Original Research Article

Physio-chemical properties and oxidative stability of microencapsulated silkworm pupae oil enriched mayonnaise

Abstract

This study investigates to enrich the mayonnaise with novel oil replacer which is from silkworm pupae insect. Due to their health benefits, the well-known omega-3 and omega-6 fatty acid families are the most significant polyunsaturated fatty acids (PUFA) demanded in foods. Insects are traditionally consumed as food in different parts of the world since they are both a good source of protein and rich in essential fatty acids (EPA and DHA). The product Mayonnaise was developed usingEncapsulated Silkworm Pupae Oil powder (Mayo-ESOP of 10 g) and SilkwormPupae Oil (Mayo-SPO OF 10 ML) and was compared with control mayonnaise prepared out of sunflower oil. The mayonnaise samples were analysed for oxidative stability through peroxide values at 0, 7, 14 and day 21days and after preparation of physical parameters such as droplet size for surface (µm), volume (µm), viscosity (γ=10 s^{-1}),proximate analysis, colour values (*L, *a and *b) fatty acids profile.The study revealed that Mayo-ESOP and Mayo-SPO samplesshowedbetteroxidative stability as a result of this not affecting any quality aspects of mayonnaise samples.The proximate composition among the three variations of mayonnaise Mayo-SPO was found to have a maximum fat content of 76.13±0.01g per 100 g, followed by Mayo-ESOP 72.3±0.01g/100 g and Control 66.21±0.01g/100 g respectively. The fat composition indicates that silkworm pupae havea very good fatty acid profile, which includes omega 9 and omega 6. The colour values (L*, a*, b*) and the total colour difference represented as (ΔE values) had no much significant differenceshow the yellowness colourfor mayonnaise sample compared to control due to the presence of carotenoids.Overall, the colour assessment reveals that the oil was of good quality. Oxidative stability indicates the mayonnaise samples stored at a refrigerated temperature for 0, 7, 14, and 21 days had significantly difference on peroxide values due to oxidation of mayonnaise samples.

Keywords: *Mayonnaise, Silkworm pupae oil,colour values, fatty acid profile and oxidative stability*

1.0. Introduction

Insects are traditionally eaten as food in several different portions of the world since they are both a good source of protein and very nutritious. The practice of entomophagy in India depicts that various tribes in our nation eat roughly 255 distinct species of insects. ColeopteranSpecies make up the largest portion of these edible insect species, accounting for approximately 34% of all consumption, followed by Orthoptera (24%), Hemiptera (17%), and Hymenoptera (10%). Tribes have chosen insects as food based on their regional preferences, culinary preferences, seasonal availability, and traditional beliefs. All phases of development involve the consumption of insects. Roasting or boiling are the primary methods used to prepare edible insects for consumption. Insects' flavour is enhanced by the addition of spices. Entomophagy is quite widespread among the ethnic groups of people of Meghalaya and Mizoram has the fewest instances of this practice. It is necessary to shed light on entomophagy studies and to encourage entomophagy research in order to catalogue all edible insects and the manner in which they are consumed by diverse tribal people in India(Chakravorty, 2014).

Silkworm (*Bombyx mori*) was consumed in China, Thailand and north-eastern India. China is the highest producer of silkworm followed by India. After the use of silkworm cocoon for reeling yarn, the pupae of the silkworm were discarded. The pupae are a waste material that is rich in many nutrients. Silkworm pupae contain 35% fat which was extracted by soxhlet extraction.Silkworm pupae oil showed 28 fatty acids; among them(12.75%) were Saturated Fatty Acids (SFA) and 86.61% of Unsaturated Fatty Acids (USFA). Unsaturated fatty acids contain Monounsaturated fatty acids (34.97%) and Polyunsaturated fatty acids (51.64%). Around 28.35% of essential fatty acids like linoleic acid, arachidonic acid and docosahexaenoic acids were also present(Patil *et al.*, 2019).

