

Development and Evaluation of an Eco-Friendly Double-Layered Self-Heating Meal Pouch

Monika N.¹; Dr. S. Ponne²

^{1,2}Department of Foods and Nutrition, Vellalar College for Women, Erode – 638012, Tamil Nadu, India.

Publication Date: 2026/10/02

Abstract: Food packaging is essential for ensuring food safety, hygiene, shelf life, and convenience; however, the extensive use of petroleum-based plastics has resulted in serious environmental challenges. Conventional plastic packaging persists in the environment, breaks into microplastics, and releases harmful chemicals, causing serious environmental pollution and health concerns. Changing lifestyles and emergency situations have increased the need for ready-to-eat meals that can be heated without fuel or electricity. The objective of the present study is to develop and evaluate an eco-friendly double-layer self-heating meal pouch that combines environmental sustainability with functional convenience. The proposed pouch consists of a CMC–starch outer layer to provide flexibility, mechanical strength, and biodegradability, and a starch–chitosan inner food-contact layer to offer natural antimicrobial activity and moisture resistance. A calcium oxide (CaO)-based self-heating system is integrated into a separate compartment, where heat is generated through an exothermic hydration reaction upon the addition of water. The study involves fabrication and multi-dimensional evaluation of a biodegradable self-heating food pouch, including physio-chemical, mechanical, thermal, safety, biodegradability, sensory, and field performance assessments. A biodegradable double-layer self-heating meal pouch using CaO achieved efficient heating (55–63°C), high sensory acceptability (>8.5), and significant field performance ($t = 5.26$ – 11.18), demonstrating a safe, eco-friendly, and effective alternative to conventional heating systems. The proposed biodegradable self-heating meal pouch is expected to provide a sustainable alternative to conventional plastic-based systems and holds strong potential for application in defence, disaster relief, emergency feeding programs and outdoor activities, contributing to environmentally responsible food packaging solutions.

Keywords: Biodegradable Packaging; Self-Heating Meal Pouch; CMC–Starch; Starch–Chitosan; Calcium Oxide Heater.

How to Cite: Monika N.; Dr. S. Ponne (2026) Development and Evaluation of an Eco-Friendly Double-Layered Self-Heating Meal Pouch. *International Journal of Innovative Science and Research Technology*, 11(9), 2466-2474.
<https://doi.org/10.38124/ijisrt/26sep1217>

I. INTRODUCTION

The amount of global plastic waste generated in 2015 was over four-fifths of the total globally produced plastic and was sent to landfills with a small portion being sent to incineration or recycling [3]. Under the same trends of waste management and production, it has been estimated that about 12,000 metric tons of plastic waste could end up in the environment by 2050 [1] if they continue. A circular economy supports the reduction, reuse, recycling, and recovery of resources through environmentally friendly (in comparison to those made from traditional petrochemicals) resource-efficient production and consumption systems [6]. Countries such as India, the United States, Canada, Taiwan, Belize, and Costa Rica restrict the use of single-use plastics such as bags, cutlery, and straws due to increasing plastic pollution [2].

However, many self-heating meals are still packaged using non-biodegradable materials, such as multilayer plastic laminates. These materials produce long-lasting waste and lead to further problems associated with heating components

and possible hazardous chemicals. Research has found that food-contact plastics, in particular those that are heated, leak microplastics and volatile organic compounds (VOCs) into foods which could pose health risks by migrating from plastic into food [8]. In addition to promoting biodegradable materials as green alternatives, evidence suggests that their performance can vary under certain environmental conditions. Low oxygen levels, limited microbial activity and low ambient temperatures—which are common in both marine environments and soil—significantly slow down the degradation of materials due to their decomposition process. In these situations, the materials will still break down; however, instead of decomposing entirely, they break down into micro- or nano-particles [7]. New research shows that these micro- and nanoparticles may persist in the environment, with as yet unknown long-term consequences to ecology and human health [2].

