Indonesian Food Science and Technology Journal
IFSTJ : Vol 8 No 2, July 2025 (PP:315-323)
ISSN : 2615-367X, DOI. 10.22437/ifstj.v8i2.36983

INDONESIAN FOOD SCIENCE AND TECHNOLOGY JOURNAL (IFSTJ)

Journal homepage : online-journal.unja.ac.id/ifstj/issue/archive

Characterization of Mandai Powder Encapsulants: A Comprehensive Analysis of Chemical Composition and Morphological Changes

Miftakhur Rohmah[1#], Rimbawan Apriadi[2], Anton Rahmadi[1]
[1] *Department of Agricultural Technology, Faculty of Agriculture, Mulawarman University, Jl. Paser Balengkong Kampus Gunung Kelua, Samarinda,, 75119 Indonesia*
[2] *Humid Tropical Agriculture Postgraduate Program, Faculty of Agriculture, Mulawarman University, Jl. Paser Balengkong Kampus Gunung Kelua, Samarinda, 75119 Indonesia*

#Corresponding author: E-mail: miftakhurrohmah@faperta.unmul.ac.id

***Abstract*— Potential: Mandai cempedak powder, rich in phenolic compounds and lactic acid, is encapsulated using a spray drying technique to maintain its unique content. This research aims to authenticate the final encapsulant product of Mandai powder by comparing it with raw materials (cempedak powder, Mandai powder) and the pre-encapsulation process. The analysis involves ATR FTIR, GC-MS techniques, morphological characteristics, and amino acid content. FTIR results identified lactic acid in the form of a carboxylic acid (-COOH) functional group and phenolic compounds with aromatic rings stretching carbon-carbon (C-C) bonds in starch and protein-based matrices, GC-MS analysis showed changes in volatile composition such as the appearance of the compound paromomycin, and Ethyl 9-hexadecenoic in mandai powder encapsulant products. Morphological characteristics also showed changes in structure from cempedak powder to mandai powder encapsulant. Apart from that, the amino acid content analysis in the encapsulant still detected relatively high levels of aspartic acid, glutamate, and arginine. In conclusion, this study discusses the successful encapsulation of mandai powder and provides information about changes in chemical composition during the encapsulation process.**

***Keywords*— Amino acid content; ATR FTIR; Bioactive components; Encapsulation; GC-MS; Lactic acid**

Manuscript received Sept 02, 2024; revised May 08, 2025; accepted July 12, 2025. Available online July 29, 2025

I. INTRODUCTION

Made from the by-product of the cempedak fruit (*Artocarpus champeden*), Mandai cempedak is a distinctive culinary invention specific to Kalimantan. The Mandai is produced by spontaneous fermentation and stored at room temperature. The fruit is then processed by peeling, de-scaling, and soaking in salt water to maintain and smooth out its texture. The length of the soaking process, which can range from a few hours to a month, creates a unique flavor [1].

In addition to culinary characteristics, Mandai powder produced from this process also attracts attention through its high content of phenolic compounds and lactic acid [1]. These compounds, with their potential as anti-cancer agents and ability to regulate metabolic effects, including increased insulin sensitivity and reduced rate of carbohydrate digestion [2-5], provide an exciting health dimension. Therefore, research on these compounds opens the opportunity to provide benefits to individuals suffering from diabetes or insulin resistance by regulating blood sugar levels [6-9].

Research found volatile compounds in Mandai powder with the highest GCMS chromatogram area, namely oleic acid (14.12% area), Ethylene oxide, dodecyl glycidyl ether (8.85%), 4-Octadecylmorpholine (7.41%), dodecyl alcohol (6.89%), Furo[3,4-d]-1,3,2-dioxaborole, 2-ethyltetrahydro- (6.26%), hexanol, ethyl hexanol (6%), phenolic content 358.8±55.6 GAE/kg^{-1} dry weight of powder sample, tannin content 143.8±9.3 mg TAE/kg^{-1} dry weight of powder sample, flavonoid content 17.5±1.3 CAE/kg^{-1} dry weight of powder sample, antioxidant capacity IC50 56.96 g/mL [1,10]. High amino acid levels were also found in Mandai powder, including 2-aminobutanedioic acid 0.55%, threonine 0.27%, serine 0.3%, glutamic acid 0.97%, glycine 0.31%, alanine 0.36%, valine

0.4%, and methionine 0.03% [10]. These components are maintained using the spray encapsulation technique drying [11-13].

Reported preliminary results regarding the optimization formula in mandai powder encapsulant by considering three variables, namely (1) the ratio of mandai powder: maltodextrin (0.145 g/g), (2) chitosan concentration 2.93%, and (3) spray drying inlet temperature at 73 °C. Mandai powder encapsulant concentration contained total phenolics of 46.36 mg GAE/g dry weight, total flavonoids of 79,467 ± 3.40 mg CE/g dry weight, total LAB of 9.17 log CFU/mg and had an antioxidant capacity IC_{50} of 91.04 µg/ml [14]. This research continues the efforts to characterize the psycho-chemical characterization of Mandai powder encapsulants by comparing them with the raw materials, namely cempedak powder, Mandai powder, and Mandai powder pre-encapsulants. The essential parameters are the bioactive components based on their functional groups, volatile compounds, morphological characteristics, and amino acid content.

II. MATERIAL AND METHODS

A. Material

Mandai cempedak fruit, predominantly yellow in color and exhibited a strong aroma, was obtained from local farmers (Samarinda, Ina). *L. casei* isolation was isolated from Yakult®, aquadest (Samarinda, Ina), maltodextrin (China), chitosan (Indonesia), ZnSe crystals, deuterated triglycine sulfate detector (Sigma-Aldrich), polydimethylsiloxane divinyl- benzene (PDMS/DVB) polymer filter (Supelco, USA), Na-acetate (Merck), Na-EDTA (Merck), methanol (Merck), and tetrahydrofuran (THF) (Merck).

