuminoids in Cleansing Gel Preparation.

Table 8. Peak area of curcuminoids working standard for method validation.

Sample	Conc. (μg/mL)	Peak Area		
		Bisdesmethoxy curcumin	Desmethoxy curcumin	Curcumin
Std 1	0.201	1049	4280	17154
Std 2	0.503	2850	9006	34052
Std 3	1.005	6677	22872	85345
Std 4	2.513	18943	60818	220988
Std 5	5.025	38303	124512	442524

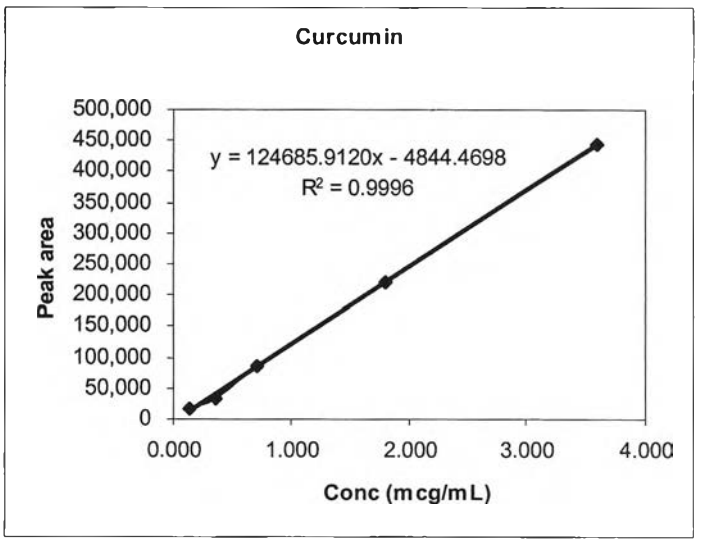


Figure 13. Standard curve of curcumin for method validation.

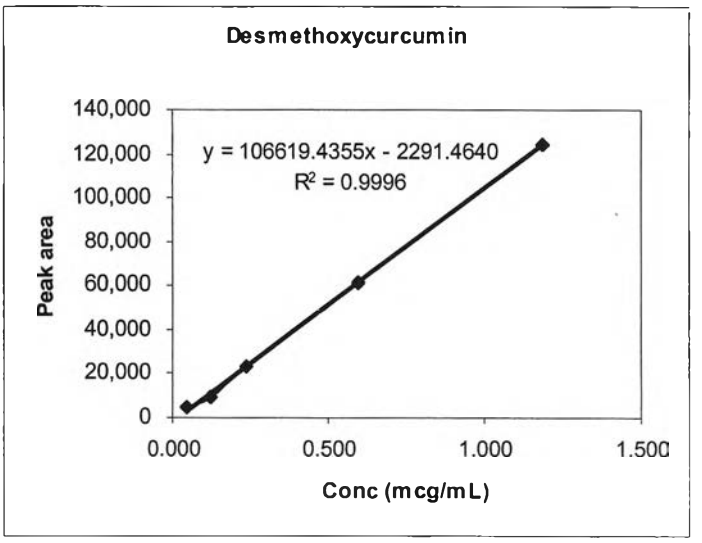


Figure 14. Standard curve of desmethoxycurcumin for method validation.

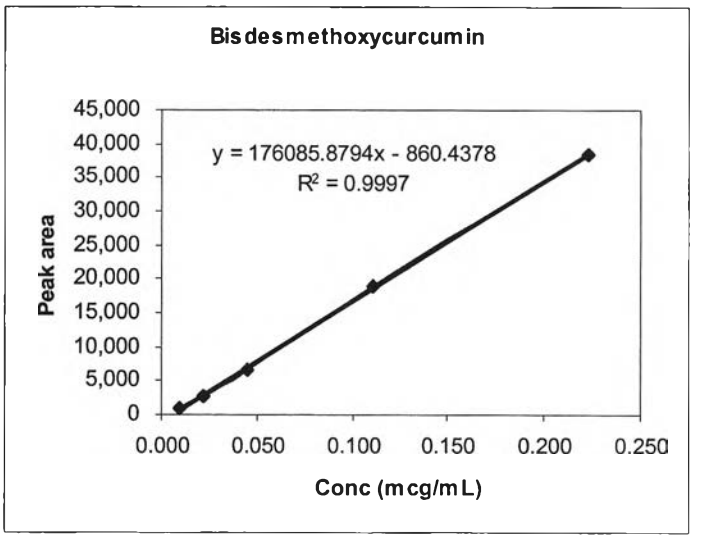


Figure 15. Standard curve of bisdesmethoxycurcumin for method validation.

2.2.1. Accuracy

Accuracy study of analytical method of curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin at five concentrations was carried out. The results were shown in table 9, 10, and 11.

From table 9 curcumin at concentrations of 0.143, 0.286, 0.715, 1.430, and 3.575 μg/mL provided the average of recovery percentages of individual concentration at 100.64%, 99.86%, 105.02%, 103.29%, and 102.65%, respectively. The Relative Standard Deviation Percentages (%RSD) of individual concentration were 0.65%, 2.41%, 0.63%, 2.43%, and 2.66%.

From table 10 desmethoxycurcumin at concentrations of 0.047, 0.095, 0.236, 0.473, and 1.182 μg/mL provided the average of recovery percentages of individual concentration at 119.18%, 105.51%, 104.95%, 102.93%, and 102.38%, respectively. The Relative Standard Deviation Percentages (%RSD) of individual concentration were 1.13%, 3.63%, 0.40%, 2.58%, and 2.36%.

From table 11 bisdesmethoxycurcumin at concentrations of 0.009, 0.018, 0.044, 0.089, and 0.222 μg/mL provided the average of recovery percentages of individual concentration at 123.52%, 96.16%, 93.18%, 103.20%, and 102.46%, respectively. The Relative Standard Deviation Percentages (%RSD) of individual concentration were 1.44%, 2.46%, 1.78%, 1.69%, and 1.15%.

2.2.2. Precision

The determination of precision in analytical method of curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin was done by analysis of six replicates of the concentration of 0.715, 0.236, and 0.044 μg/mL, respectively. The results were shown in table 12, 13, and 14.

Table 12 showed the average of recovery percentage of curcumin at concentration of 0.715 μg/ml was 105.19% and %RSD was 2.27%.

Table 13 showed the average of recovery percentage of desmethoxycurcumin at concentration of 0.236 μg/ml was 105.04% and %RSD was 2.07%.

Table 14 showed the average of recovery percentage of bisdesmethoxycurcumin at concentration of 0.044 μg/ml was 93.87% and %RSD was 2.63%.

2.2.3. Linearity

The linearity of analytical method for curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin was determined at five different concentrations. The results were shown in table 15, 16, and 17 and figure 16, 17, and 18.

Table 15 and figure 16 showed that, at curcumin concentrations of 0.143, 0.286, 0.715, 1.430, and 3.575 μg/mL, the actual concentrations and the observed concentration provided the linear relationship with linear equation $y = 1.027x + 0.0024$ and $r^2 \geq 0.9999$.

Table 16 and figure 17 showed that, at desmethoxycurcumin concentrations of 0.047, 0.095, 0.236, 0.473, and 1.182 μg/mL, the actual concentrations and the observed concentration provided the linear relationship with linear equation $y = 1.0184x + 0.0061$ and $r^2 \geq 0.9999$.

Table 17 and figure 18 showed that, at bisdesmethoxycurcumin concentrations of 0.009, 0.018, 0.044, 0.089, and 0.222 μg/mL, the actual concentrations and the observed concentration provided the linear relationship with linear equation $y = 1.0272x - 0.0007$ and $r^2 = 0.9994$.

2.2.4. Specificity

Since the microencapsulated curcuminoids had to be incorporated into cleansing gel, therefore it had to be proved that the peak of cleansing gel would not disturb the curcuminoids analysis. The results showed that peaks of curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin did not overlap the peak of cleansing gel as being shown in figure 19, the HPLC chromatogram showing the specificity of the analysis.

From the study of these four topics, it could be concluded that the developed analytical method could be used to analyze curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin in microencapsulated curcuminoids which was incorporated in cleansing gel preparation.

Table 9. Accuracy of curcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
1 A	0.143	0.144	100.42	100.64 (100.11-101.38)	0.65
1 B	0.143	0.143	100.11		
1 C	0.143	0.145	101.38		
2 A	0.286	0.291	101.9	99.86 (97.20-101.90)	2.41
2 B	0.286	0.278	97.2		
2 C	0.286	0.287	100.49		
3 A	0.715	0.751	105.05	105.02 (104.35-105.66)	0.63
3 B	0.715	0.746	104.35		
3 C	0.715	0.755	105.66		
4 A	1.43	1.501	104.95	103.29 (100.41-104.95)	2.43
4 B	1.43	1.436	100.41		
4 C	1.43	1.494	104.5		
5 A	3.575	3.558	99.52	102.65 (99.52-104.52)	2.66
5 B	3.575	3.715	103.91		
5 C	3.575	3.737	104.52		

Table 10. Accuracy of desmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
1 A	0.047	0.056	118.53	119.18 (118.27-120.73)	1.13
1 B	0.047	0.057	120.73		
1 C	0.047	0.056	118.27		
2 A	0.095	0.104	109.86	105.51 (102.63-109.86)	3.63
2 B	0.095	0.098	104.05		
2 C	0.095	0.097	102.63		
3 A	0.236	0.249	105.22	104.95 (104.47-105.22)	0.4
3 B	0.236	0.248	105.16		
3 C	0.236	0.247	104.47		
4 A	0.473	0.501	105.97	102.93 (101.04-105.97)	2.58
4 B	0.473	0.478	101.04		
4 C	0.473	0.481	101.78		
5 A	1.182	1.177	99.6	102.38 (99.60-104.00)	2.36
5 B	1.182	1.223	103.55		
5 C	1.182	1.229	104		