Consumer expectations for the manufacturing of functional foods have significantly expanded during the last few decades. Functional foods have a remarkable impact on maintaining good health, extending life, and reducing the development of chronic diseases. The well-known omega-3 and omega-6 fatty acid families are the most significant PUFA. Both of these fatty acid families share the same long-chain enzymes, and they both start out as precursorsALA for n-3 families and linoleic acid for omega-6 families end up as terminal products after a series of elongation and desaturations during metabolism. The human body cannot produce these precursor substances, but it can absorb them into longer-chain derivatives, making them necessary. Additionally, the diet must provide the body with the fatty acids it requires. Many different ailments, including autoimmune disorders, certain forms of cancer and cardiovascular disorders,have been linked to the absence of EFA in a typical diet. For daily ω-3 supplementation, it is crucial to produce low-cost edible oil with a high concentration of ω-3 fatty acids. Silkworm pupae oil is a suitable option in this case. A lucrative oil type called crude SPO is taken out of silkworm pupae. The primary by-product of mulberry silkworms (*Bombyx mori L.*), which are primarily utilised as fertiliser and feed, is a silkworm pupa, which is currently classified as industrial waste (Hu *et al.*, 2017)

Insect as food has environmental benefits with respect to less special usage and H_2O requirement. For example, 150 g grasshopper requires less water (3.78 L) than same amount of cattle meat which requires 3290 litres and for beef 10 times more plant materials is needed to one kilogram of insect biomass(Premalatha et al., 2011).In some parts of the world, pupae are used as food. However, the spent silkworm pupae discarded after reeling the silk yarn which. they are frequently thrown away, which results in a loss of possible nutrients and a significant environmental problem(Wang et al., 2010)

For reducing lipid oxidation generally, encapsulation techniques were used extensively when enhancing food with omega-3 and omega-6 fatty acids. The purpose of this research is to study the oxidative stability and physical characteristics of mayonnaise enriched with microencapsulated silkworm pupae oil. During a storage periodof up to 21 days, assessed oxidative stability of the enriched mayonnaisewas along with control.

2.0. Materials and methods

2.1 Experiment sample procurement

Silk growing farmer's cooperative society® in the Chintamani taluk of Karnataka, India, supplied the mulberry silkworm cocoon. Silkworm cocoons for Eri and Muga were provided by the Indian state of Assam farmers who raise silkworms. By cut opening the cocoons, live silkworm pupae were separated and preserved in freezing conditions at -14 °C until they were used. The pupae of silkworms were then dried completely for 48 hours by being placed in a freeze dryer at -80 °C. For subsequent experimental examination, dried silkworm pupae were ground into a powder, sealed in HDPE, and maintained at 4 °C in the refrigerator. The Silkworm Pupae Oil (SPO) and Encapsulated Silkworm Oil Powder (ESOP) were used for fortifyingthe mayonnaise encapsulated from silkworm pupae in the research work.

2.2. Preparation of mayonnaise

The standard method and formulation for mayonnaise preparation is presented in Table 1. For the control sample, one whole egg was taken,and whisked well along with a required proportion of salt, sugar and vinegar. As the egg turns foamy, then slowly edible oil is incorporated and whisked continuously till it holds a fluffy texture. The same procedure was followed for enriched mayonnaise, where ESOPand SPO were incorporated by replacing the edible oil content and whisking continuously till it held the fluffy texture. The prepared mayonnaise wassubjected to further analysis.

Table 1: Formulation used for the micro-encapsulated oil powder and silkworm pupae oil

Ingredients	**Control**	**Mayo ESOP**	**Mayo SPO**
Edible oil (ml)	50	40	40
Egg (no.)	1	1	1
Salt (g)	2	2	2
Sugar (g)	5	5	5
Vinegar (ml)	3	3	3
*ESOP (g)	-	10	-
*SPO (ml)	-	-	10

*ESOP: Encapsulated oil powder *SPO: Silkworm pupae oil

2.2. Analysisof Proximate compositionof mayonnaise formulation

The developed product's'Nutritional composition of the mayonnaise was analysed usingstandardmethodsinthelaboratory ofNIFTEM, Thanjavur. Proximate composition for protein, fat, ash and crude fiber wasanalysed using AOAC (2006) by (Horowitz & Latimer, 2006), and the carbohydrate values were computed using the Indian food composition table.

2.3. Analysis of oxidative stability of the mayonnaise samples.

Mayonnaisesamples were subjected to an oxidative stability study through peroxide values. To determine the peroxide value, 2g of oil was dissolved in 25 ml of chloroform and acetic acid (2:3 by volume ratio), 1 ml of potassium iodide solution, which was saturated and left in the dark for ten minutes. Then 30 ml of distilled waterwas added with 1% starch solution, and the mixturewas titrated with sodium thiosulfate (0.01N) until the blue colour disappeared(Jeon et al., 2016). The sampleswere stored in a glass bottle for three weeks at a refrigerated temperature (4°C), and Samples were used at 0,7,14 and 21days.