B. Methods

Sample Preparation [1]

After peeling and removing the fruit from the skin, the cempedak fruit was chopped into pieces and cleaned. The inner skin of the cempedak was pre-heated at 100 °C for five minutes to remove the sap. The samples were dried and then cooked at 100°C in a covered container for five minutes. After cooling the sample to below 40°C, the procedure of producing Mandai and cempedak powders was carried out using this sample.

Cempedak powder sample was added. Aquadest at ratio of 1:1 (v/v) was added and was mixed and separated between the filtrate and the residue. The cempedak residue was dried at 50 °C for 24 hours, ground with a blender, and sieved with an 80-mesh sieve.

Fermentation. Cempedak powder samples were added. As a starting culture, *L. casei* strain Shirota from Yakult was injected at a concentration of 4% (v/v). The cempedak culture was mixed and filtered. The solid portion was removed and dried for 24 hours at 50 °C in an oven. After drying, the fermented cempedak (Mandai) aggregate was crushed and then put through an 80-mesh filter.

Pre Encapsulant and Mandai Powder Encapsulant

Mandai cempedak powder encapsulant refers to research [14] on the optimum formula, namely the comparison of the ratio of mandai powder: maltodextrin (0.145g/g), chitosan concentration 2.93%, and spray drying inlet temperature at 73 °C. Concentrations of Mandai this formula measured before (pre-encapsulant Mandai powder) and after encapsulation (encapsulant Mandai powder).

FTIR Characterization [15]

Thermo Nicolet FT-IR spectrometer i50 (Waltham, MA, USA) analyzed FTIR spectra of cempedak Powder and Mandai Powder. ZnSe crystals and a deuterated triglycine sulfate detector were used for the analysis, which included 32 iterations observed at 650–4000 cm^{-1} with a resolution of 4 cm^{-1}.

Volatile Components (GC-MS)

Gas Chromatography-Mass Spectrometry (GC-MS) analyzed volatile components [16]. Three main steps are involved, namely: (1) extraction using solid phase microextraction (SPME), (2) inserting the sample into the GC-MS device, and (3) qualitative evaluation of the evaporated volatile components.

The sample was carefully weighed preceding to the SPME extraction step for volatile chemicals. Of 5 g samples were placed in 40 ml bottles. Subsequently, the sample-containing vial was heated to 60°C in a water bath. Using a 1-cm-long polydimethylsiloxane/divinylbenzene (PDMS/DVB) polymer was used as an absorbent, the powder's volatile components were extracted using SPME throughout this procedure (Supelco, USA).

A split-spitless injector set at 260°C. Shimadzu GCMS-QP2010 Plus equipment was utilized for the GCMS analysis of volatile component composition. The temperature of the MS detector was adjusted to 200°C, and a Rtx-50 column of 0.25 mm in inner diameter, 30 m in length, and 0.25 µm in thickness was employed. The detector temperature was set to begin at 60°C for three minutes, then step-up rise at a rate of 5°C per minute until reaching 220°C for twenty minutes.

A sample of 1 µL was injected with the help of helium as a carrier at a speed of 3 mL/minute. The device was set as follows: pressure 38.9 kPa, total flow 37.5 mL/minute, column flow 0.78 mL/minute with sampling duration 1 minute. Purge flow at 3.0 ml/min and a linear speed separation ratio of -1.0 was 32.2 cm/sec. The analysis was conducted at Gadjah Mada University (UGM), East Java, at the Integrated Research and Testing Laboratory (LPPT). With the use of the Shimadzu Mass Spectral Library and Database, chromatogram peaks were located.

Morphological Structure [17]

SEM analysis was done with SEM-EDS (JSM-6510 LA, JEOL, Japan). The sample was placed on the stubs. A gold sputter run for 10 minutes to coat the material. The coated sample was placed into an SEM microscope and then observed at a magnification of up to 1000

Amino Acid Analysis [18]
Using the orthophthalaldehyde (OPA) fluorescence technique, amino acid (AAA) analysis was performed by the standards supplied by the Testing, Calibration, and Certification Procedures Laboratory Unit of the Bogor Agricultural Institute, with number IK.LP-04.7-LT-1.0 [18]. The settings used while utilizing Shimadzu HPLC are as follows: a ThermoScientific ODS-2Hypersil column; a gradient flow rate of mobile phase buffers A and B applied at 1 mL/minute; and a Shimadzu fluorescence detector. Buffer A is made up of a liter of ultrapure water (Merck-Millipore) diluted in a solution of Na-acetate (pH 6.5; 0.02%), Na-EDTA (0.005%), methanol (9.00%), and tetrahydrofuran (THF) (1.50%). After being filtered using 0.45 µm Millipore paper, the buffer was utilized for five days at room temperature (28 ± 2°C). It was then kept in a dark container and filled with either nitrogen or hydrogen gas. 95% methanol and ultrapure water (Merck-Millipore) were made of buffer B and filtered via 0.45-micron Millipore paper.

III. RESULT AND DISCUSSION

FTIR analysis
The Mandai powder's lactic acid and bioactive components were identified via FTIR analysis, and their interactions with starch- and protein-based matrices are shown in (**figure 1**). The wave number range in which the spectrum was measured was 4000–650 cm^{-1}. In each sample, there are functional groups of lactic acid and phenolic compounds. Stretching of the hydroxyl group (-OH) occurred in the region of 3500-3200 cm^{-1}, and stretching of C-H bonds appears in the region of 3000-2800 cm^{-1}. The carboxylic acid (-COOH) functional group found in lactic acid is linked to a prominent absorption peak near 1754–1740 cm^{-1}. This peak corresponds to the stretching C=O bond vibration in the carboxylic acid group, phenolic compounds containing aromatic rings observed from 1450 to 1600 cm^{-1}.