Table 11. Accuracy of bisdesmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
1 A	0.009	0.011	125.4	123.52 (121.88-125.40)	1.44
1 B	0.009	0.011	123.29		
1 C	0.009	0.011	121.88		
2 A	0.018	0.017	98.12	96.16 (93.53-98.12)	2.46
2 B	0.018	0.017	96.83		
2 C	0.018	0.017	93.53		
3 A	0.044	0.041	92.08	93.18 (92.08-95.09)	1.78
3 B	0.044	0.041	92.37		
3 C	0.044	0.042	95.09		
4 A	0.089	0.09	101.87	103.20 (101.87-105.17)	1.69
4 B	0.089	0.093	105.17		
4 C	0.089	0.091	102.55		
5 A	0.222	0.224	101.12	102.46 (101.12-103.36)	1.15
5 B	0.222	0.229	103.36		
5 C	0.222	0.228	102.91		

Table 12. Precision of curcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
3 A	0.715	0.751	105.05	105.19 (101.17-108.21)	2.27
3 B	0.715	0.746	104.35		
3 C	0.715	0.723	101.17		
3 D	0.715	0.763	106.69		
3 E	0.715	0.774	108.21		
3 F	0.715	0.755	105.66		

Table 13. Precision of desmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
3 A	0.236	0.249	105.22	105.04 (101.18-107.27)	2.07
3 B	0.236	0.248	105.16		
3 C	0.236	0.239	101.18		
3 D	0.236	0.253	106.92		
3 E	0.236	0.253	107.27		
3 F	0.236	0.247	104.47		

Table 14. Precision of bisdesmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	%Recovery	Average (Range)	%RSD
3 A	0.0443	0.041	92.08	93.87 (90.93-97.47)	2.63
3 B	0.0443	0.041	92.37		
3 C	0.0443	0.04	90.93		
3 D	0.0443	0.042	95.28		
3 E	0.0443	0.043	97.47		
3 F	0.0443	0.042	95.09		

Table 15. Linearity of curcumin.

Samples	Actual Conc. (µg/ml)	Average Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	Average Observed Conc. (µg/ml)
1 A	0.143	0.143	0.144	0.144
1 B	0.143		0.143	
1 C	0.143		0.145	
2 A	0.286	0.286	0.291	0.286
2 B	0.286		0.278	
2 C	0.286		0.287	
3 A	0.715	0.715	0.751	0.751
3 B	0.715		0.746	
3 C	0.715		0.755	
4 A	1.43	1.43	1.501	1.477
4 B	1.43		1.436	
4 C	1.43		1.494	
5 A	3.575	3.575	3.558	3.67
5 B	3.575		3.715	
5 C	3.575		3.737	

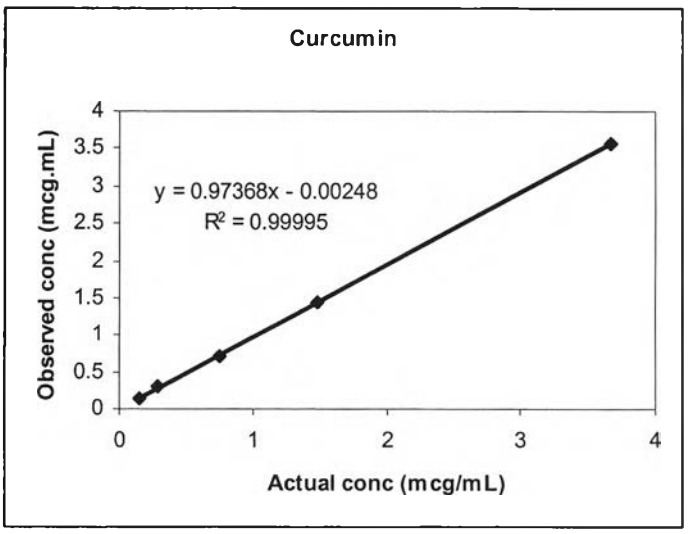


Figure 16. Linearity graph of curcumin.

Table 16. Linearity of desmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Average Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	Average Observed Conc. (µg/ml)
1 A	0.047	0.047	0.056	0.056
1 B	0.047		0.057	
1 C	0.047		0.056	
2 A	0.095	0.095	0.104	0.100
2 B	0.095		0.098	
2 C	0.095		0.097	
3 A	0.236	0.236	0.249	0.248
3 B	0.236		0.248	
3 C	0.236		0.247	
4 A	0.473	0.473	0.501	0.486
4 B	0.473		0.478	
4 C	0.473		0.481	
5 A	1.182	1.182	1.177	1.210
5 B	1.182		1.223	
5 C	1.182		1.229	

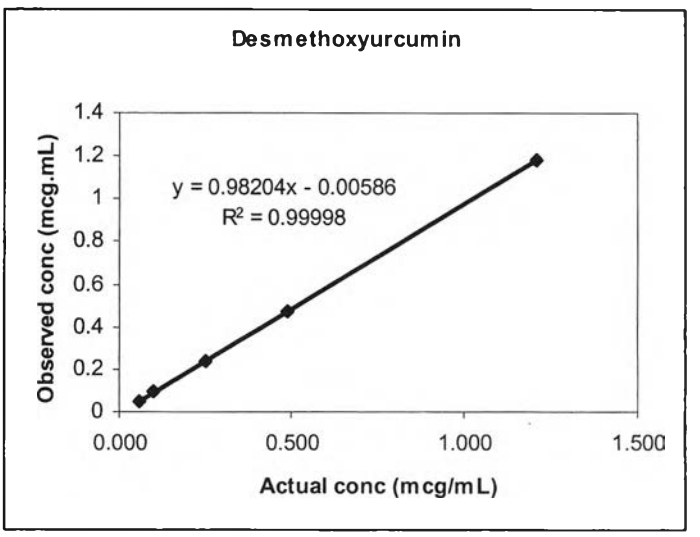


Figure 17. Linearity graph of desmethoxycurcumin.

Table 17. Linearity of bisdesmethoxycurcumin.

Samples	Actual Conc. (µg/ml)	Average Actual Conc. (µg/ml)	Observed Conc. (µg/ml)	Average Observed Conc. (µg/ml)
1 A	0.009	0.009	0.011	0.011
1 B	0.009		0.011	
1 C	0.009		0.011	
2 A	0.018	0.018	0.017	0.017
2 B	0.018		0.017	
2 C	0.018		0.017	
3 A	0.044	0.044	0.041	0.041
3 B	0.044		0.041	
3 C	0.044		0.042	
4 A	0.089	0.089	0.09	0.091
4 B	0.089		0.093	
4 C	0.089		0.091	
5 A	0.222	0.222	0.224	0.227
5 B	0.222		0.229	
5 C	0.222		0.228	

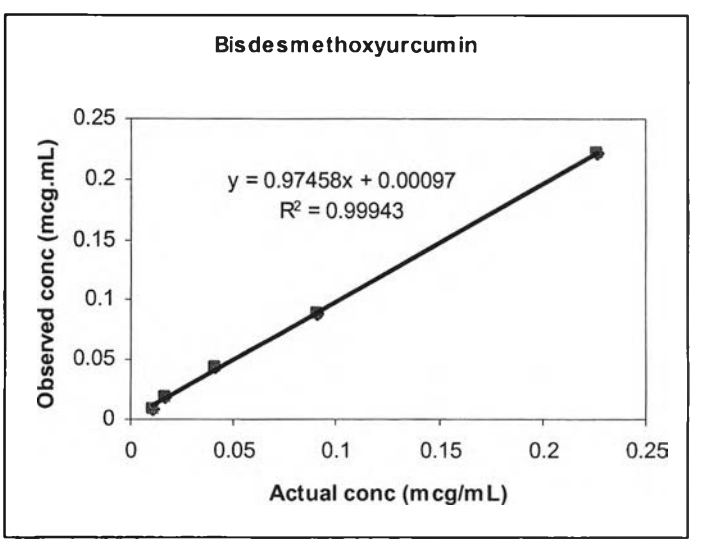


Figure 18. Linearity graph of bisdesmethoxycurcumin.

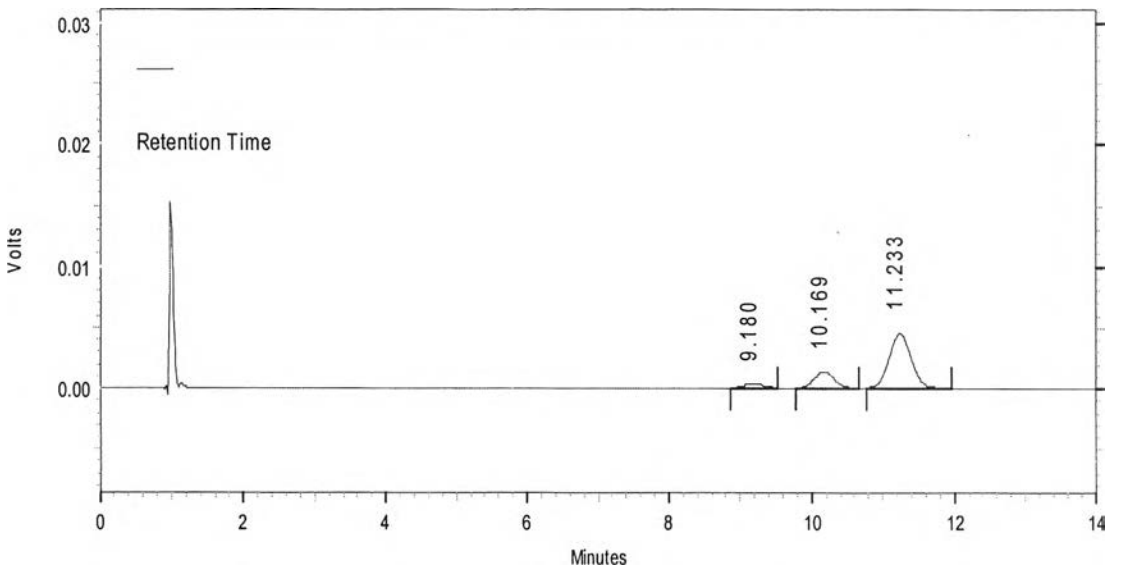


Figure 19. Chromatogram showing the specificity of analytical method

2.3. Percent Content of Curcuminoids and Entrapment Efficiency of Curcuminoid Microcapsules

To calculate the percent content of total curcuminoids and the entrapment efficiency of the curcuminoids in microcapsules, three types of curcuminoids composing of bisdesmethoxycurcumin, desmethoxycurcumin, and curcumin were quantified by HPLC. The analytical results were shown in table 18.