2.4. Analysis of droplet size and apparent viscosity

Mayonnaise samples were taken out after 21 days of storage at 25°C, and droplet size dispersion & viscosity of mayonnaise were evaluated. To measure the dispersion of droplet sizepersistence, 1 g of mayonnaise was liquified at a ratio of 1:5 (w/w) in sodium dodecyl sulphate (SDS) buffer (10-mM NaH_2PO_4) with pH 7(Miguel et al., 2019). To prevent droplet aggregation, the solution was sonicated for 15 minutes. The results were represented in surface area withthe mean diameter (µm), and volume weighed withthe mean diameter (µm), and measurements were performed in triplicates.

A Brookfield Prime digital viscometer (Model DV-I) was used to analyse the viscosity of mayonnaise samples with a 100rpm rotating speed at 25 °C. The upper plate and bottom base (PP 25) both had a 2 mm gap. Up to 65 Pa, a gradient of increasing stress was applied.

2.5.Color analysis

The colour of mayonnaise is considered to have an important role in determining its appearance and overall acceptability. This test's objective was to determine the extent to which the inclusion of silkworm pupae oil changed the colour of samples of mayonnaise. The colour parameters (L, a, b) of silkworm pupae powder were calculated using a Hunter colour flex model. It operates on the concept of capturing light and measuring energy from a sample that has been reflected throughout the overall visible spectrum. Each time the equipment was standardised with standards like white and black. Samples were scanned to determine the L*, a* and b* where L* indicates lightness and darkness, a* indicates red (+a) and green (-a), b* indicates blue (+b) and yellow (-b). *(Das et al.,* 2013)

2.6. Analysis of Fatty acid profile using GCMS

To study the fatty acid composition,Silkworm Pupae Oil was first transformed into FAME (Fatty acid methyl esters). A sample of 500 µl silkworm pupae oil was taken, and 2 ml of dichloro methane (DCM) and sodium methoxide were added. The sample was then vortexed for 2 min, and it was then kept in a water bath at 40 °C until it evaporated up to 95%. The sample is then cooled, and 5 ml of distilled water is added and vortexed for another 2 to 3 minutes. The top layer of the supernatant is then collected, and the sample is injected into the GC unit. GC Column Rtx-5MS equipment 8890GC/5977B GC/MSDAgilent. Carrier gas 1ml/min with single quadrupole mass spectrometer detector used, then 2 µl sample injected with Oven temperature-110 °C and raised up to 200 °C at the rate of 10 °C/min-no hold up to 280 °C. The mass spectrometer programme was established using the NIST Version 2020 library. The electron energy was 70 eV, the source temperature was 250 ℃, the inlet line temperature was 290 °C, and the entire run time was around 40 minutes(Akbari et al., 2012).

2.7. Statistical analysis

Using ANOVA and grouping data from the Tukey's range test, all the raw data were entered into the Minitab programme to establish the significance of the differences between mayonnaise samples. Differences between means were measuredas significant at $P \leq 0.05$(Patil *et al.*, 2022)

3.0. Results and discussion

3.1. Effect of proximate composition on formulated mayonnaise

The proximate composition of the mayonnaise was analysed using the AOAC method, and the results are presented in Table 2. Among the three variations of mayonnaise, Mayo-SPO was found to have the maximum fat content of 76.13±0.01g per 100 g, followed by Mayo-ESOP 72.3±0.01g/100 g and control showed 66.21±0.01g/100 g respectively due to addition of ESOP and SPO to mayonnaise.The fat composition indicates that silkwormpupae havea very good profile of fatty acid profile, which also includes omega 9 and omega 6 fatty acidsshown in Table 5. Mayo-ESOP has a good amount of protein 6.5±0.01g/100 g, followed by Mayo-SPO 5.9±0.01g/100 g and Control 5.4±0.01g/100 g, respectively. There is no significant differencein moisture and ash content of mayonnaise variations,*i.e.*, 18.43±0.01% (Control), 17.03±0.01% (Mayo-ESOP),and 17.92±0.01% (Mayo-SPO), respectively. The ash content was found in Mayo-SPO 1.7±0.01g/100 g followed by Mayo-ESOP 1.5±0.01g/100 g and Control 1.4±0.01g/100 g, respectively. For the control 2.53±0.01g/100 g, Mayo-SPO 2.62±0.01g/100 g and Mayo-ESOP 2.78±0.01g/100 g were found to be low in carbohydrates and crude fibre present in all the mayonnaise samples such as control (0.8±0.01g/100 g) followed by Mayo-SPO (0.61±0.01g/100 g) and Mayo-ESOP (0.6±0.01 g/100 g) respectively. The study conducted by(Longvah *et al.*, 2011) is creditable with present study.