This proposed study explores the possibility of developing a double-wall self-heating meal pouch that combines functionality with eco-responsibility. The outer wall of the pouch will be made of an outer layer of

carboxymethyl cellulose (CMC) and starch for strength and flexibility, while the food contact inner wall will be manufactured from a starch–chitosan composite, providing both antimicrobial properties, as well as increased resistance to moisture. As an example, the use of calcium oxide (CaO) will generate heat through an exothermic reaction with water and will allow for the warming of food with no combustion [4]. The heating system is kept separate from the food compartment to protect consumers. The use of biodegradable polymer films and a self-heating system add convenience while addressing environmental issues. This product will be beneficial to various areas, such as emergency food, military, travel, recreation, and on-the-go food markets. Traditional forms of self-heating use multiple layers of non-biodegradable plastic [5], but this alternative will reduce plastic waste and provide consumers with access to a safe, hot meal.

II. METHODOLOGY

➤ Phase-I

- *Raw Material Procurement*

All required food- and laboratory-grade materials were procured from authorized suppliers and stored under dry, hygienic conditions.

- *Formulation of CMC- Starch Outer Layer Film*

A CMC–starch film-forming solution (30:70 w/w) containing glycerol, agar agar, gelatin, and pectin was prepared under controlled heating and continuous stirring to ensure complete gelatinization and homogeneity. The solution was cast on 13 x 9 inch acrylic plates and dried at 60 °C for 10 hrs to obtain flexible outer-layer films.

- *Formulation of Starch- Chitosan Inner Layer Film*

Starch and chitosan solutions (70:30 w/w) with glycerol, agar agar, gelatin and pectin were prepared separately, blended uniformly, and degassed to form a homogeneous composite film solution. The mixture was cast in 13 x 9 inch acrylic plates and dried at 60 °C for 10 hrs to produce antimicrobial inner-layer films.

- *Lamination to Form Double – Layer Pouch*

The outer and inner films were laminated using a gelatinized starch-based adhesive containing glycerol for improved bonding flexibility. The layered films were pressed, dried at 40–45 °C for 6-8 hrs, and conditioned to obtain a stable double-layer biodegradable pouch.

➤ Phase-II

- *Fabrication of Calcium Oxide (CaO) Self-Heating Pack*

A predetermined quantity of CaO (10g) was enclosed in an absorbent layer and activated using water at a 1:1.5 (w/w) CaO-to-water ratio to initiate controlled exothermic heating. The heating unit was stored in moisture-proof conditions and designed to remain physically isolated from the food compartment for safety.

- *Integration of Self- Heating Pack & Food Pouch Assembly*

The CaO heating pack was placed in a separate outer compartment of the double-layer biodegradable pouch, ensuring no direct contact with the sealed food chamber. Upon activation, heat was transferred through the pouch layers for uniform warming, and the assembled system was tested for sealing integrity and structural stability.

➤ Phase-III

- *Physio-Chemical Testing of Packaging Material*

Thickness, density, tensile strength, FTIR, surface morphology, and biodegradability tests were conducted to evaluate mechanical strength, structural stability, and thermal resistance of the films.

- *Storage Stability and Functional Performance Evaluation*

Moisture stability and heating efficiency were assessed over storage to determine functional shelf-life and consistent thermal output of the CaO heating system.

- *Thermal Efficiency Testing*

Temperature mapping and external surface measurements were performed to evaluate uniform heating and ensure safe handling limits.

- *Microbial & Safety Analysis*

Total viable count (TVC) and pH tests were conducted before and after heating to confirm microbial safety and absence of alkaline contamination.

➤ Phase-IV

- *Sensory Evaluation of Heated Food*

Heated foods were evaluated by 25 panelists using a hedonic scale to assess acceptability and heating effectiveness.

- *Field Testing*

Real-world usability, safety, and performance were tested with 10 participants.

- *Cost Calculation of the Self Heating Meal Pouch*

Material and heating costs were calculated to determine per-unit economic feasibility.

- *Data Analysis & Final Evaluation*

Fuzzy logic analysis and t-test are used for statistical analysis.