From table 18, it was observed that the increase in percent solid content of the feed formulation resulted in the decrease of percent content and percent entrapment of curcuminoid microcapsules in most cases, with the exception of formulation no.9, 37, 39, and 47. The reason could be due to too much solid dispersion in the feed formulation which leaded to the clog in atomizer resulting in uncertainty of the spray and spray-dried products.

It was also remarked that the addition of plasticizers other than PG resulted in the decrease in percent content and percent entrapment of curcuminoid microcapsules. With EC as a coating polymer, microcapsules plasticized with PG showed higher percent content and percent entrapment of curcuminoid microcapsules than those plasticized with the combination of PG/PEG400 and PG/GTA, and the microcapsules

plasticized with the combination of PG/PEG400 were found to have higher percent content and percent entrapment of curcuminoid microcapsules than those plasticized with the combination of PG/GTA.

Table 18. The percent content and percent entrapment of curcuminoids in spray-dried microcapsules.

No.	Conc. of weighed microcapsule in solution(μg/ml)	Assayed total curcuminoids conc. (μg/ml)	% Assayed total curcuminoids content	%Curcuminoids entrapment
7	10.099	3.764	37.27	74.54
8	9.802	3.186	32.50	65.01
9	9.802	3.102	15.82	47.48
10	9.802	3.175	16.20	48.59
11	9.901	2.893	14.61	58.44
12	9.901	2.161	10.91	43.65
13	10.099	2.757	27.30	54.60
14	9.802	1.877	19.15	38.30
15	9.901	3.416	17.25	51.76
16	10.000	3.099	15.50	46.49
17	9.901	2.112	10.67	42.67
18	10.000	2.853	12.24	48.96
37	9.901	4.149	41.90	83.80
38	10.099	3.660	36.24	72.48
39	9.802	2.676	13.65	40.96
40	9.802	3.935	20.07	60.23
41	9.703	2.480	12.78	51.12
42	9.802	1.792	9.14	36.57
43	10.000	5.360	53.60	107.20
44	10.099	4.508	44.64	89.28
45	10.000	6.965	34.82	104.48
46	9.802	5.746	29.31	87.94
47	10.000	4.148	20.74	82.96
48	10.297	5.138	24.95	99.80
49	9.901	4.763	48.11	96.22
50	9.901	3.703	37.40	74.80
51	9.703	3.532	18.20	54.61
52	9.802	3.421	17.45	52.35
53	9.901	2.550	12.88	51.51
54	9.703	2.294	11.82	47.29

The plasticizer and polymer are generally thought to be held together by intermolecular secondary valence forces forming a complex or molecular aggregate. The basic requirements of any plasticizer in a polymer system are compatibility and permanence. To be compatible the plasticizer must be miscible with the polymer, indicating similar intermolecular forces in two components (Banker G.S., 1966). Thus EC retaining a high ratio of hydroxyls to such ether, were best plasticized by hydroxyl containing compounds liked PG and resulted in more effective wall system.

Table 18 showed that the EC-coated microcapsules plasticized with PG (no.43) had highest percent content (53.60%) and percent entrapment (107.20%) of curcuminoid microcapsules while PM-coated microcapsules plasticized with the combination of PG/PEG400 (no.13) had lowest percent content (27.30%) and percent entrapment (54.60%) of curcuminoid microcapsules.

Among the microcapsules with the same wall materials, microcapsules no.7, no.13, no.37, no.43, and no.49 were found to be superior in percent content of curcuminoids and entrapment efficiency of the microcapsules. It was remarked that all of these six types of microencapsulated curcuminoids represented 1:1 curcuminoids: polymer ratio and 1%solid content formulations.

The percent content of total curcuminoids of microcapsules no.7, no.13, no.37, no.43, and no.49 were 37.27%, 27.30%, 41.90%, 53.60%, and 48.11%, respectively, and the percent entrapment of total curcuminoids of microcapsules no.7, no.13, no.37, no.43, and no.49 were 74.54%, 54.60%, 83.80%, 107.20%, and 96.22%, respectively.

Thus, these six formulations of curcuminoid microcapsules were selected for further study on physical properties and chemical stability of both the curcuminoid microcapsules themselves and chemical stability of those in skin-care products including cleansing gel and cream.

2.4. Determination of Physical Properties of Curcuminoid Microcapsules

2.4.1. Morphology and Particle Size

The size distribution of the curcuminoid microcapsules was measured by using a laser light scattering spectrometer, Mastersizer S long bed Ver. 2.11, Malvern, UK, (Figure 21, 23, 25, 27, and 29). The smallest average particle size observed was 7.09 μm for the curcuminoid microcapsules coated with ethylcellulose using PG and GTA as the plasticizers. The largest average diameter observed was 44.32 μm for the microcapsules coated with polymethacrylate using PG and PEG-400 as the plasticizers. However, from Figure 22(A), the largest average particle size observed could be the result of a particle agglomeration rather than the actual sizes of microcapsules.

The outer topographies of spray-dried microencapsulated products were assessed by SEM (Figure 20, 22, 24, 26, and 28). Electron Microscopy is the only method that provides direct information concerning both the size and the shape of the particles. In order to study the effect of wall composition on the micro-structural features of the spray-dried curcuminoid microcapsules, the same atomization and drying conditions were maintained in this study.

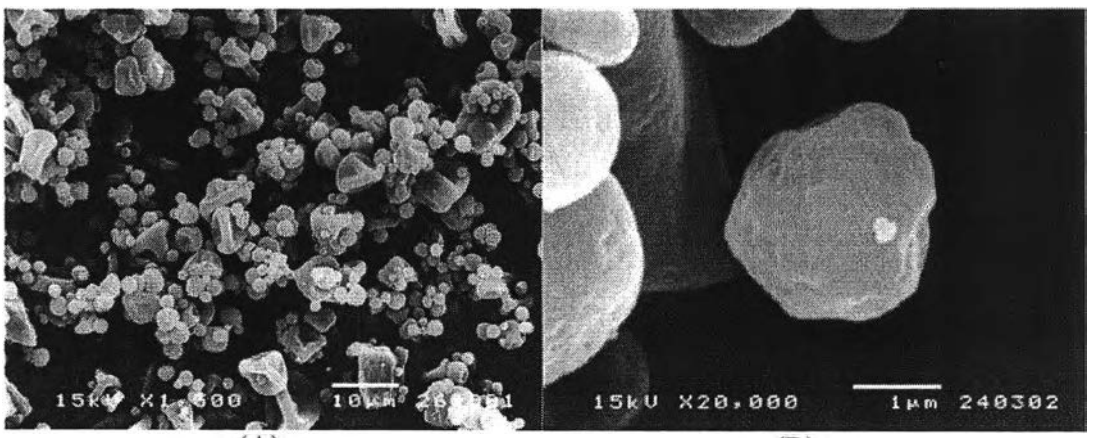
From SEM images, it was found that all types of spray-dried microcapsules contained some un-encapsulated parts of curcuminoid extract.

SEM images showed that the PM-coated microcapsules appeared to have smoother and more continuous surface whereas the EC-coated microcapsules appeared to have rugged and uneven surface. The reason could be due to the greater intermolecular forces caused by strongly polar groups (-COOH) distributed along PM chains which promote cohesion and packed order as described in section 2.1.

Polymeric film plasticized with additional PEG400 was observed to promote the homogeneous of the film surface. In contrast EC-coated microcapsules plasticized with additional GTA had the most rugged surfaces. This could be attributed to the compatibility of polymers and plasticizers. PM and EC are the polymers containing carboxyl (-COOH) and hydroxyl (-OH) groups, respectively, which are best plasticized and compatible with hydroxyl containing compounds such as PG and

PEG400 but GTA. Therefore the incorporation of GTA in wall system of PM and EC could result the un-uniform film coating.

PM-coated curcuminoid microcapsules plasticized with PG (No.7)



(A) (B)

Figure 20. SEM image of spray-dried curcuminoid microcapsules no.7 (polymer : polymethacrylate, plasticizer : PG, 1:1 curcuminoids: polymer ratio).
(A)magnification 1,500x, scale bar 10 μm. (B)magnification 20,000x, scale bar 1 μm.

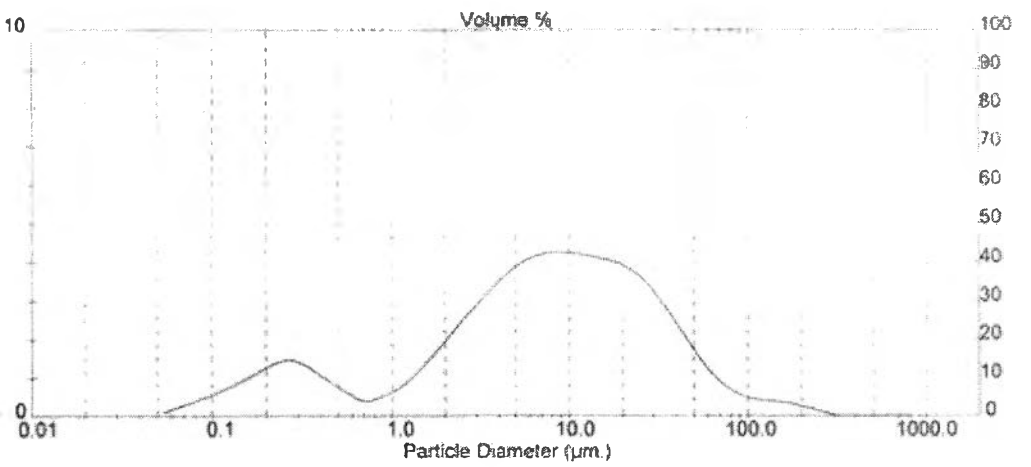
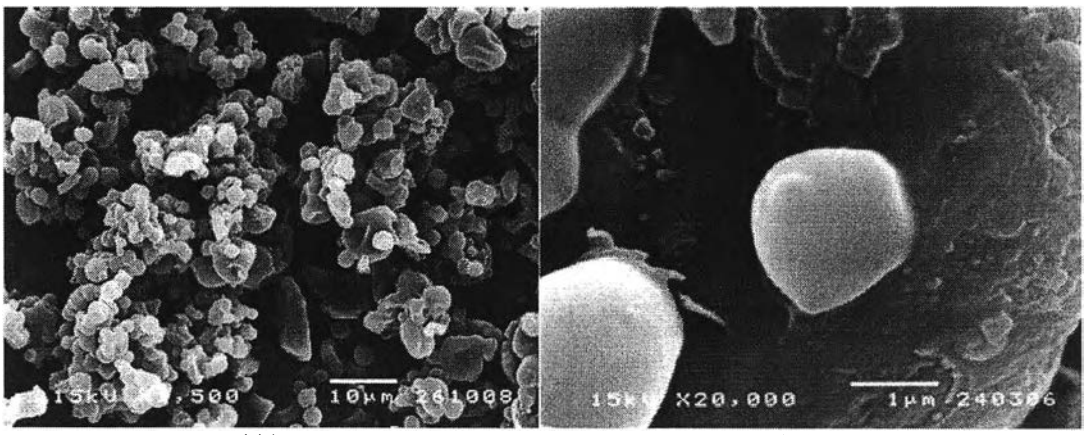


Figure 21. Size distribution of spray-dried curcuminoid microcapsules no.7 (polymer : polymethacrylate, plasticizer : PG, 1:1 curcuminoids: polymer ratio).