Table 2. Proximate composition of formulated mayonnaise (Mayo-ESOP and Mayo-SPO) compared with the control sample.

Proximate composition	Mayo Control	Mayo ESOP	Mayo SPO
Protein (g)	5.4±0.01^{c}	6.5±0.01^{a}	5.9±0.01^{b}
Fat(g)	66.21±0.01^{c}	72.3±0.01b	76.13±0.01^{a}
Moisture (%)	18.43±0.01^{a}	17.03±0.01^{c}	17.92±0.01^{b}
Ash(g)	1.4±0.01^{c}	1.5±0.01^{b}	1.7±0.01^{a}
Carbohydrate (g)	2.53±0.01^{b}	2.78±0.01^{a}	2.62±0.01^{c}
Crude fiber(g)	0.8±0.01^{a}	0.6±0.01^{b}	0.61±0.01^{b}

Different superscripts denote statistically significant differences (*P<0.05*) across various mayonnaise formulations.

3.2. Droplet size and viscosity of formulated mayonnaise

The sizeof the mayonnaise droplets was measured before and after 21days storage period. Table 3. represents that, as compared to the control mayonnaise prepared from sunflower oil, the mayonnaise enhanced with encapsulated silkworm pupae oil powder (Mayo-ESOP) and silkworm pupae oil (Mayo-SPO) displayed considerably (*P*<0.05) greater D (4,3)values after 21 dayswhileit showed no much significant changesseen in the D3,2 values. At the same time, D4,3 includes data on the droplet size of the mayonnaise prepared. The D3,2 primarily represents the size of the small dropletsexisting in the emulsion-like substance(McClements, 2005). As a result, as related to the presence of sunflower oil control, the reduction in droplet size during the production of mayonnaise was significantly reduced in the presence of Mayo-ESOP.

Likewise, (Hermund *et al.,* 2019) reporteda bigger droplet size for mayonnaise enriched with Mayo-SPO when compared to the control. Nevertheless, Mayo-SPO had a larger droplet size compared to the control. This might be explained by the fact that Mayo ESOP was still present in the mayonnaise matrix, which prevented the droplet size from being reduced too much during homogenisation. On the other hand, it's possible that the control matrix, when added to the mayonnaise-based watery matrix, disintegrated, encouraging homogenisation. The droplet size of Mayo-ESOP greatly increases during storage, as evidenced by the D4,3 values in Table 3,Despite the fact that no creaming was seen. On the other hand, after 21 days of storage, Mayo-D4,3 SPOs dropped. This indicated a physical destabilisation in Mayo-ESOP caused by flocculation or coalescence, whereas possible floccules in Mayo-SPO after manufacturing vanished during storage. In mayonnaise products, these occurrences were reported by (Hermund et al. 2019).

The apparent viscosity values for the mayonnaise sampleswere at a shear rate of 10 $^{s-1}$. The Mayo-ESOP demonstrated a much higher apparent viscosity than the Mayo-SPO and control mayonnaise, it was found. These outcomes are consistent with previous reportsof (Miguel *et al.*, 2019), who claimed that the microcapsules hadagglomeration effect in the aqueous phase was the cause of the mayonnaise samples with increased viscosity when it was enhanced with microcapsules. The Mayo-ESOP and M-SPO samples showed greater physical stability as a result of this fact was linked to an increase in viscosity. Overall, the mayonnaise fortified by the silkworm pupae oil-based enrichment system had a high level of physical stability and enhanced viscosity.

Table 3.Droplet size and viscosity of different mayonnaise samples.