In this region, a noticeable increase in the absorption intensity was detected in the encapsulated Mandai powder compared to the raw materials. This suggests stronger interactions between the phenolic compounds and the encapsulating agents (chitosan and maltodextrin), which may enhance the stability and retention of phenolics. In addition, slight band broadening in this region indicates a more complex hydrogen bonding environment, supporting the successful incorporation of bioactive compounds into the encapsulation matrix. These peaks represent the stretching vibration of the carbon-carbon (C-C) bond in the aromatic ring. The coating ingredients in Mandai powder encapsulant are chitosan and maltodextrin. Chitosan contains the amide group of its glucosamine monomer and the Amide I band, which appeared in the region of 1628 cm^{-1} in the pre-encapsulant and Mandai powder encapsulant and represents the stretching vibration of the C=O bond in the amide group while maltodextrin consists of glucose monomers linked together by bonds. Glycosidic linkages can be observed as peaks in the region 1100-900 cm^{-1}. In the encapsulated Mandai powder, increased peak intensity and slight spectral shifts in this region suggest stronger molecular interactions between maltodextrin and the bioactive compounds. This indicates the formation of a more cohesive matrix, which enhances physical stability and may lead to a more controlled and sustained release profile. The interaction of phenolic compounds and lactic acid on the carrier matrix is a change in the stretching C=O carbonyl group vibration of the phenolic compound in the range of 1419-1265 cm^{-1} and a change in the vibration of the C-O-C (glycosidic) or amide group 1100-900 cm^{-1}. Comparable outcomes were noted for several bioactive substances as well. [19] Chitosan coating's effect on the stability of flaxseed peptide fraction-loaded nanoliposomes during spray drying: This study investigated the encapsulation of bioactive compounds using chitosan and maltodextrin microparticles. FTIR spectroscopy assessed chemical interactions between encapsulation materials and bioactive compounds. Although this study provides evidence of encapsulation effectiveness based on FTIR spectral changes, this section did not evaluate the encapsulated compounds' release behavior and long-term stability. These parameters require further investigation using dedicated methods such as in vitro release studies and accelerated stability tests, which are recommended for future work.

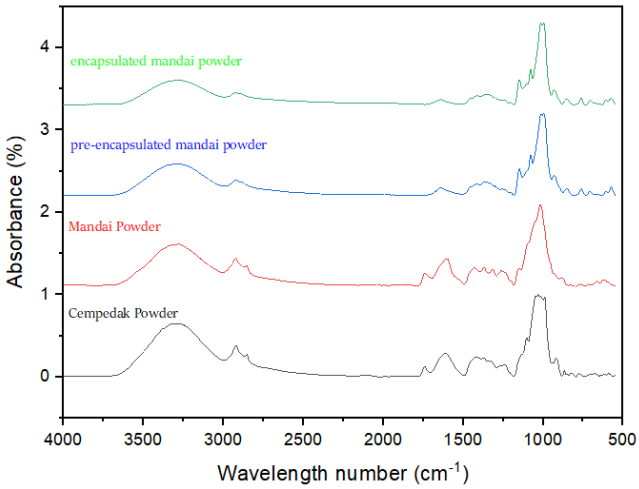

Fig 1. ATR-FTIR spectra of cempedak fruit peel powder (black), Mandai powder (red), Mandai powder pre-encapsulant (blue), and Mandai powder encapsulant (green)

Analysis of Volatile Components (GC-MS)
Figure 2 presents the chromatographic composition of volatile compounds from samples of (i) cempedak powder, (ii) Mandai powder, (iii) Mandai powder pre-encapsulant, and (iv) Mandai powder encapsulant. **Table 2** presents the identification results using mass spectroscopy (Shimadzu) bank data. A few constituents stand out, mainly (11, 16) Isosorbide Dinitrate % area (10.33 and 5.18), (8) 4H-Pyran-4-one, 2,3-dihydro- 3,5-dihydroxy-6-methyl- area %area 4.84, (10) L-Sorbose area %area 4.29, (5) Pyrimidine-4,6-diol, 5-methyl-. [20] have analyzed the aromatic components of jackfruit skin (Artocarpus heterophyllus). Several aromatic compound components were detected, namely 2,3-Butanediol, Butyrolactone, 1-Methoxy-2-

propyl acetate, Butanoic acid, 3-methyl-, butyl ester, n -Amyl isovalerate, n-Hexadecanoic acid.

Some of the compounds identified for Mandai powder are (1, 2) Muramic acid area % 12.62 and 5.74, (3) 13,27-Cycloursan-3-one % area 8.34, (4) 9,19-Cyclolanost-24- en-3-ol, acetate, (3ß)- %area 10.74, (5) 9,19-Cyclolanostane-3,7-diol %area 5.55 (6) Ethyl iso-allocate 5.51 other research [10] reported that fermented Mandai cempedak in powder form identified compounds such as hexanol, dodecanol, oxirane, morpholine, and octadecenoic acid.