III. RESULTS AND DISCUSSIONS

➤ Physio-Chemical Testing of Packaging Material

- *Thickness Measurement*

The thickness of the developed biodegradable packaging films was measured using a digital micrometre with the accuracy of 0.001m. The average thickness of the developed double-layer self-heating meal pouch was 0.928

mm (928 μm). The greater thickness observed in the present study is due to double layer and to provide enhanced mechanical strength, thermal resistance, and puncture resistance, which are required for integrating the self-heating reaction system within the pouch structure.

- *Density Measurement*

The density of the packaging films was determined using the mass–volume method, as commonly employed for biodegradable polymer films. The calculated density was 0.14 g/cm³, indicating a lightweight polymer structure. Biopolymer-based films prepared from polysaccharides such as starch, CMC and chitosan generally exhibit lower density due to the formation of a porous matrix and the incorporation of plasticizers like glycerol, which increases intermolecular spacing.

- *Tensile Strength and Elongation at Break (Static Load Method)*

The tensile strength and elongation at break of the developed biodegradable films were determined using a static load (hanging weight) method. The average tensile strength and average elongation was 1.143 MPa and 16.4% respectively. Overall, the results demonstrate that the developed biopolymer films possess adequate tensile strength and flexibility, suggesting their potential applicability in sustainable food packaging systems, particularly in applications such as self-heating food packaging where moderate mechanical stability is required.

- *Chemical Changes During Heating Using FTIR*

Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify the functional groups present in the developed meal pouch film and to evaluate structural changes after the heating process is shown in the figures 1 and 2.