Sample	**Surface D[3,2] (µm)**		**Volume D[4,3] (µm)**		**Apparent Viscosity (γ=10 s^{-1}), Pa.s**	
	Initial (0^{th} day)	**day 21**	**Initial (0^{th} day)**	**day 21**	**Initial (0^{th} day)**	**day 21**
Control	1.0 ± 0.005^{a}	0.5 ± 0.01^{c}	35.5 ± 0.02^{a}	43.4 ±0.01^{a}	2.6 ± 0.3^{c}	2.0 ±0.01^{c}
Mayo-EOP	1.0 ± 0.005^{a}	0.7 ± 0.02^{a}	27.7 ± 0.01^{c}	35.6 ±0.02^{b}	4.8 ±0.1^{a}	5.1 ±0.05^{a}
Mayo-SPO	1.0 ±0.005^{a}	0.6 ± 0.01^{b}	30.2 ± 0.005^{b}	30.7 ± 0.01^{c}	3.7 ± 0.3^{b}	3.4 ±0.02^{b}

Different superscripts denote statistically significant differences ($P<0.05$) across various mayonnaise formulations.

3.3. Colour values ofthe formulated mayonnaise

The silkworm pupae powder colour parameters (L, a, b) were calculated using a Hunter colour flex model. It operates on the theory of absorbing light and measuring energy from a sample that has been reflected throughout the whole visible spectrum. Each time the equipment was standardised with standards like white and black. Samples were scanned to determine the L*, a* and b* where L* indicates lightness and darkness, a* indicates red (+a) and green (-a), and b* indicates blue (+b) and yellow (-b). The colour values assessed are tabulated in Table 4. for mayonnaise variations,which shows that the mayonnaise with L value was light in colour in all three mayonnaise variations (Control: 84.56±0.005, Mayo-ESOP: 83.06±0.005and Mayo-SPO: 80.49±0.005) followed by a parameter indicated by slightly negative value (Mayo-ESOP: -1.29±0.002, Mayo-SPO: -0.70±0.005and control: -0.63±0.005) resulting in slightly green tinge and b parameter having positive values (Control: 12.46±0.005, Mayo-SPO: 11.41±0.005 and Mayo-ESOP: 10.82±0.005) indicates as the oil is yellowness in colour, this is due to the presence of carotenoidsin the silkworm pupae oil(Tangsanthatkun et al., 2022). The total colour values had no significant difference among (ΔE) for SPO and mayo ESOP. Overall, the colour assessment reveals that the mayonnaise had an acceptable colour appearance compared to the control.

Table 4. Colour values of formulated mayonnaise (Mayo-ESOP and Mayo-SPO) and control samples

Variations	Colour values			ΔE
	*L**	*a**	*b**	
Mayo Control	84.56 ± 0.005^{a}	-0.63 ± 0.005^{c}	12.46 ± 0.005^{a}	0.91 ± 0.01^{a}
Mayo SPO	83.06 ± 0.005^{b}	-0.70 ± 0.005^{b}	11.41 ± 0.005^{b}	0.77 ± 0.005^{b}
Mayo ESOP	80.49 ± 0.005^{c}	-1.29 ± 0.002^{a}	10.82 ± 0.005^{c}	0.73 ± 0.01^{c}

Different superscripts denote statistically significant differences ($P<0.05$) across various mayonnaise formulations.