Figure 20(A), 20(B), and 21 showed SEM images and size distribution graph of PM-coated curcuminoid microcapsules (no.7) plasticized with PG. Some of them had spherical shape with a rugged surface. However, others were partially or totally

collapsed as if the air had gone out of the microcapsules. The average particle size of the curcuminoid microparticles no.7 was 16.58±0.17 μm.

PM-coated curcuminoid microcapsules plasticized with the combination of PG and PEG400 (No.13)



(A) (B)

Figure 22. SEM image of spray-dried curcuminoid microcapsules no.13 (polymer : polymethacrylate, plasticizer : PG and PEG400, 1:1 curcuminoids: polymer ratio) (A)magnification 1,500x, scale bar 10 μm. (B)magnification 20,000x, scale bar 1 μm.

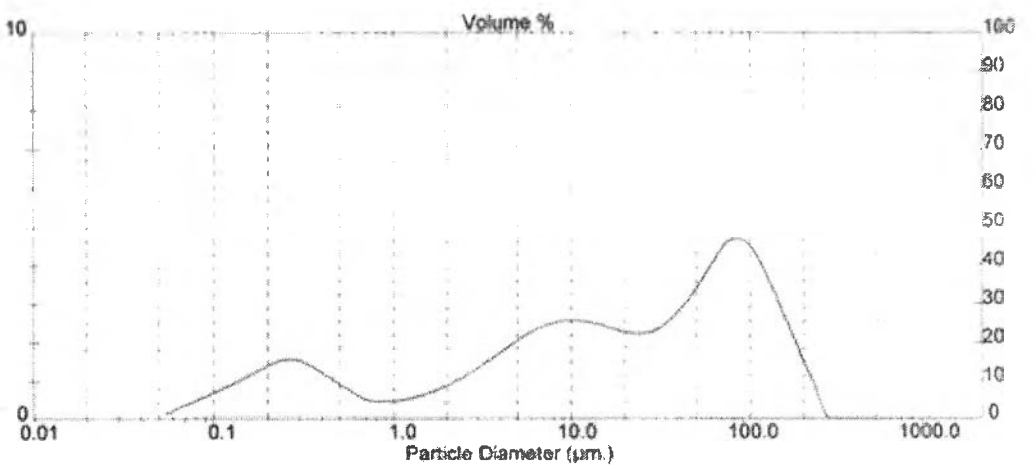
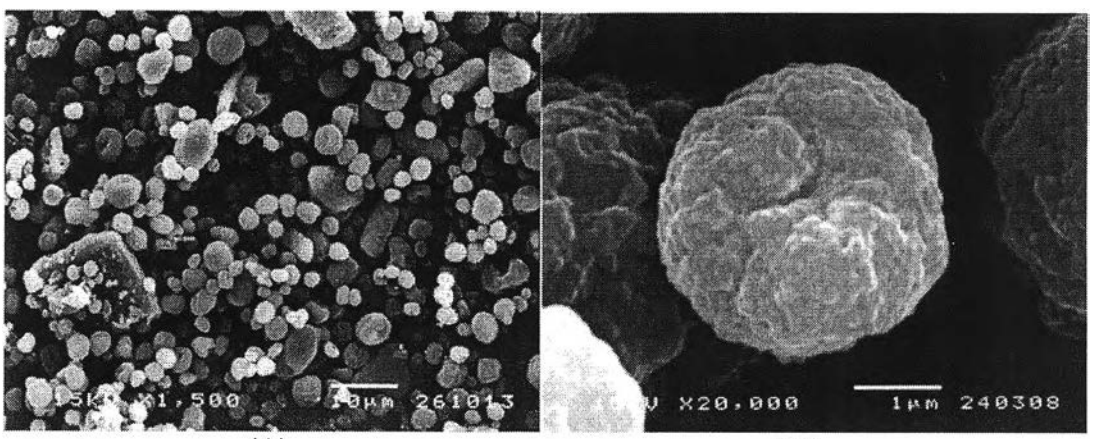


Figure 23. Size distribution of spray-dried curcuminoid microcapsules no.13 (polymer : polymethacrylate, plasticizer : PG and PEG400, 1:1 curcuminoids: polymer ratio).

Figure 22(A) and 22(B) displayed PM-coated curcuminoid microcapsules (no.13) plasticized with the combination of PG and PEG400 that were dented and agglomerated. Curcuminoid microcapsules no.13 was found to have smoother surface than the curcuminoid microcapsules no.7. The agglomeration of the particles and formation of smooth outer surface were probably attributed to the addition of PEG400 in the formulation, which could retained some more water molecules linked to its own structure, filling the intern empty space of the microcapsules, promoting agglomeration, preserving the hydration, avoiding depression on the surface, and thus assuring a more uniform and smooth wall of the obtained microcapsules. The average particle size of the curcuminoid microparticles no.13 was 44.32±1.88 μm.

EC-coated curcuminoid microcapsules plasticized with the combination of PG and GTA (No.37)



(A) (B)

Figure 24. SEM image of spray-dried curcuminoid microcapsules no.37 (polymer : ethylcellulose, plasticizer : PG and GTA, 1:1 curcuminoids: polymer ratio)
(A)magnification 1,500x, scale bar 10 μm. (B)magnification 20,000x, scale bar 1 μm.

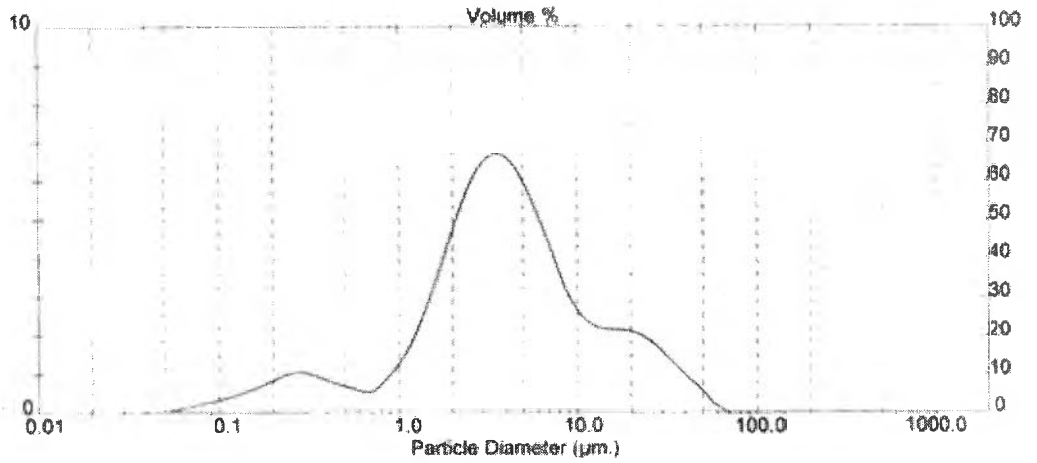
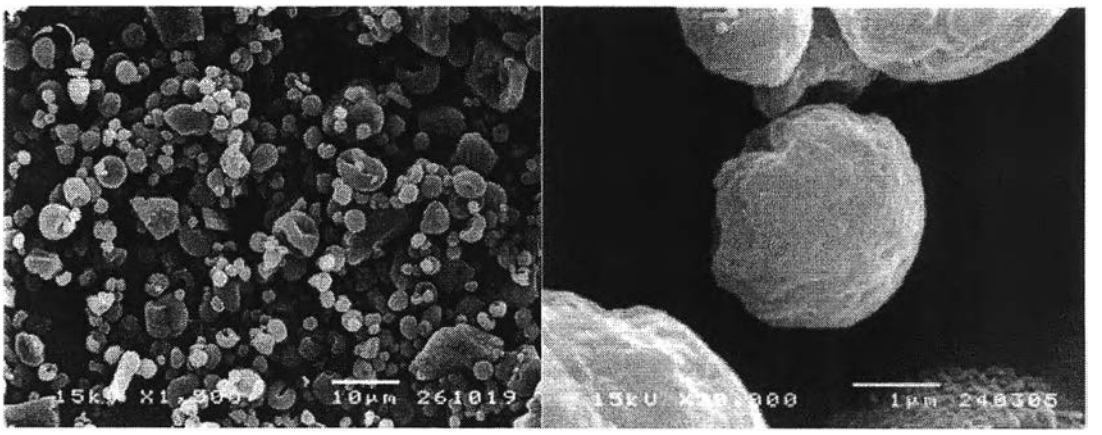


Figure 25. Size distribution of spray-dried curcuminoid microcapsules no.37 (polymer : ethylcellulose, plasticizer : PG and GTA, 1:1 curcuminoids: polymer ratio).

Figure 24(A), 24(B), and 25 showed EC-coated curcuminoid microcapsules plasticized with the combination of PG and GTA that had rougher surface than those coated with PM. Ethylcellulose consists of ether and hydroxyl groups which are capable of interacting with plasticizer molecules via hydrogen bonds (Heng et al., 2003). PG, PEG400, and GTA have different molecular structures and number of functional groups for hydrogen bonding. In this respect, GTA was generally worse plasticizer than PG and PEG400. The average particle size of the curcuminoid microparticles no.37 was 7.09±0.17 μm.