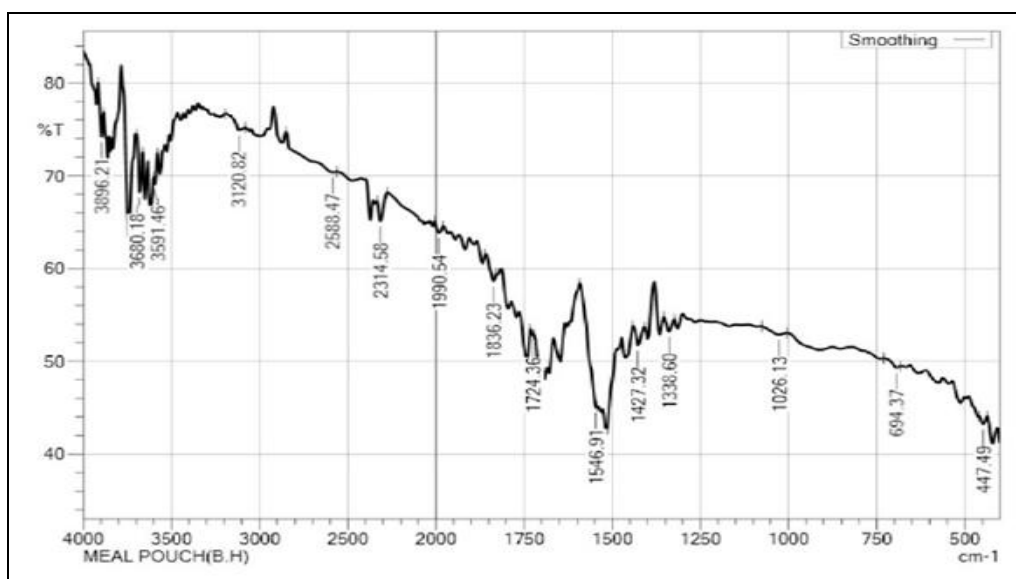


Fig 1 FTIR Analysis of the Self-Heating Meal Pouch Before Heating

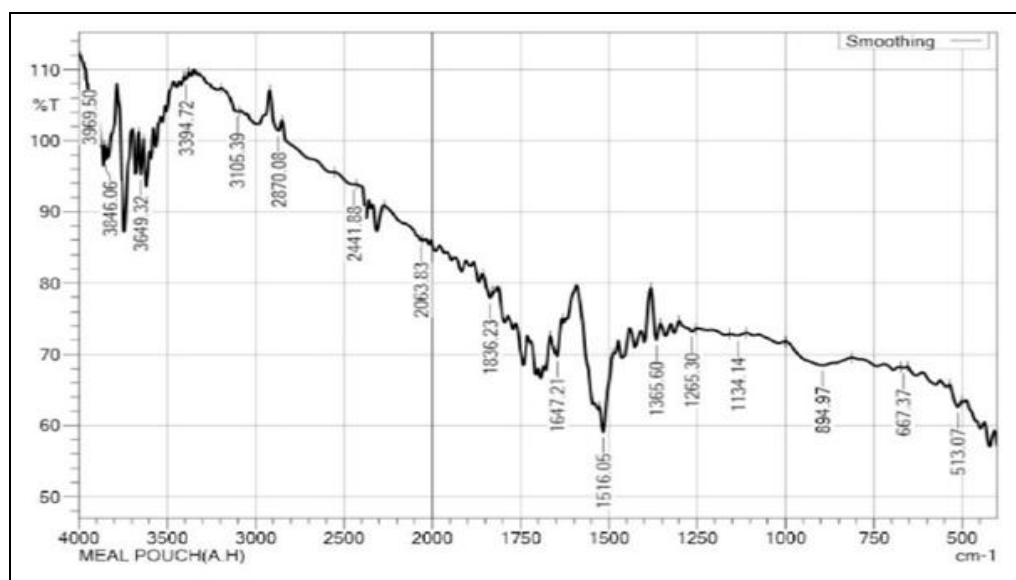


Fig 2 FTIR Analysis of Self Heating Meal Pouch After Heating

Overall, the FTIR spectra before and after heating showed no significant shift or disappearance of major functional group peaks, indicating that the biopolymer matrix remained chemically stable during the heating process. Minor variations in peak intensity and slight shifts in wavenumbers may be attributed to changes in hydrogen bonding interactions and moisture content after heating. These findings suggest that the developed meal pouch film possesses good thermal stability and structural integrity, making it suitable for application in self-heating food packaging systems.

• *Surface Morphology Analysis Using Optical Microscopy*

Surface morphology of the developed biodegradable packaging films before and after heating was examined using optical microscopy to assess the presence of cracks, pores, voids, and surface irregularities, which indicate structural stability and resistance to thermal stress is shown in the plate I and II.