Gas chromatography can identify compounds that impact the sense of smell, as shown in previous research [21]. The reliability of GCMS test results is influenced by various factors, especially instrument calibration, the test method's accuracy, and the processing of the materials [22-24]. Judging from the results obtained on the samples tested for Mandai powder pre-encapsulant and Mandai powder encapsulant (**Table 2**), there are differences in the compounds identified, some compounds are not found in the Mandai powder encapsulant, such as (1) [1,1'-Bicyclopropyl] -2-octanoic acid, 2'-hexyl-, methyl ester area %area 2.94, (3) Cyclopropanebutanoic acid, 2-[[2-[[2-[(2 pentylcyclopropyl)methyl]cyclopropyl]methyl]-cyclopropyl]methyl] -, methyl ester area %area 1.77, (8) 9,19-Cyclolanostane-3,7-diol area %area 13.22, (9) 13,27-Cycloursan-3-one %area 2.41, (10, 11) 9,19-Cyclolanost-24-en-3-ol, acetate, (3ß)- area 8.59 and 23.43, (12) Spirost-8-en-11-one, 3-hydroxy-, (3ß,5a, 14ß,20ß,22ß,25R)-area %area 2.28 and gave rise to new aroma compounds such as (1) paromomycin area 2.94, and (3) Ethyl 9-hexadecenoate area 1.77, The appearance of new compounds such as paromomycin and ethyl 9-hexadecenoate in the Mandai powder encapsulant is likely due to chemical interactions between bioactive compounds and encapsulating agents (e.g., chitosan and maltodextrin), or thermal degradation and transformation reactions during spray drying. This process may promote esterification or molecular rearrangement of precursor compounds. Similar findings have been reported in previous studies [25-27], which observed changes in volatile profiles and the formation of new aroma-active compounds during encapsulation of fruit extracts and other fermented materials under thermal processing. These findings support the hypothesis that the encapsulation process alters not only the quantity but also the chemical nature of volatile components in Mandai powder. This is supported by FTIR analysis, which still shows the presence of relevant functional groups such as hydroxyl (-OH), carbonyl (C=O), and glycosidic C–O–C stretching in the encapsulated Mandai powder. These functional groups are likely part of the structure of newly formed compounds, suggesting that transforming specific precursor molecules into new esters or bioactive volatiles is chemically feasible. The persistence of these functional groups indicates that although the specific compounds changed (as seen in GC-MS), their fundamental chemical backbones may have been retained or modified rather than thoroughly degraded.