EC-coated curcuminoid microcapsules plasticized with PG (No.43)



(A) (B)

Figure 26. SEM image of spray-dried curcuminoid microcapsules no.43 (polymer: ethylcellulose, plasticizer : PG, 1:1 curcuminoids: polymer ratio) (A)magnification 1,500x, scale bar 10 μm. (B)magnification 20,000x, scale bar 1 μm.

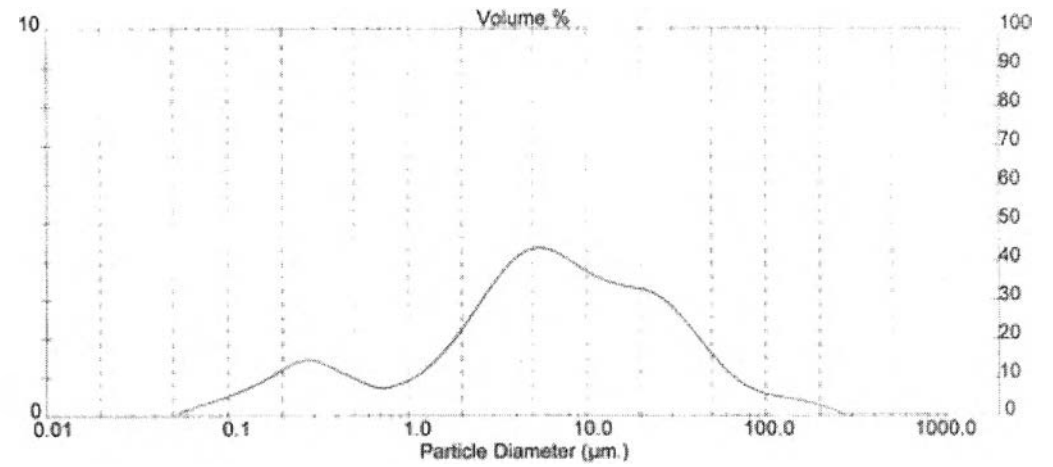


Figure 27. Size distribution of spray-dried curcuminoid microcapsules no.43 (polymer: ethylcellulose, plasticizer : PG, 1:1 curcuminoids: polymer ratio).

Figure 26(A), 26(B), and 27 displayed EC-coated curcuminoid microcapsules plasticized with PG. Some of them were spherical with rugged surface similar to curcuminoid microcapsules no.37. However there were some collapsed particles. The average particle size of the curcuminoid microparticles no.43 was 15.52±0.14 μm.

EC-coated curcuminoid microcapsules plasticized with the combination of PG and PEG400 (No.49)

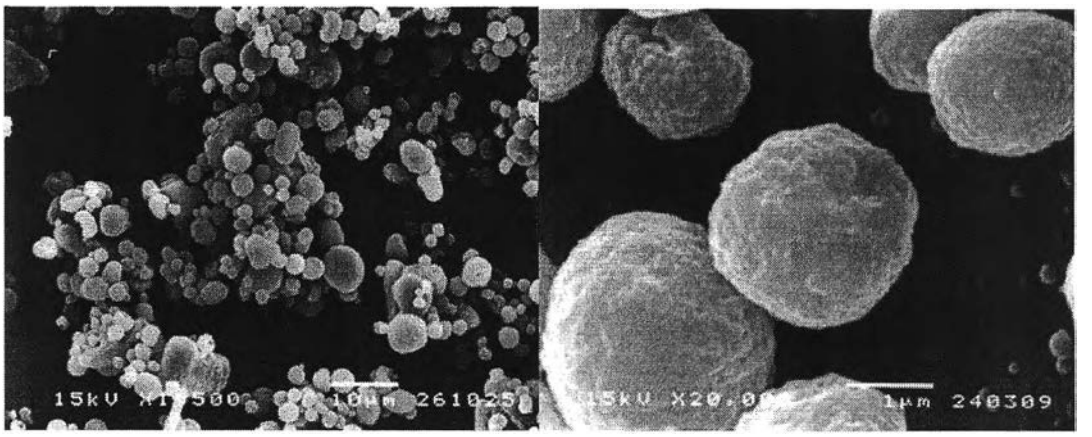


Figure 28. SEM image of spray-dried curcuminoid microcapsules no.49 (polymer: ethylcellulose, plasticizer : PG and PEG400, 1:1 curcuminoids: polymer ratio) (A)magnification 1,500x, scale bar 10 μm. (B)magnification 20,000x, scale bar 1 μm.

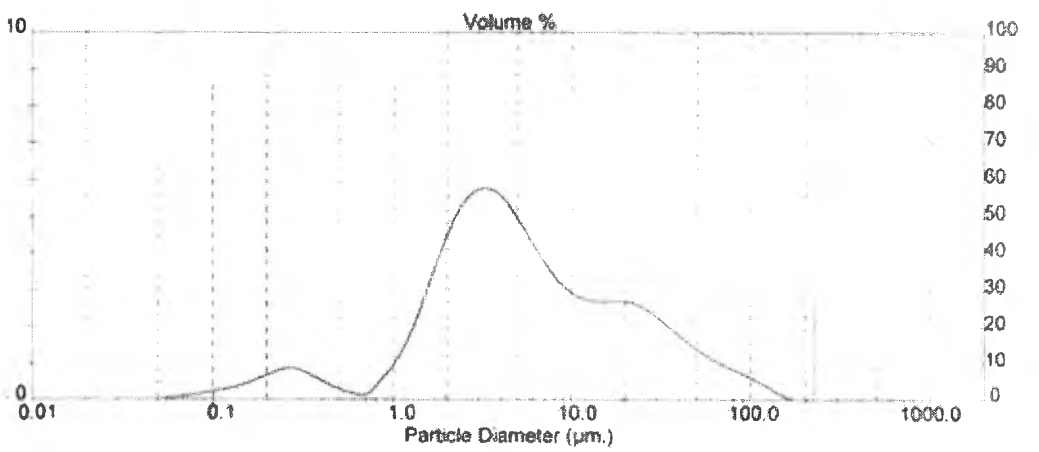


Figure 29. Size distribution of spray-dried curcuminoid microcapsules no. 49 (polymer : ethylcellulose, plasticizer : PG and PEG400, 1:1 curcuminoids: polymer ratio).

From Figure 28(A), 28(B), and 29, it could be found that EC-coated curcuminoid microcapsules plasticized with the combination of PG and PEG400 showed spherical shape and agglomeration. The reason could be the addition of

PEG400 which had the effects on the agglomeration and the formation of smoother outer surface as mentioned earlier. The average particle size of the curcuminoid microparticle no.49 was 12.47±0.44 μm.

2.4.2. Bulk Density, Tapped Density, and Hausner Ratio

Table 19. Bulk density, tapped density, and Hausner ratio of microencapsulated curcuminoids.

Sample	Polymer : Plasticizer (Ratio)	Particle Size (μm)	Bulk Density (g/ml)	Tapped Density (g/ml)	Hausner Ratio
7	PM : PG (1 : 1)	16.58 ± 0.17	0.33	0.45	1.35
13	PM : PG/PEG (1 : 1)	44.32 ± 1.88	0.20	0.28	1.41
37	EC : PG/GTA (1 : 1)	7.09 ± 0.17	0.36	0.49	1.36
43	EC : PG (1 : 1)	15.52 ± 0.14	0.33	0.49	1.48
49	EC : PG/PEG (1 : 1)	12.47 ± 0.44	0.31	0.44	1.43

From table 19, the microcapsules prepared by spray-drying technique of five different formulations using PM and EC aqueous dispersion as coating film; PG, GTA, and PEG400 as plasticizers, with 1:1 curcuminoids: polymer ratio and 1%solid content were used to investigate bulk density, tapped density, and Hausner ratio. With the exception of microcapsule no.13, the rest were found to have similar bulk and tapped densities. It was remarked that microcapsules no.13 revealed the lowest bulk and tapped densities. From figure 22(A) and 23, it could be seen that microcapsules no.13 revealed the highest degree of agglomeration with the highest represented particle size of 44.32 μm, which could limited the packing, resulting in lowest bulk and tapped density.

The Hausner ratio represented the relative important of interparticular interactions. Table 19 showed that the Hausner Ratios of all microcapsules formulation were about the same which revealed the similarity of particular interactions among those microcapsules.

2.4.3. Moisture Content of Curcuminoid Microcapsules

Table 20. Moisture content of curcuminoid microcapsules.

Sample	Polymer : Plasticizer (Ratio)	% Moisture content				
		1	2	3	Mean	SD
7	PM : PG (1 : 1)	2.99	2.20	2.00	2.40	0.52
13	PM : PG/PEG (1 : 1)	2.79	2.60	2.80	2.73	0.11
37	EC : PG/GTA (1 : 1)	1.20	1.00	0.80	1.00	0.20
43	EC : PG (1 : 1)	1.20	0.80	0.80	0.93	0.23
49	EC : PG/PEG (1 : 1)	1.39	1.00	1.20	1.20	0.20

PM-coated microcapsules (no.7 and 13) were found to have a little higher water content than EC-coated microcapsules (no.37, 43, and 49).

Comparing EC-coated microcapsules plasticized with PG/GTA, PG alone, and PG/PEG400, it was found that the addition of PEG400 increased the water content value and this was also happened with PM-coated microcapsules. The addition of GTA in EC-coated microcapsules did not showed significant change in water content value.

From statistical analysis, there was no significant different in moisture contents of microcapsules plasticized with different plasticizers whereas the types of polymer significantly affected the percent moisture contents of microencapsulated curcuminoids at significant level of 0.5. Table 20 showed that PM-coated microcapsules had greater percent moisture contents than EC-coated ones.

2.5. Determination of the Chemical Stability of Spray-Dried Curcuminoid Microcapsules in Different Storage Temperatures

Five formulations of microencapsulated curcuminoids possessed high percent content of curcuminoids were selected to the study of their chemical stability in different storage temperatures, which were 4°C, room temperature, 40°C, and 50°C. The study was conducted for 3 months at ambient relative humidity and percent curcuminoids contents were tested at 0, 1, 2, and 3 month. The results were shown in table 21, 22, 23, 24 and 25.

Table 21. Percent retention of curcuminoids in PG-plasticized microcapsules coated with different polymers.