➤ *PLATE I*

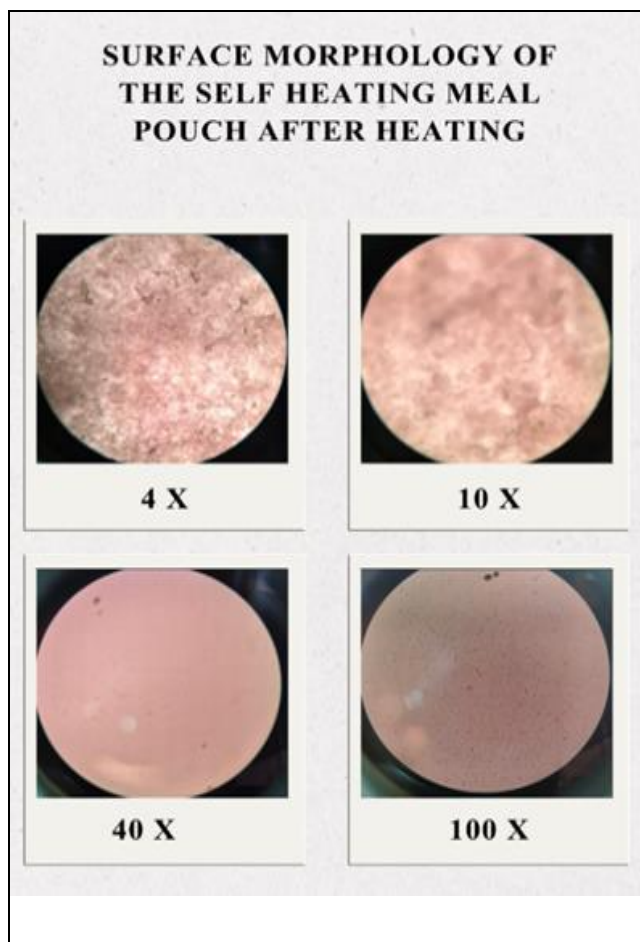


Plate 1 Surface Morphology of the Self Heating Meal Pouch after Heating

➤ *PLATE II*

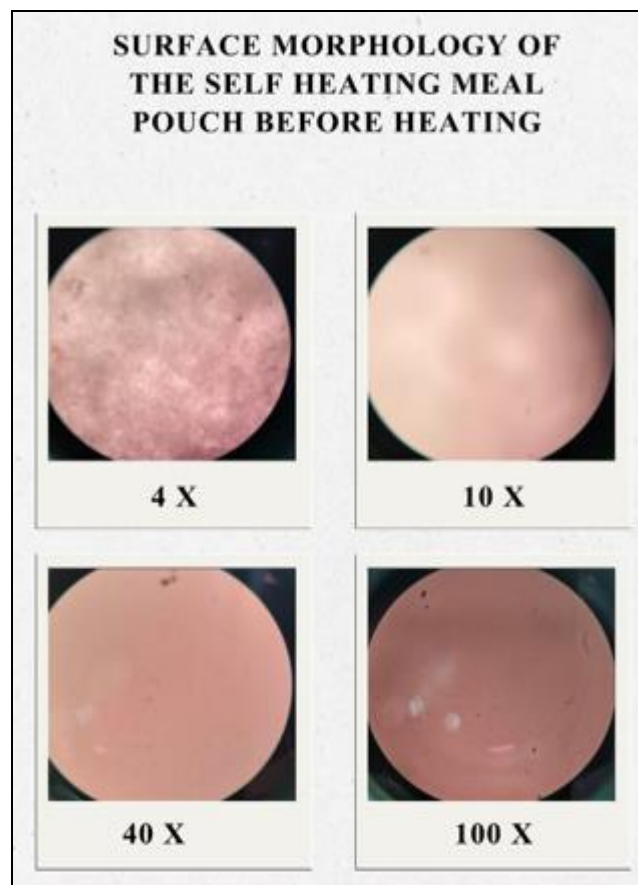


Plate 2 Surface Morphology of the Self Heating Meal Pouch before Heating

The interpretation before and after heating at 4x magnification indicates good macroscopic film integrity after heating, at 10x magnification suggests slight polymer rearrangement under heat, at 40x magnification increased roughness with dispersed micro-particles visible likely due to thermal stress and expansion of polymer components and at 100x magnification small surface particles and microstructural irregularities observed and no cracks or fractures confirms that the film maintains structural stability despite minor microstructural changes.

• *Biodegradability test*

The biodegradability of the developed double-layer self-heating meal pouch was evaluated using the soil burial method. The initial weight was 2.78g, on Day 0 the structure of the film was intact, on Day 1 the weight was unable to measure as it was partially degraded and on Day 2 the film was softer get like residue and highly degradable.

➤ *Storage Stability and Functional Performance Evaluation*

• *Moisture Stability of the Calcium Oxide (CaO) Heating Pack*

The observation of moisture stability of the Calcium Oxide heating pack is shown in table 1.

Table 1 Moisture Stability of the Calcium Oxide (CaO) Heating Pack

Storage Period (Days)	Initial Weight (g)	Weight After Storage (g)	Moisture Uptake (%)
0 (Initial)	11.29	11.29	0
7	11.25	12.02	6.84
14	11.72	12.55	7.08
21	11.66	13.29	13.98

- *Heating Efficiency After Storage*

The observation of the heating efficiency of CaO heating pack after storage is shown in table 2.