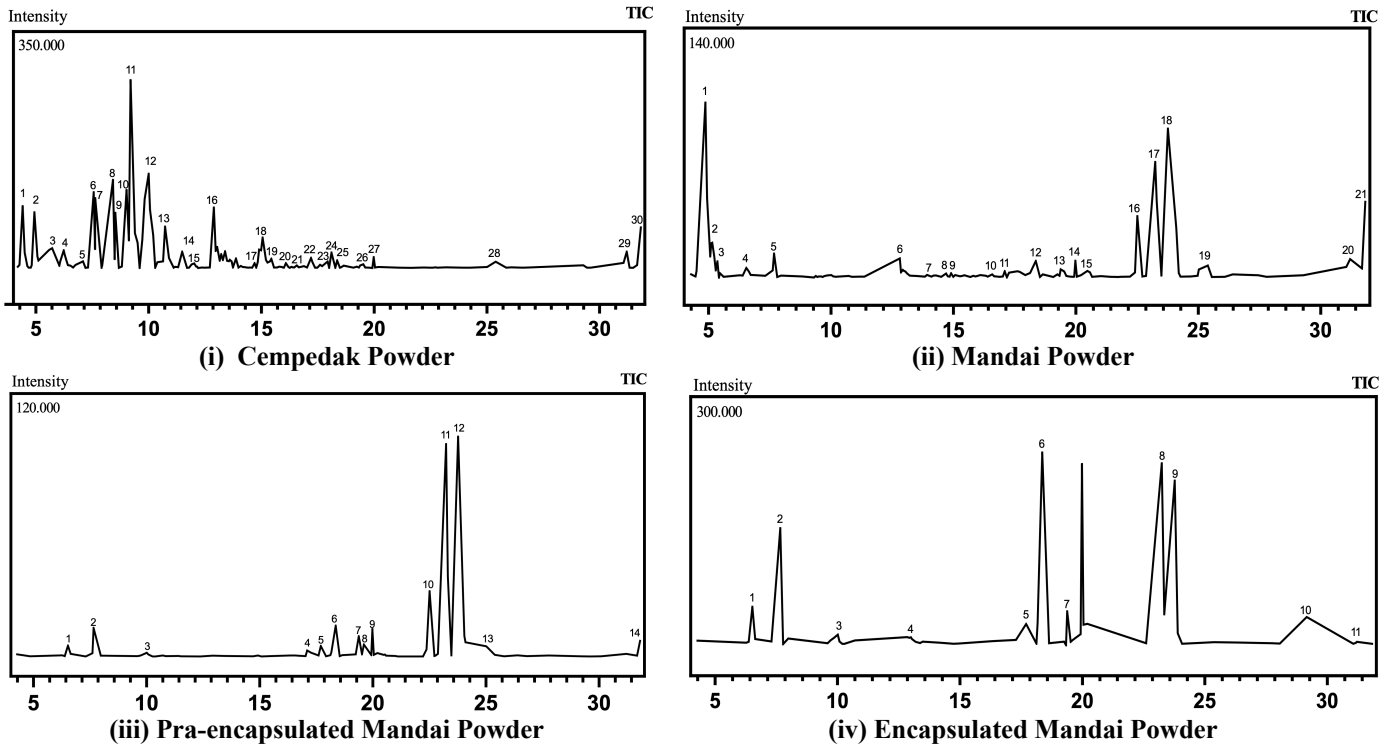

Fig. 2 Chromatogram from GCMS

TABLE I
RESULTS OF GCMS IDENTIFICATION OF VOLATILE COMPOUND CONTENT

No	Cempedak Powder		Mandai Powder		Pre-encapsulated mandai powder		Encapsulated mandai powder	
	Compound Name	**%Area**	**Compound Name**	**%Area**	**Compound Name**	**%Area**	**Compound Name**	**%Area**
1	o-Acetyl-L-serine	3.40	Muramic acid	12.62	[1,1'-Bicyclopropyl]-2-octanoic acid, 2'-hexyl-, methyl ester	1.26	o-Acetyl-L-serine	3.40
2	Dihydroxyacetone	3.06	Muramic acid	5.74	4,8-Decadienal, 5,9-dimethyl-	3.13	Dihydroxyacetone	3.06
3	D(+)-Talose	1.00	Muramic acid	3.73	Cyclopropanebutanoic acid, 2-[[2-[[2-[(2-pentyl cyclopropyl)methyl]cyclopropyl]methyl]cyclopropyl] methyl]-, methyl ester	1.21	D(+)-Talose	1.00
4	DL-Arabinose	1.09	Muramic acid	1.54	Hexadecanoic acid, ethyl ester	3.37	DL-Arabinose	1.09
5	Pyrimidine-4,6-diol, 5-methyl-	4.17	Methyltartronic acid	2.48	10-Octadecenoic acid, methyl ester	2.25	Pyrimidine-4,6-diol, 5-methyl-	4.17
6	Pyrimidine-4,6-diol, 5-methyl-	1.05	Muramic acid	2.51	Heptadecanoic acid, 16-methyl-, methyl ester	1.37	Pyrimidine-4,6-diol, 5-methyl-	1.05
7	Pyrimidine-4,6-diol, 5-methyl-	3.84	Muramic acid	1.54	(E)-9-Octadecenoic acid ethyl ester	3.01	Pyrimidine-4,6-diol, 5-methyl-	3.84
8	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	4.84	Muramic acid	0.92	9,19-Cyclolanostane-3,7-diol	7.03	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	4.84
9	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	3.03	Muramic acid	1.16	13,27-Cycloursan-3-one	22.65	Methyl glycocholate, 3TMS derivative	2.41
10	L-Sorbose	4.29	Methyl 6-oxoheptanoate	1.72	9,19-Cyclolanost-24-en-3-ol, acetate, (3ß)-	L-Sorbose	4.29	Methyl 6-oxoheptanoate
11	Isosorbide Dinitrate	10.33	Melezitose	1.39	9,19-Cyclolanost-24-en-3-ol, acetate, (3ß)-	23.43	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-	2.21
12	Isosorbide Dinitrate	1.92	Hexadecanoic acid, ethyl ester	1.20	Isosorbide Dinitrate	1.92		
13	Isosorbide Dinitrate	1.39	(E)-9-Octadecenoic acid ethyl ester	1.21	Isosorbide Dinitrate	1.39		
14	Maltose	1.55	9,19-Cyclolanostane-3,7-diol	4.43	Maltose	1.55		
15	6-Acetyl-ß-d-mannose	3.79	13,27-Cycloursan-3-one	8.34				
16	Isosorbide Dinitrate	5.18	Ethyl iso-allocholate	5.51				
17	Isosorbide Dinitrate	3.21	9,19-Cyclolanost	10.74				

			-24-en-3-ol, acetate, (3ß)-	
18	Isosorbide Dinitrate	1.81	Methyl glycocholate, 3TMS derivative	3.61
19	Melezitose	2.27	Ethyl iso-allocholate	0.88
20	d-Glycero-d-ido-heptose	3.32	.psi.,.psi.-Carotene, 1,1',2,2'-tetrahydro-1,1'-dimethoxy-	1.34
21	Melezitose	0.95	9,19-Cyclolanostane-3,7-diol	5.55
22	Melezitose	1.15		
23	d-Glycero-d-ido-heptose	0.91		
24	2-Myristynoyl pantetheine	1.02		
25	Melezitose	0.98		
26	Desulphosinigrin	1.67		
27	8-Androsten-3-ol, 17-(2-methylallyl)-4,4,14-trimethyl-	0.89		
28	9,19-Cyclolanostane-3,7-diol	2.29		

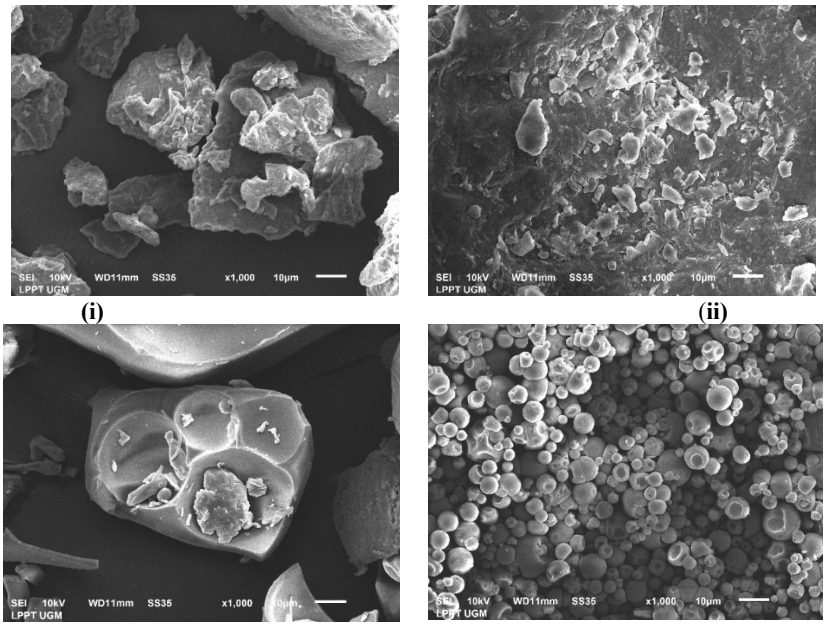

Fig. 3 Scanning electron microstructure of i) cempedak powder, ii) Mandai powder, iii) Mandai powder pre-encapsulant, iv) Mandai powder encapsulant

Morphological Characteristics

Figure 3i shows scanning electron micrographs of cempedak powder, which shows an irregular, rough surface distribution. Then, the fermentation process was carried out on the cempedak skin, and mandai powder with the same structure but a smoother surface was produced. **Figure 3ii** can be attributed to the presence of lactic acid compound on the surface, affecting the morphology of Mandai powder [28,29]. The product was mixed with maltodextrin and chitosan coating materials as a pre-encapsulant before continuing the encapsulation process by spray drying. The morphology can be seen in **Figure 3iii**, which shows an irregular surface containing the morphology of maltodextrin, chitosan, and mandai powder. The following process is carried out by encapsulating the morphology seen in **Figure 3iv**. which shows morphological changes in the Mandai powder encapsulant, forming a circle with an etching hole in the middle with an irregular distribution. [30-32] showed changes in particle morphology during spray drying. When linked to the GC-MS results, the morphological changes observed in the Mandai powder encapsulant, especially the more spherical structure and reduced surface irregularities, may indicate a partial reduction in porosity. This denser morphology can help protect certain volatile and bioactive compounds from degradation or evaporation during processing and storage. However, the presence of central etching holes suggests that some diffusion pathways remain, possibly allowing the loss of more volatile components. Therefore, the encapsulation process appears to selectively retain certain compounds, as seen in the GC-MS results, and the morphological structure plays a role in influencing the release and stability of these active compounds.