3.4. GCMS - Fatty acid profile of formulated mayonnaise

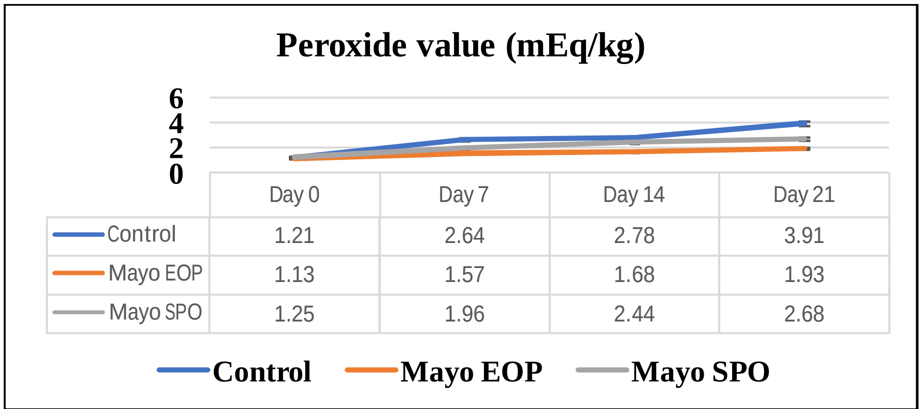
Fattyacid profiles of three distinct types of mayonnaise are listed in Table 5, whichshows that the samples are good sources of omega 9 and omega 6 fatty acids as well as unsaturated fatty acids. Linoleic acid (ω-6) is a very good source in Mayo-SPO (48.44%), Mayo-ESOP (47.70%), and control (45.77%) samplesAll three samples of mayonnaise show a strong sourceof PUFA and MUFA.Yan et al., 2021reported that silkworm pupae oil can be alternate source of alpha linolenic acid that having better absorption and greater digestive properties.It also contains a minimal quantity of Eicosanoic acid and Docosanoic acid. The therapeutic benefits of eicosanoic acid and docosanoic acid can be used to treat coronary heart disease (Han *et al.*, 1991).Similar study done for enrichment of mayonnaise from fish oil encapsulated with zein protein shown better oxidative stability and quality of mayonnaise(Miguel et al., 2019).

Table 5. Fatty acid profile of formulated mayonnaise (Mayo-ESOP and Mayo-SPO) and control samples

Sl. No.	Fatty acid compounds	Formula	Control	Mayo ESOP	Mayo SPO
1.	Palmitoleic acid	$C_{16}H_{30}O_2$	0.28	0.37	0.39
2.	Palmitic acid	$C_{17}H_{34}O_2$	9.99	9.85	9.09
3.	Linoleic acid (ω-6)	$C_{18}H_{32}O_2$	45.77	47.70	48.44
4.	Oleic acid (ω-9)	$C_{19}H_{36}O_2$	38.07	35.36	35.27
5.	Methylstearate	$C_{19}H_{38}O_2$	5.38	5.83	5.73
6.	Eicosanoicacid	$C_{21}H_{40}O_3$	ND	0.26	0.29
7.	Docosanoicacid	$C_{23}H_{46}O_2$	0.51	0.63	0.79

3.5. Oxidative stability of formulated mayonnaise

All the mayonnaise samples stored at a refrigerated temperature for 0, 7, 14, and 21 days had significantly different peroxide values ($P<0.05$),which are depicted in Figure 1. The rancidity of the mayonnaise samples was shown by the progressive rise in peroxide values from initial values 1.13mEq/kg on day 0 to 3.91 mEq/kg on day 21 of oil during storage due to oxidation of oil content in samples, but the stability was high in Mayo ESOP and Mayo SPO as it contained high amountsof antioxidants and also got better protection from encapsulation of oil as well as it was stored in refrigerated conditions had more oxidative stability for the longer storage period. Mayonnaise samples have good keeps quality when it is stored in refrigerators,and theirperoxide readings are less than 10meq/kg oil that can be considered as safer to consume. Similar results were reported for fish oil enriched mayonnaise reported by (Miguel et al., 2019).



	Day 0	Day 7	Day 14	Day 21
Control	1.21	2.64	2.78	3.91
Mayo EOP	1.13	1.57	1.68	1.93
Mayo SPO	1.25	1.96	2.44	2.68

Figure 1: Peroxide value mayonnaise variations

Conclusion:

The mayonnaise formulated using silkworm pupae oil and silkworm pupae oil encapsulated powder showed better quality characteristics inthe oxidative stability and physicochemicalpropertiescompared to Control mayonnaise prepared out of sunflower oil. Further studies have to be conducted using silkworm pupae oil and protein-based value-added products in the form of convenience foods to meet the growing demands of the population and also to enhance the nutritional value of foods.

References:

Akbari, M., Razavizadeh, R., Mohebbi, G. H., & Barmak, A. (2012). Oil characteristics and fatty acid profile of seeds from three varieties of date palm (Phoenix dactylifera) cultivars in Bushehr-Iran. *African Journal of Biotechnology*, *11*(57), 12088–12093.