Table 2 Heating Efficiency of CaO Heating Pack During Storage

Storage Period (Days)	Time to Reach 60 °C (min)	Maximum Temperature Achieved (°C)	Duration Above 50 °C (min)
0 (Initial)	10	65.5	13
7	10.8	63.9	12.2
14	11.7	62.1	11.0
21	13.0	59.8	9.8

➤ *Thermal Efficiency Testing*

- *Uniformity and Hotspot Mapping*

Uniformity and hotspot mapping test is carried out with the help of infrared thermometer measured in °F at surface temperature at the time interval of 5, 10, 15, 20, 25 and 30 minutes. The highest temperatures were recorded in the lower central region of the pouch, particularly at grid points G8 and G9, which reached peak temperatures of approximately 150.3 °F at 15 minutes. This indicates that the primary heating reaction occurred near this region, creating a localized hotspot zone. The surrounding grids (G7 and G6) also exhibited relatively high temperatures, suggesting that heat propagated outward from the heating chamber toward adjacent areas. In contrast, the upper grid regions (G1–G3) showed comparatively lower and more stable temperatures, likely due to heat dissipation toward the edges of the pouch.

- *External Surface Temperature Measurement*

The external surface temperature of the developed self-heating pouch was monitored at different locations (top, bottom, front, and back) over a period of 20 minutes. The

temperature values indicate a gradual increase in surface temperature during the initial heating phase, followed by a decline after reaching peak levels. The bottom surface exhibited the highest temperature rise, increasing from 93.8 °F (≈34.3 °C) at 2 minutes to a peak of 150.7 °F (≈65.9 °C) at 14 minutes, before gradually decreasing. This higher temperature at the bottom surface can be attributed to the direct contact with the heating element (CaO reaction zone). In contrast, the top surface temperature remained relatively stable, ranging between 80.0–85.9 °F (≈26.7–29.9 °C) throughout the heating period, indicating effective insulation and reduced heat transfer to the upper surface. The front and back surfaces showed moderate temperature increases, with peak values of 103.9 °F (≈39.9 °C) and 117.2 °F (≈47.3 °C), respectively.

➤ *Microbial and Safety Analysis*

- *Total Viable Count (TVC)*

The total viable count of white rice before and after heating with the self-heating meal pouch is shown in table 3.

Table 3 Total Viable Count of White Rice Before and After Heating

White Rice Sample	Total Viable Count (CFU/g)
	24 hrs (CFU/g)
Before Heating	25×10^6
After Heating	19×10^6

Although the reduction observed was moderate, the results suggest that the self-heating pouch has the potential to reduce microbial contamination and improve the microbiological quality of the food product. Further optimization of heating temperature and duration may enhance the microbial reduction efficiency.

- *pH Test*

The pH test was performed for the white rice before and after heating with the self-heating meal pouch. The pH of distilled water used in the study was 7.39. The pH of white rice before heating was recorded as 7.21, while the pH after

heating using the CaO-based self-heating meal pouch increased slightly to 7.72.

➤ *Sensory Evaluation of Heated Food*

The temperature of the chapatti heated using the double-layer self-heating meal pouch was observed to be approximately 55°C, whereas the chapatti heated using the standard heating box reached about 60°C, with the slight difference attributed to heat loss and insulation effects caused by the double-layer structure of the pouch is shown in table 4, figures 3 and 4.

Table 4 B – Value, Final Fuzzy Score and Mean Calculated Acceptability for the Chapatti Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

Samples	B- Value	Final Fuzzy Score	Mean of Calculated Acceptability
Standard	(0, 0, 0.89164)	8.02	8.672
Pouch	(0, 0, 0.89308)	8.04	8.676

The fuzzy logic evaluation of chapatti samples heated using the standard method and the self-heating pouch revealed very close and high acceptability scores. The B-values for both samples—(0, 0, 0.89164) for the standard and (0, 0, 0.89308) for the pouch—fall entirely within the “like” region, indicating strong positive sensory perception for both methods. The slightly higher B-value for the pouch suggests a marginally better overall fuzzy performance, although the

difference is negligible. The final fuzzy scores were 8.02 (standard) and 8.04 (pouch), further confirming that both products were highly acceptable, with the pouch showing a slight edge in sensory quality. Similarly, the mean of calculated acceptability values (8.672 and 8.676) were almost identical, indicating consistent panelist agreement and reliability of results.