Storage Temp	Sample	Polymer	% Total curcuminoid content								Mean of % Retention			
			Month0		Month1		Month2		Month3					
			rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	Month0	Month1	Month2	Month3
4°C	7	PM	41.60	37.27	37.73	40.26	48.84	45.76	32.96	40.25	100.00	98.88	119.94	92.82
	43	EC	54.77	53.60	57.58	65.18	70.23	66.35	56.77	55.76	100.00	113.28	126.03	103.84
RT	7	PM	41.60	37.27	40.83	39.71	37.14	38.65	41.24	40.33	100.00	102.12	96.09	103.43
	43	EC	54.77	53.60	54.74	58.57	53.16	54.82	56.38	56.51	100.00	104.56	99.64	104.17
40°C	7	PM	41.60	37.27	42.36	41.50	53.91	50.96	39.77	39.45	100.00	106.33	132.97	100.44
	43	EC	54.77	53.60	58.10	57.83	66.50	68.62	54.82	55.94	100.00	106.98	124.68	102.21
50°C	7	PM	41.60	37.27	43.28	38.66	51.52	49.31	38.75	36.02	100.00	103.89	127.85	94.80
	43	EC	54.77	53.60	58.10	59.72	70.92	66.08	54.60	52.98	100.00	108.72	126.42	99.28

From table 21, with the same plasticizer of PG, EC-coated microcapsules showed a little higher of percent retention of curcuminoids than that of PM-coated microcapsules for all storage temperatures, in which the results were related to the previous research (Ubonthip et al., 2005).

Table 22. Percent retention of curcuminoids in PG/PEG400-plasticized microcapsules coated with different polymers.

Storage Temp	Sample	Polymer	% Total curcuminoid content								Mean of % Retention			
			Month0		Month1		Month2		Month3					
			rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	Month0	Month1	Month2	Month3
4°C	13	PM	27.30	27.30	30.07	30.35	38.11	37.12	28.59	28.99	100.00	110.66	137.78	105.46
	49	EC	51.18	48.11	42.52	48.21	58.07	58.87	49.86	48.01	100.00	91.38	117.78	98.57
RT	13	PM	27.30	27.30	35.40	36.27	39.84	33.82	34.83	31.81	100.00	131.26	134.91	122.06
	49	EC	51.18	48.11	49.73	51.27	54.45	57.42	49.12	48.72	100.00	101.72	112.67	98.54
40°C	13	PM	27.30	27.30	34.39	32.23	43.34	41.53	31.34	31.05	100.00	122.01	155.44	114.27
	49	EC	51.18	48.11	49.19	55.10	55.81	58.46	46.46	43.46	100.00	105.04	115.09	90.57
50°C	13	PM	27.30	27.30	38.85	38.27	40.61	37.16	30.13	27.27	100.00	141.25	142.44	105.13
	49	EC	51.18	48.11	42.92	50.87	59.93	57.14	46.82	42.22	100.00	94.46	117.91	89.68

Table 22 showed that, with the same plasticizers of PG/PEG400, PM-coated microcapsules had greater percent retention of curcuminoids than EC-coated ones at all storage temperatures.

Table 23. Percent retention of curcuminoids in PM-coated microcapsules plasticized with different plasticizers

Storage Temp	Sample	Plasticizer	% Total curcuminoid content								Mean of % Retention			
			Month0		Month1		Month2		Month3					
			rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	Month0	Month1	Month2	Month3
4°C	7	PG	41.60	37.27	37.73	40.26	48.84	45.76	32.96	40.25	100.00	98.88	119.94	92.82
	13	PG/PEG400	27.30	27.30	30.07	30.35	38.11	37.12	28.59	28.99	100.00	110.66	137.78	105.46
RT	7	PG	41.60	37.27	40.83	39.71	37.14	38.65	41.24	40.33	100.00	102.12	96.09	103.43
	13	PG/PEG400	27.30	27.30	35.40	36.27	39.84	33.82	34.83	31.81	100.00	131.26	134.91	122.06
40°C	7	PG	41.60	37.27	42.36	41.50	53.91	50.96	39.77	39.45	100.00	106.33	132.97	100.44
	13	PG/PEG400	27.30	27.30	34.39	32.23	43.34	41.53	31.34	31.05	100.00	122.01	155.44	114.27
50°C	7	PG	41.60	37.27	43.28	38.66	51.52	49.31	38.75	36.02	100.00	103.89	127.85	94.80
	13	PG/PEG400	27.30	27.30	38.85	38.27	40.61	37.16	30.13	27.27	100.00	141.25	142.44	105.13

From Table 23, it was found that PM-coated microcapsules plasticized with the combination of PG/PEG400 showed better retentive curcuminoids after storing for three months at all testing temperatures.

Table 24. Percent retention of curcuminoids in EC-coated microcapsules plasticized with different plasticizers

Storage Temp	Sample	Plasticizer	% Total curcuminoid content								Mean of % Retention			
			Month0		Month1		Month2		Month3					
			rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	rep 1	rep 2	Month0	Month1	Month2	Month3
	37	PE/GTA	43.95	41.90	43.88	43.70	53.02	51.99	42.87	44.59	100.00	102.02	122.32	101.88
	43	PG	54.77	53.60	57.58	65.18	70.23	66.35	56.77	55.76	100.00	113.28	126.03	103.84
4°C	49	PG/PEG400	51.18	48.11	42.52	48.21	58.07	58.87	49.86	48.01	100.00	91.38	117.78	98.57
	37	PE/GTA	43.95	41.90	48.38	45.41	40.52	40.85	41.97	42.67	100.00	109.25	94.78	98.59
	43	PG	54.77	53.60	54.74	58.57	53.16	54.82	56.38	56.51	100.00	104.56	99.64	104.17
RT	49	PG/PEG400	51.18	48.11	49.73	51.27	54.45	57.42	49.12	48.72	100.00	101.72	112.67	98.54
	37	PE/GTA	43.95	41.90	47.44	42.78	55.24	50.26	37.39	41.95	100.00	105.09	122.90	92.43
	43	PG	54.77	53.60	58.10	57.83	66.50	68.62	54.82	55.94	100.00	106.98	124.68	102.21
40°C	49	PG/PEG400	51.18	48.11	49.19	55.10	55.81	58.46	46.46	43.46	100.00	105.04	115.09	90.57
	37	PE/GTA	43.95	41.90	50.21	51.57	55.44	50.74	46.55	40.03	100.00	118.56	123.68	100.85
	43	PG	54.77	53.60	58.10	59.72	70.92	66.08	54.60	52.98	100.00	108.72	126.42	99.28
50°C	49	PG/PEG400	51.18	48.11	42.92	50.87	59.93	57.14	46.82	42.22	100.00	94.46	117.91	89.68

From table 24, with the exception of EC-coated microcapsules stored at 50°C, it was found that EC-coated microcapsules plasticized with PG had greater percent retention of curcuminoids than those plasticized with the combination of PG/GTA and PG/PEG400. Moreover, EC-coated microcapsules plasticized with the combination of PG/GTA showed higher percent retention of curcuminoids than those plasticized with the combination of PG/PEG400.

Table 25. Chemical stability of curcuminoid microcapsules at different storage temperatures.

condition	sample no	% Total curcuminoid content								Mean of % Retention			
		month 0		month 1		month 2		month 3		m0	m1	m2	m3
		rep1	rep2	rep1	rep2	rep1	rep2	rep1	rep2				
4C	7	41.60	37.27	37.73	40.26	48.84	45.76	32.96	40.25	100	98.88	119.94	92.82
	13	27.30	27.30	30.07	30.35	38.11	37.12	28.59	28.99	100	110.66	137.78	105.46
	37	43.95	41.90	43.88	43.70	53.02	51.99	42.87	44.59	100	102.02	122.32	101.88
	43	54.77	53.60	57.58	65.18	70.23	66.35	56.77	55.76	100	113.28	126.03	103.84
	49	51.18	48.11	42.52	48.21	58.07	58.87	49.86	48.01	100	91.38	117.78	98.57
RT	7	41.60	37.27	40.83	39.71	37.14	38.65	41.24	40.33	100	102.12	96.09	103.43
	13	27.30	27.30	35.40	36.27	39.84	33.82	34.83	31.81	100	131.26	134.91	122.06
	37	43.95	41.90	48.38	45.41	40.52	40.85	41.97	42.67	100	109.25	94.78	98.59
	43	54.77	53.60	54.74	58.57	53.16	54.82	56.38	56.51	100	104.56	99.64	104.17
	49	51.18	48.11	49.73	51.27	54.45	57.42	49.12	48.72	100	101.72	112.67	98.54
40C	7	41.60	37.27	42.36	41.50	53.91	50.96	39.77	39.45	100	106.33	132.97	100.44
	13	27.30	27.30	34.39	32.23	43.34	41.53	31.34	31.05	100	122.01	155.44	114.27
	37	43.95	41.90	47.44	42.78	55.24	50.26	37.39	41.95	100	105.09	122.90	92.43
	43	54.77	53.60	58.10	57.83	66.50	68.62	54.82	55.94	100	106.98	124.68	102.21
	49	51.18	48.11	49.19	55.10	55.81	58.46	46.46	43.46	100	105.04	115.09	90.57
50C	7	41.60	37.27	43.28	38.66	51.52	49.31	38.75	36.02	100	103.89	127.85	94.80
	13	27.30	27.30	38.85	38.27	40.61	37.16	30.13	27.27	100	141.25	142.44	105.13
	37	43.95	41.90	50.21	51.57	55.44	50.74	46.55	40.03	100	118.56	123.68	100.85
	43	54.77	53.60	58.10	59.72	70.92	66.08	54.60	52.98	100	108.72	126.42	99.28
	49	51.18	48.11	42.92	50.87	59.93	57.14	46.82	42.22	100	94.46	117.91	89.68

From table 25, PM-coated microcapsules plasticized with the combination of PG/PEG400 (no.13) was most stable as it showed the highest retention percentage at all testing temperatures after storing for three months. The formulation had remarkably higher percent retention of curcuminoids than other microcapsule formulations.

Table 25 also showed that, with the exception of 4°C storage-temperature, EC-coated microcapsules plasticized with the combination of PG/PEG400 (no.49) was the most unstable.