Chakravorty, J. (2014). Diversity of Edible Insects and Practices of Entomophagy in India: An Overview. *Journal of Biodiversity, Bioprospecting and Development*, *01*(03), 1–9. https://doi.org/10.4172/2376-0214.1000124

Das, A., Raychaudhuri, U., & Chakraborty, R. (2013). Effect of wheatgrass for enhancing the nutritional, textural, total antioxidant and sensory characteristics of 'idli'-An Indian steamed rice cake. *J Food Technol*, *11*(3), 67–74.

Han, Y.-S., Yoon, J.-Y., & Lee, S.-R. (1991). Effect of palm oil blending on the thermal and oxidative stability of soybean oil. *Korean Journal of Food Science and Technology*, *23*(4), 465–470.

Hermund, D., Jacobsen, C., Chronakis, I. S., Pelayo, A., Yu, S., Busolo, M., Lagaron, J. M., Jónsdóttir, R., Kristinsson, H. G., & Akoh, C. C. (2019). Stabilization of fish oil□loaded electrosprayed capsules with seaweed and commercial natural antioxidants: effect on the oxidative stability of capsule□enriched mayonnaise. *European Journal of Lipid Science and Technology*, *121*(4), 1800396.

Horowitz, W., & Latimer, G. W. (2006). Official methods of analysis of AOAC International. *Gaithersburg, Md. AOAC International*, *18*.

Hu, B., Li, C., Zhang, Z., Zhao, Q., Zhu, Y., Su, Z., & Chen, Y. (2017). Microwave-assisted extraction of silkworm pupal oil and evaluation of its fatty acid composition, physicochemical properties and antioxidant activities. *Food Chemistry*, *231*, 348–355. https://doi.org/10.1016/j.foodchem.2017.03.152

Jeon, Y. H., Son, Y. J., Kim, S. H., Yun, E. Y., Kang, H. J., & Hwang, I. K. (2016). Physicochemical properties and oxidative stabilities of mealworm (Tenebrio molitor) oils under different roasting conditions. *Food Science and Biotechnology*, *25*(1), 105–110. https://doi.org/10.1007/s10068-016-0015-9

Longvah, T., Mangthya, K., & Ramulu, P. (2011). Nutrient composition and protein quality evaluation of eri silkworm (Samia ricinii) prepupae and pupae. *Food Chemistry*, *128*(2), 400–403.

McClements, D. J. (2005). Theoretical analysis of factors affecting the formation and stability of multilayered colloidal dispersions. *Langmuir*, *21*(21), 9777–9785.

Miguel, G. A., Jacobsen, C., Prieto, C., Kempen, P. J., Lagaron, J. M., Chronakis, I. S., & García-Moreno, P. J. (2019). Oxidative stability and physical properties of mayonnaise fortified with zein electrosprayed capsules loaded with fish oil. *Journal of Food Engineering*, *263*, 348–358.

Patil, A. R., Dip, G., Meenatchi, R., Moses, J. A., & Bhuvana, S. (2019). Extraction and Characterization of Silkworm Pupae (Bombyx mori) Oil by LC-MS/MS Method. *Int. J. Pure App. Biosci*, *7*(3), 503–509.

Patil, A. R., Wadje, P., & Meenatchi, R. (2022). *Extraction and characterization of three different species of silkworm pupae oil of Indian origin*. *11*(12), 1553–1557.

Premalatha, M., Abbasi, T., Abbasi, T., & Abbasi, S. A. (2011). Energy-efficient food production to reduce global warming and ecodegradation: The use of edible insects.

Renewable and Sustainable Energy Reviews, *15*(9), 4357–4360.

Tangsanthatkun, J., Peanparkdee, M., Katekhong, W., Harnsilawat, T., Tan, C. P., & Klinkesorn, U. (2022). Application of Aqueous Saline Process to Extract Silkworm Pupae Oil (Bombyx mori): Process Optimization and Composition Analysis. *Foods*, *11*(3), 291.

Wang, J., Wu, F., Liang, Y., & Wang, M. (2010). Process optimization for the enrichment of α-linolenic acid from silkworm pupal oil using response surface methodology. *African Journal of Biotechnology*, *9*(20).

Yan, C. H., Xun, X. M., Wang, J., Wang, J. Z., You, S., Wu, F. A., & Wang, J. (2021). An alternative solution for α-linolenic acid supplements:: In vitro digestive properties of silkworm pupae oil in a pH-stat system. *Food and Function*, *12*(6), 2428–2441. https://doi.org/10.1039/d0fo03469j