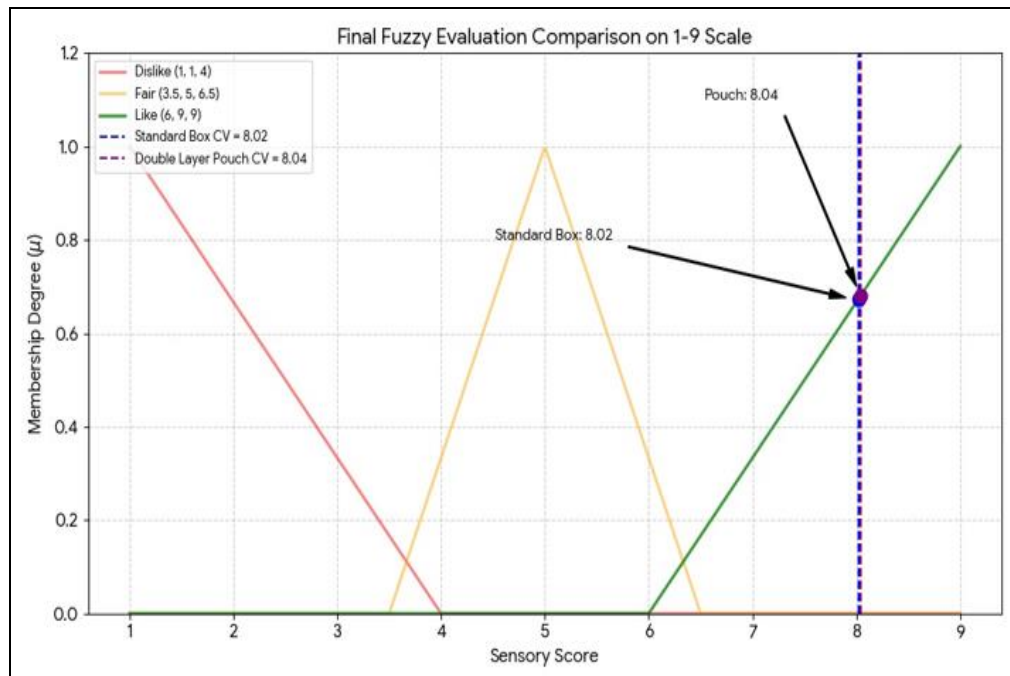


Fig 3 Comparison of Final Fuzzy Score Chapatti Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

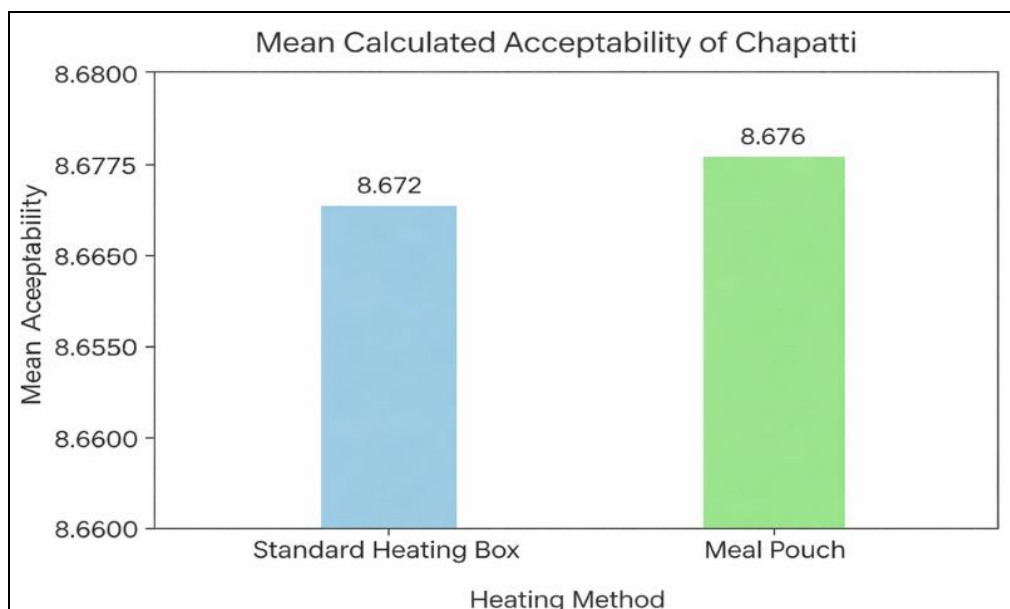


Fig 4 Comparison of Mean Calculated Acceptability of Chapatti Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