Amino Acid Content

A range of amino acids may be found in fermented foods. The type of fermented substance, fermentation method, and microorganisms can affect the amino acid composition of fermented goods [33,34,35,36]. The items cempedak powder, Mandai powder, Mandai powder pre-encapsulant, and Mandai powder encapsulant are listed in **Table 2** and include some of the following amino acids, it can be seen that the fermentation process of cempedak powder into Mandai powder increases the 15 amino acid contents detected, increasing This occurs because during the fermentation process bacteria produce proteolytic enzymes, these enzymes break down proteins into their constituent amino acids which causes an increase in overall amino acids [37,38,39], and there is a significant decrease during pre-encapsulation of Mandai powder, namely after mixing Mandai powder with a combination of maltodextrin and chitosan coating material to continue the encapsulation process, the encapsulation results showed an increase in total amino acids during the fermentation process and decreased after the encapsulation process, some amino acids were also detected relatively high, such as asparatic acid, glutamate, amino acids and arginine respectively (443.85, 544.21, and 417.23%), amino acids have a tendency to absorb onto the surface of encapsulant coating materials such as maltotextrin and chitosan. The absorption of amino acids by coating material reducing the concentration of free amino acids in the final encapsulant product [40-42].

TABLE 2
AMINO ACID PROFILE OF CEMPEDAK POWDER, MANDAI POWDER, MANDAI POWDER PRE-ENCAPSULANT, MANDAI POWDER ENCAPSULANT

Amino Acid	Cempedak Powder	Mandai Powder	Mandai Pre-encapsulant	Mandai Encapsul-ant
Aspartic Acid	3998.99	5995.35	1055.55	443.85
Threonine	2074.96	3086.91	616.39	189.92
Serine	2346.98	3455.48	740.63	225.72
Glutamate	5228.75	8233.71	1597.72	544.21
Glycine	2203.29	3058.89	643.44	208.52
Alanine	2423.25	3497.24	707.33	227.10
Valine	2435.95	3653.34	652.55	172.04
Methionin e	181.02	303.47	52.16	106.31
Isoleucine	2070.12	3087.31	<0.05	<0.05
Leucine	3682.46	5416.54	<0.08	<0.08
Tyrosine	1340.13	2083.94	<0.15	<0.15
Phenylala nine	1658.29	2943.52	560.48	141.14
Histidine	2155.48	3135.10	1809.04	103.21
Lysine	3755.71	5932.96	830.19	349.96
Arginine	1846.01	3097.12	497.86	417.23

Amino acid content in mg/Kg units.

IV. CONCLUSION

Mandai powder shows potential as an anti-cancer agent and metabolic regulator. The encapsulation process with spray drying provides a quality product. GC-MS and FTIR analysis identified functional groups, volatile components, and interactions of lactic acid and bioactive compounds. Morphological changes during encapsulation were significant from cempedak powder to Mandai powder encapsulant. Amino acid analysis showed an increase during fermentation and a decrease during encapsulation, although critical amino acids were still maintained. This study provides an essential contribution to the development of Mandai powder as a functional product with effective encapsulation techniques.

ACKNOWLEDGMENT

The author would like to thank the Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology, for funding the 2023 master's research scheme.

CONFLICT OF INTEREST

The Authors declare no conflict of interest to disclose.

USE OF ARTIFICIAL INTELLIGENCE (AI) TOOLS STATEMENT

We used Grammarly (Grammarly Inc., 2025) to improve the clarity and grammar of the manuscript. The authors reviewed and approved all changes.

REFERENCES

[1] A. Rahmadi, Y. Sabarina, and S. Agustin, "Different drying temperatures modulate chemical and antioxidant properties of mandai cempedak (Artocarpus integer)," F1000Research, vol. 7, p. 1706, Oct. 2018, doi: 10.12688/f1000research.16617.1.

[2] D. Lin et al., "An Overview of Plant Phenolic Compounds and Their Importance in Human Nutrition and Management of Type 2 Diabetes," Molecules, vol. 21, no. 10, p. 1374, Oct. 2016, doi: 10.3390/molecules21101374.

[3] A. Septembre-Malaterre, F. Remize, and P. Poucheret, "Fruits and vegetables, as a source of nutritional compounds and phytochemicals: Changes in bioactive compounds during lactic fermentation," Food Research International, vol. 104, pp. 86–99, Feb. 2018, doi: 10.1016/j.foodres.2017.09.031.

[4] C. Cerella, F. Radogna, M. Dicato, and M. Diederich, "Natural Compounds as Regulators of the Cancer Cell Metabolism," International Journal of Cell Biology, vol. 2013, pp. 1–16, 2013, doi: 10.1155/2013/639401.

[5] Y. Khasanah, Anastasia Wheni Indrianingsih, P. Triwitono, and Agnes Murdiati, "Production, biological activities and functional food of modified cassava flour (mocaf)," Canrea Journal: Food Technology, Nutritions, and Culinary Journal, pp. 213–229, Dec. 2024, doi: 10.20956/canrea.v7i2.1280.

[6] M. Shahwan, F. Alhumaydhi, G. Md. Ashraf, P. M. Z. Hasan, and A. Shamsi, "Role of polyphenols in combating Type 2 Diabetes and insulin resistance," International Journal of Biological Macromolecules, vol. 206, pp. 567–579, May 2022, doi: 10.1016/j.ijbiomac.2022.03.004.