The reason could be because film coating prepared from aqueous ethylcellulose dispersions were relatively weaker and more brittle compared to those prepared from acrylate (Heng et al., 2003). Due to its dense structure, polymethacrylate coating is less permeable. However, the stability of spray-dried curcuminoid microcapsules during storage was also influenced by several factors, including type of plasticizers, plasticizer content, storage temperature, and storage humidity.

From the analytical results, it was found that curcuminoids contents markedly increased in the second month, which could be attributed to the lack of content uniformity.

2.6. Determination of Chemical Stability of Curcuminoid Microcapsules in Skin-Care Preparations

2.6.1. Stability Test of Skin-Care Preparations

The prepared cleansing gel and moisturizing cream were undergone the freeze-thaw cycle , in which the formulations were stored in the oven with controlled temperature of 40°C for 48 hours, then they were stored in the freezer with temperature of -4°C for 48 hours. The same process was carried out 3 cycles and the physical properties of the formulations were then assessed. It was found that the physical appearances had not been changed.

2.6.2. Chemical Stability of Curcuminoid Microcapsules in Skin-Care Preparations

The study of chemical stability of curcuminoid microcapsules was conducted by separating microcapsules sample into 4 parts. Part1 was incorporated into cleansing gel pH 5, part2 was incorporated into cleansing gel pH7, part3 was incorporated in to cleansing gel pH8, and the last part was incorporated into moisturizing cream. All samples were stored in the dark for 4 weeks at room temperature and the tests of curcuminoids content were carried out at 0, 2, and 4 weeks. The results were shown below.

Table 26. The percent retention of curcuminoids in the skin-care preparations containing PG-plasticized microcapsules coated with different polymers

Skin-care formulation	Sample no.	Polymer	%Total curcuminoid content						Mean of %Retention		
			Week0		Week2		Week4		Week0	Week2	Week4
			Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2			
microcapsules in cleansing gel pH5	7	PM	16.15	20.71	10.93	13.79	13.27	12.91	100.00	67.06	71.04
	43	EC	12.66	34.05	17.87	19.51	17.82	16.55	100.00	80.03	73.59
microcapsules in cleansing gel pH7	7	PM	18.40	23.16	11.74	13.05	5.24	5.34	100.00	59.66	25.47
	43	EC	24.46	28.31	14.48	14.61	11.64	5.80	100.00	55.13	33.04
microcapsules in cleansing gel pH8	7	PM	8.57	10.40	1.46	2.38	0.63	0.59	100.00	20.25	6.41
	43	EC	9.42	10.67	0.73	0.85	UD	UD	100.00	7.87	UD
microcapsules in cream	7	PM	24.15	17.21	8.07	10.51	8.91	14.07	100.00	44.92	55.57
	43	EC	34.96	33.27	6.32	7.77	16.27	15.26	100.00	20.66	46.22

*UD = Undetectable

From Table 26, with the same plasticizer of PG, it was found that the percent retention of curcuminoids of EC-coated microcapsules in cleansing gel pH5 and pH7 were greater than PM-coated ones. In contrast, PM-coated microcapsules in cleansing gel pH8 and moisturizing cream exhibited greater value of percent retention of curcuminoids than EC-coated microcapsules in the same preparations.

Table 27. The percent retention of curcuminoids in the skin-care preparations containing PG/PEG400-plasticized microcapsules coated with different polymers

Skin-care formulation	Sample no.	Polymer	%Total curcuminoid content						Mean of %Retention		
			Week0		Week2		Week4		Week0	Week2	Week4
			Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2			
microcapsules in cleansing gel pH5	13	PM	14.32	18.54	7.74	10.87	6.51	8.57	100.00	56.62	45.90
	49	EC	21.06	26.71	8.78	9.59	11.23	10.02	100.00	38.46	44.48
microcapsules in cleansing gel pH7	13	PM	14.23	16.86	8.94	8.93	5.19	2.12	100.00	57.46	23.51
	49	EC	24.44	28.05	11.64	11.45	4.38	4.06	100.00	43.99	16.09
microcapsules in cleansing gel pH8	13	PM	6.45	6.64	1.13	1.20	UD	UD	100.00	17.74	UD
	49	EC	9.40	9.03	1.01	1.10	UD	UD	100.00	11.48	UD
microcapsules in cream	13	PM	14.66	11.37	2.52	3.06	8.62	9.51	100.00	21.42	69.65
	49	EC	17.15	16.45	6.32	8.54	11.61	8.93	100.00	44.22	61.13

*UD = Undetectable

Table 27 showed that, with the same plasticizers of PG/PEG400, PM-coated microcapsules exhibited the greater percent retention of curcuminoids than EC-coated microcapsules for all types of skin-care preparation.

Table 28. The percent retention of curcuminoids in the skin-care preparations containing PM-coated microcapsules plasticized with different plasticizers

Skin-care formulation	Sample no.	Polymer	%Total curcuminoid content						Mean of %Retention		
			Week0		Week2		Week4		Week0	Week2	Week4
			Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2			
microcapsules in cleansing gel pH5	7	PG	16.15	20.71	10.93	13.79	13.27	12.91	100.00	67.06	71.04
	13	PG/PEG400	14.32	18.54	7.74	10.87	6.51	8.57	100.00	56.62	45.90
microcapsules in cleansing gel pH7	7	PG	18.40	23.16	11.74	13.05	5.24	5.34	100.00	59.66	25.47
	13	PG/PEG400	14.23	16.86	8.94	8.93	5.19	2.12	100.00	57.46	23.51
microcapsules in cleansing gel pH8	7	PG	8.57	10.40	1.46	2.38	0.63	0.59	100.00	20.25	6.41
	13	PG/PEG400	6.45	6.64	1.13	1.20	UD	UD	100.00	17.74	UD
microcapsules in cream	7	PG	24.15	17.21	8.07	10.51	8.91	14.07	100.00	44.92	55.57
	13	PG/PEG400	14.66	11.37	2.52	3.06	8.62	9.51	100.00	21.42	69.65

*UD = Undetectable

From Table 28, PM-coated microcapsule plasticized with PG showed better results of percent retention of curcuminoids for all cleansing gel preparations whereas those plasticized with the combination of PG/PEG400 had greater percent retention of curcuminoids in moisturizing cream preparation.

Table 29. The percent retention of curcuminoids in the skin-care preparations containing EC-coated microcapsules plasticized with different plasticizers

Skin-care formulation	Sample no.	Polymer	%Total curcuminoid content						Mean of %Retention		
			Week0		Week2		Week4		Week0	Week2	Week4
			Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2			
microcapsules in cleansing gel pH5	37	PE/GTA	22.30	23.55	13.17	14.63	13.00	12.87	100.00	60.64	56.42
	43	PG	12.66	34.05	17.87	19.51	17.82	16.55	100.00	80.03	73.59
	49	PG/PEG400	21.06	26.71	8.78	9.59	11.23	10.02	100.00	38.46	44.48
microcapsules in cleansing gel pH7	37	PE/GTA	21.18	24.41	13.22	13.67	11.39	9.99	100.00	58.98	46.87
	43	PG	24.46	28.31	14.48	14.61	11.64	5.80	100.00	55.13	33.04
	49	PG/PEG400	24.44	28.05	11.64	11.45	4.38	4.06	100.00	43.99	16.09
microcapsules in cleansing gel pH8	37	PE/GTA	7.45	8.23	0.77	0.95	UD	UD	100.00	11.03	UD
	43	PG	9.42	10.67	0.73	0.85	UD	UD	100.00	7.87	UD
	49	PG/PEG400	9.40	9.03	1.01	1.10	UD	UD	100.00	11.48	UD
microcapsules in cream	37	PE/GTA	25.21	21.15	5.22	6.51	14.07	14.47	100.00	25.31	61.56
	43	PG	34.96	33.27	6.32	7.77	16.27	15.26	100.00	20.66	46.22
	49	PG/PEG400	17.15	16.45	6.32	8.54	11.61	8.93	100.00	44.22	61.13

*UD = Undetectable

From Table 29, in cleansing gel pH5, EC-coated microcapsules plasticized with PG had highest percent retention of curcuminoids followed by those plasticized with the combination of PG/GTA and PG/PEG400, respectively.

In cleansing gel pH7, EC-coated microcapsules plasticized with the combination of PG/GTA had highest percent retention of curcuminoids followed by those plasticized with PG and the combination of PG/PEG400, respectively.

In cleansing gel pH8, there was no detectable data at week 4 due to the decomposition of curcuminoids in alkaline medium.

In moisturizing cream, EC-coated microcapsules plasticized with the combination of PG/GTA had highest percent retention of curcuminoids followed by those plasticized with combination of PG/PEG400 and PG, respectively.

Table 30. Chemical stability of curcuminoid microcapsule and curcuminoid extract in skin-care preparations

Skin-care formulation	Sample no.	%Total curcuminoid content						Mean of %Retention		
		Week0		Week2		Week4		Week0	Week2	Week4
		Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2			
Cleansing gel pH 5	7	16.15	20.71	10.93	13.79	13.27	12.91	100.00	67.06	71.04
	13	14.32	18.54	7.74	10.87	6.51	8.57	100.00	56.62	45.90
	37	22.30	23.55	13.17	14.63	13.00	12.87	100.00	60.64	56.42
	43	12.66	34.05	17.87	19.51	17.82	16.55	100.00	80.03	73.59
	49	21.06	26.71	8.78	9.59	11.23	10.02	100.00	38.46	44.48
	cur	36.79	29.21	24.54	26.41	18.39	18.09	100.00	77.20	55.27
Cleansing gel pH 7	7	18.40	23.16	11.74	13.05	5.24	5.34	100.00	59.66	25.47
	13	14.23	16.86	8.94	8.93	5.19	2.12	100.00	57.46	23.51
	37	21.18	24.41	13.22	13.67	11.39	9.99	100.00	58.98	46.87
	43	24.46	28.31	14.48	14.61	11.64	5.80	100.00	55.13	33.04
	49	24.44	28.05	11.64	11.45	4.38	4.06	100.00	43.99	16.09
	cur	43.99	53.42	23.06	35.27	16.70	16.39	100.00	59.88	33.97
Cleansing gel pH 8	7	8.57	10.40	1.46	2.38	0.63	0.59	100.00	20.25	6.41
	13	6.45	6.64	1.13	1.20	UD	UD	100.00	17.74	UD
	37	7.45	8.23	0.77	0.95	UD	UD	100.00	11.03	UD
	43	9.42	10.67	0.73	0.85	UD	UD	100.00	7.87	UD
	49	9.40	9.03	1.01	1.10	UD	UD	100.00	11.48	UD
	cur	31.98	47.47	3.45	7.16	5.95	6.13	100.00	13.35	15.20
Moisturizing cream	7	24.15	17.21	8.07	10.51	8.91	14.07	100.00	44.92	55.57
	13	14.66	11.37	2.52	3.06	8.62	9.51	100.00	21.42	69.65
	37	25.21	21.15	5.22	6.51	14.07	14.47	100.00	25.31	61.56
	43	34.96	33.27	6.32	7.77	16.27	15.26	100.00	20.66	46.22
	49	17.15	16.45	6.32	8.54	11.61	8.93	100.00	44.22	61.13
	cur	28.82	27.24	9.20	15.13	13.59	13.49	100.00	43.40	48.31

*UD = Undetectable

From Table 30, in cleansing gel pH5, preparation contained uncoated-curcuminoids showed percent retention of curcuminoids at week 4 which was 55.27%. The percent retention of curcuminoids at week 4 of the preparations contained microcapsules no.7, 37, and 43 were 71.04%, 56.42%, and 73.59%, respectively, which were greater than that of preparation contained uncoated-

curcuminoids. PG-plasticized microcapsules coated with PM and EC (no.7 and 43) had remarkably higher percent retention of curcuminoids.