[7] J. O. Unuofin and S. L. Lebelo, "Antioxidant Effects and Mechanisms of Medicinal Plants and Their Bioactive Compounds for the Prevention and Treatment of Type 2 Diabetes: An Updated Review," Oxidative Medicine and Cellular Longevity, vol. 2020, pp. 1–36, Feb. 2020, doi: 10.1155/2020/1356893.

[8] C. Ning et al., "Recent advances in the managements of type 2 diabetes mellitus and natural hypoglycemic substances," Food Science and Human Wellness, vol. 11, no. 5, pp. 1121–1133, Sep. 2022, doi: 10.1016/j.fshw.2022.04.004.

[9] C. Zhao et al., "Regulation of glucose metabolism by bioactive phytochemicals for the management of type 2 diabetes mellitus," Critical Reviews in Food Science and Nutrition, vol. 59, no. 6, pp. 830–847, Dec. 2018, doi: 10.1080/10408398.2018.1501658.

[10] M. Rohmah, B. Saragih, N. Amaliah, R. Apriadi, and A. Rahmadi, "Panelist Acceptance, Proximate Characteristics of Amino Acids and Volatile Compounds, and Color Profile of Fermented Cempedak (Artocarpus champeden) and Oyster Mushroom (Pleurotus ostreatus) Seasoning," Journal of Food Quality, vol. 2022, pp. 1–13, Jul. 2022, doi: 10.1155/2022/3092246.

[11] Z. Akbarbaglu, S. H. Peighambardoust, K. Sarabandi, and S. M. Jafari, "Spray drying encapsulation of bioactive compounds within protein-based carriers; different options and applications," Food Chemistry, vol. 359, p. 129965, Oct. 2021, doi: 10.1016/j.foodchem.2021.129965.

[12] A. Rezvankhah, Z. Emam-Djomeh, and G. Askari, "Encapsulation and delivery of bioactive compounds using spray and freeze-drying techniques: A review," Drying Technology, vol. 38, no. 1–2, pp. 235–258, Aug. 2019, doi: 10.1080/07373937.2019.1653906.

[13] C. I. Piñón-Balderrama, C. Leyva-Porras, Y. Terán-Figueroa, V. Espinosa-Solís, C. Álvarez-Salas, and M. Z. Saavedra-Leos, "Encapsulation of Active Ingredients in Food Industry by Spray-Drying and Nano Spray-Drying Technologies," Processes, vol. 8, no. 8, p. 889, Jul. 2020, doi: 10.3390/pr8080889.

[14] R. Apriadi. "Optimization of Mandai (Artocarpus Champeden) Powder Encapsulant Formula Using Response Surface Method (RSM)". (Master's Thesis, Mulawarman University). 2023

[15] E. D. Herculano, H. C. B. de Paula, E. A. T. de Figueiredo, F. G. B. Dias, and V. de A. Pereira, "Physicochemical and antimicrobial properties of nanoencapsulated Eucalyptus staigeriana essential oil," LWT - Food Science and Technology, vol. 61, no. 2, pp. 484–491, May 2015, doi: 10.1016/j.lwt.2014.12.001.

[16] BT. Ariza. "Use of Gas Chromatography--Olfactometry in combination with Solid Phase Micro Extraction for cocoa liquor aroma analysis". International Food Research Journal. 2011 May 1;18(2).

[17] S. R. Falsafi, H. Rostamabadi, K. Nishinari, R. Amani, and S. M. Jafari, "The role of emulsification strategy on the electrospinning of β-carotene-loaded emulsions stabilized by gum Arabic and whey protein isolate," Food Chemistry, vol. 374, p. 131826, Apr. 2022, doi: 10.1016/j.foodchem.2021.131826.

[18] E. M. Brahmana and I. A. R. Astitiasih, "Developing biochemical teaching material based on research results of amino acid compound identification of seaweed (Dictyota patens) in the Segara beach Sanur," JPBI (Jurnal Pendidikan Biologi Indonesia), vol. 3, no. 2, pp. 160–165, Jun. 2017, doi: 10.22219/jpbi.v3i2.4036.

[19] K. Sarabandi and S. M. Jafari, "Effect of chitosan coating on the properties of nanoliposomes loaded with flaxseed-peptide fractions: Stability during spray-drying," Food Chemistry, vol. 310, p. 125951, Apr. 2020, doi: 10.1016/j.foodchem.2019.125951.

[20] S. D. Peng et al., "Comparative Analysis of Volatile Compounds between Jackfruit (<i>Artocarpus heterophyllus L.</i>) Peel and its Pulp," Advanced Materials Research, vol. 781–784, pp. 1413–1418, Sep. 2013, doi: 10.4028/www.scientific.net/amr.781-784.1413.

[21] M. Biniecka and S. Caroli, "Analytical methods for the quantification of volatile aromatic compounds," TrAC Trends in Analytical Chemistry, vol. 30, no. 11, pp. 1756–1770, Dec. 2011, doi: 10.1016/j.trac.2011.06.015.

[22] C. Rimayi, D. Odusanya, F. Mtunzi, and S. Tsoka, "Alternative calibration techniques for counteracting the matrix effects in GC–MS-SPE pesticide residue analysis – A statistical approach," Chemosphere, vol. 118, pp. 35–43, Jan. 2015, doi: 10.1016/j.chemosphere.2014.05.075.

[23] I. Romero, D. L. García-González, R. Aparicio-Ruiz, and M. T. Morales, "Validation of SPME–GCMS method for the analysis of virgin olive oil volatiles responsible for sensory defects," Talanta, vol. 134, pp. 394–401, Mar. 2015, doi: 10.1016/j.talanta.2014.11.032.

[24] D. Djozan and B. Ebrahimi, "Preparation of new solid phase micro extraction fiber on the basis of atrazine-molecular imprinted polymer: Application for GC and GC/MS screening of triazine herbicides in water, rice and onion," Analytica Chimica Acta, vol. 616, no. 2, pp. 152–159, Jun. 2008, doi: 10.1016/j.aca.2008.04.037.