In cleansing gel pH7, preparation containing uncoated-curcuminoids showed percent retention of curcuminoids at week 4 which was 33.97%. The percent retention of curcuminoids at week 4 of the preparation containing microcapsules no.37 was 46.87% which was greater than that of preparation containing uncoated-curcuminoids.

In cleansing gel pH8, preparation containing uncoated-curcuminoids showed percent retention of curcuminoids at week 4 which was 15.20%. The percent retention of curcuminoids at week 4 of the preparation containing microcapsules no.7 was 6.41% which was the only preparation that curcuminoids remained detectable.

In moisturizing cream, preparation containing uncoated-curcuminoids showed percent retention of curcuminoids at week 4 which was 48.31%. The percent retention of curcuminoids at week 4 of the preparations containing microcapsules no.7, 13, 37, and 49 were 55.57%, 69.65%, 61.56%, and 61.13%, respectively, which were higher than that of preparation containing uncoated-curcuminoids. Anyway there was no remarked difference between percent retentions of curcuminoids of differently-coated microcapsules.

Table 4-24 showed low retention percentages of curcuminoids in cleansing gel preparation pH7 and pH8, which related to the properties of curcuminoids that could be easily degradable in neutral to alkaline pH solution.

Figure 4-23, 4-24, 4-25, and 4-26 showed the column graphs of percent retention of curcuminoids in different skin-care preparation containing different types of microencapsulated curcuminoids.

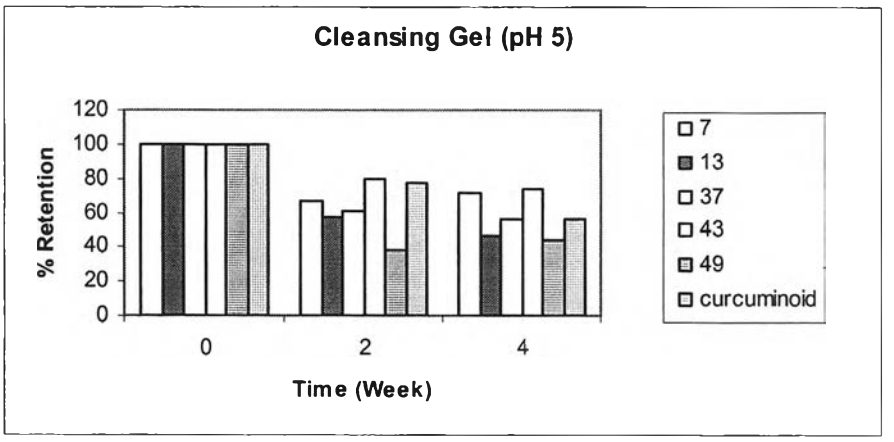


Figure 30. Percent retention of curcuminoids of different microcapsules and curcuminoid extract in cleansing gel pH5.

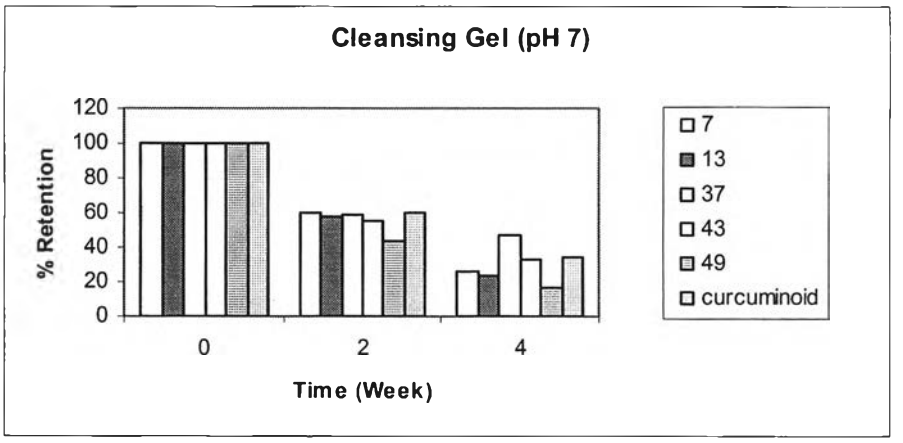


Figure 31. Percent retention of curcuminoids of different microcapsules and curcuminoid extract in cleansing gel pH7.

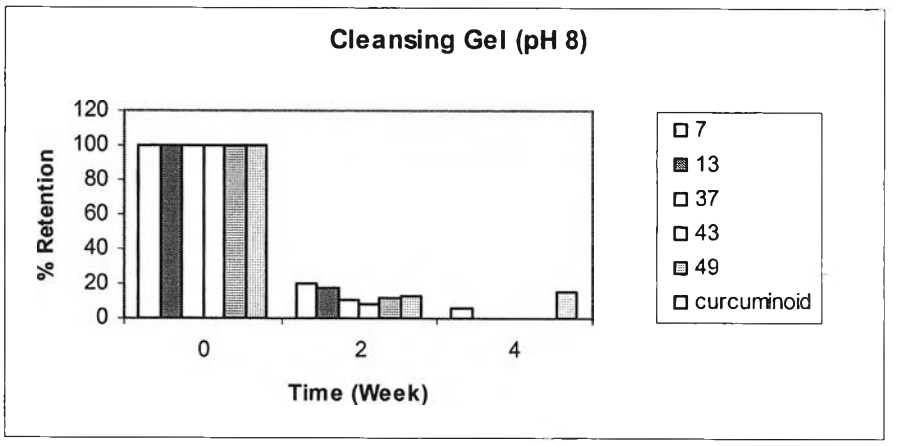


Figure 32. Percent retention of curcuminoids of different microcapsules and curcuminoid extract in cleansing gel pH8.

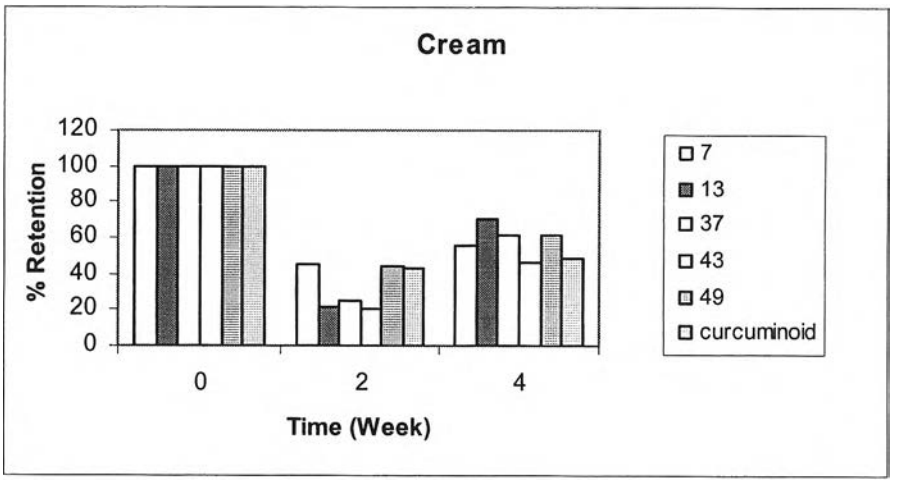


Figure 33. Percent retention of curcuminoids of different microcapsules and curcuminoid extract in moisturizing cream.

In the study of chemical stability of curcuminoid microcapsules in skin-care preparation, it was found that curcuminoid microcapsules and curcuminoid extract showed very low to undetectable amount of retentive curcuminoids in cleansing gel pH7and pH8. Therefore, the preparation of cleansing gel pH7 and pH8 were found to be unsuitable preparation for curcuminoids.

For cleansing gel pH 5 containing different formulations of curcuminoid microcapsules, it was observed that percent retentions notably dropped in week 2 and remained about the same values at week 4. This could be due to the degradation of un-encapsulated curcuminoids in cleansing gel at week 2, whereas the coating could protect the encapsulated curcuminoids from degradation in week 4. In contrast, cleansing gel pH 5 containing curcuminoid extract exhibited the remarked decrease in percent retention of curcuminoid in week 2 and continuously decreased in week 4. PM-coated microcapsules plasticized with PG (no.7) and EC-coated microcapsules plasticized with PG (no.43) were found to be most suitable formulations. The wall system of these two microcapsules formulations was found to increase the stability of curcuminoids in cleansing gel pH5.

For moisturizing cream, though PM-coated microcapsules plasticized with PG/PEG400 (no.13), EC-coated microcapsules plasticized with PG/GTA (no.37), and EC-coated microcapsules plasticized with PG/PEG400 (no.49) were found to be superior, statistical data (Appendix III) showed that there was no significant difference between percent retentions of curcuminoids of differently-coated microcapsules.

However, from the analytical results, it was found that the amount of curcuminoids was remarkedly decreased in the second week, which could be due to the lack of content uniformity.