[25] Z. Sanchez-Reinoso, C. Osorio, and A. Herrera, "Effect of microencapsulation by spray drying on cocoa aroma compounds and physicochemical characterisation of microencapsulates," Powder Technology, vol. 318, pp. 110–119, Aug. 2017, doi: 10.1016/j.powtec.2017.05.040.

[26] X. Xin, S. Essien, K. Dell, M. W. Woo, and S. Baroutian, "Effects of Spray-Drying and Freeze-Drying on Bioactive and Volatile Compounds of Smoke Powder Food Flavouring," Food and Bioprocess Technology, vol. 15, no. 4, pp. 785–794, Feb. 2022, doi: 10.1007/s11947-022-02779-3.

[27] S.P Chen, B.S. Pan. "Food Flavors. Chemical and Functional Properties of Food Components". 2023 May 22:363-400.

[28] A. M. Pinto, S. Moreira, I. C. Gonçalves, F. M. Gama, A. M. Mendes, and F. D. Magalhães, "Biocompatibility of poly(lactic acid) with incorporated graphene-based materials," Colloids and Surfaces B: Biointerfaces, vol. 104, pp. 229–238, Apr. 2013, doi: 10.1016/j.colsurfb.2012.12.00

[29] P. Florou-Paneri, E. Christaki, and E. Bonos, "Lactic Acid Bacteria as Source of Functional Ingredients," Lactic Acid Bacteria - R & D for Food, Health and Livestock Purposes, Jan. 2013, doi: 10.5772/47766.

[30] L. Alamilla-Beltrán, J. J. Chanona-Pérez, A. R. Jiménez-Aparicio, and G. F. Gutiérrez-López, "Description of morphological changes of particles along spray drying," Journal of Food Engineering, vol. 67, no. 1–2, pp. 179–184, Mar. 2005, doi: 10.1016/j.jfoodeng.2004.05.063.

[31] F. Iskandar, L. Gradon, and K. Okuyama, "Control of the morphology of nanostructured particles prepared by the spray drying of a nanoparticle sol," Journal of Colloid and Interface Science, vol. 265, no. 2, pp. 296–303, Sep. 2003, doi: 10.1016/s0021-9797(03)00519-8.

[32] M. Nuzzo, A. Millqvist-Fureby, J. Sloth, and B. Bergenstahl, "Surface Composition and Morphology of Particles Dried Individually and by Spray Drying," Drying Technology, vol. 33, no. 6, pp. 757–767, Dec. 2014, doi: 10.1080/07373937.2014.990566.

[33] R. Mukherjee, R. Chakraborty, and A. Dutta, "Role of Fermentation in Improving Nutritional Quality of Soybean Meal — A Review," Asian-Australasian Journal of Animal Sciences, vol. 29, no. 11, pp. 1523–1529, Dec. 2015, doi: 10.5713/ajas.15.0627.

[34] R. Sharma, P. Garg, P. Kumar, S. K. Bhatia, and S. Kulshrestha, "Microbial Fermentation and Its Role in Quality Improvement of Fermented Foods," Fermentation, vol. 6, no. 4, p. 106, Nov. 2020, doi: 10.3390/fermentation6040106.

[35] K. J. Heller, "Probiotic bacteria in fermented foods: product characteristics and starter organisms," The American Journal of Clinical Nutrition, vol. 73, no. 2, pp. 374s–379s, Feb. 2001, doi: 10.1093/ajcn/73.2.374s.

[36] N. E. Diether and B. P. Willing, "Microbial Fermentation of Dietary Protein: An Important Factor in Diet–Microbe–Host Interaction," Microorganisms, vol. 7, no. 1, p. 19, Jan. 2019, doi: 10.3390/microorganisms7010019.

[37] M. Kieliszek, K. Pobiega, K. Piwowarek, and A. M. Kot, "Characteristics of the Proteolytic Enzymes Produced by Lactic Acid Bacteria," Molecules, vol. 26, no. 7, p. 1858, Mar. 2021, doi: 10.3390/molecules26071858.

[38] M. D'Este, M. Alvarado-Morales, and I. Angelidaki, "Amino acids production focusing on fermentation technologies – A review," Biotechnology Advances, vol. 36, no. 1, pp. 14–25, Jan. 2018, doi: 10.1016/j.biotechadv.2017.09.001.

[39] D. E. Cruz-Casas, C. N. Aguilar, J. A. Ascacio-Valdés, R. Rodríguez-Herrera, M. L. Chávez-González, and A. C. Flores-Gallegos, "Enzymatic hydrolysis and microbial fermentation: The most favorable biotechnological methods for the release of bioactive peptides," Food Chemistry: Molecular Sciences, vol. 3, p. 100047, Dec. 2021, doi: 10.1016/j.fochms.2021.100047.

[40] Y. Ma, J. Xu, S. Jiang, and M. Zeng, "Effect of chitosan coating on the properties of nanoliposomes loaded with oyster protein hydrolysates: Stability during spray-drying and freeze-drying," Food Chemistry, vol. 385, p. 132603, Aug. 2022, doi: 10.1016/j.foodchem.2022.132603.

[41] Z. A. Raza, S. Khalil, A. Ayub, and I. M. Banat, "Recent developments in chitosan encapsulation of various active ingredients for multifunctional applications," Carbohydrate Research, vol. 492, p. 108004, Jun. 2020, doi: 10.1016/j.carres.2020.108004.

[42] K. Sarabandi, P. Gharehbeglou, S. M. Jafari, and Z. Akbarbaglu, "Spray Drying Encapsulation of Proteins and Bioactive Peptides," Spray Drying Encapsulation of Bioactive Materials, pp. 241–270, Aug. 2021, doi: 10.1201/9780429355462-10..