The temperature of the vegetable soup heated using the double-layer self-heating meal pouch was observed to be approximately 63°C, whereas the standard heating box attained a temperature of around 71°C, owing to its higher

heat generation capacity and better insulation efficiency. The quantity of soup carried by double layer self-heating meal pouch is less than the standard heating box. The values are shown in the table 5, figures 5 and 6.

Table 5 B – Value, Final Fuzzy Score and Mean Calculated Acceptability for the Vegetable Soup Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

Samples	B- Value	Final Fuzzy Score	Mean of Calculated Acceptability
Standard	(0, 0, 0.92464)	8.32	8.772
Pouch	(0, 0, 0.91408)	8.22	8.74

The fuzzy logic evaluation indicates that both the standard heating method and the double-layer self-heating meal pouch achieved high overall acceptability, with B-values lying entirely in the “like” region. The standard sample recorded a slightly higher B-value (0, 0, 0.92464) compared to the pouch (0, 0, 0.91408), reflecting a marginally better fuzzy performance. This is further supported by the final fuzzy scores of 8.32 (standard) and 8.22 (pouch), indicating that both samples were highly liked,

with only a minor difference in preference. Similarly, the mean of calculated acceptability values (8.772 and 8.74) are very close, demonstrating strong agreement among panelists and consistency in evaluation. Overall, the results suggest that while the standard heating method shows a slight advantage, the self-heating meal pouch performs comparably well, confirming its effectiveness in delivering acceptable sensory quality.

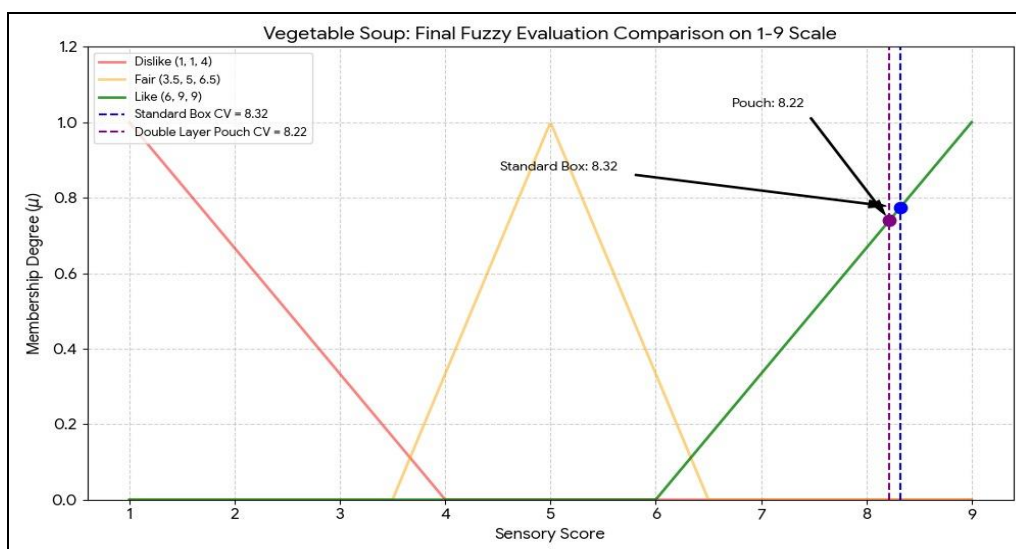


Fig 5 Comparison of Final Fuzzy Score Vegetable Soup Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

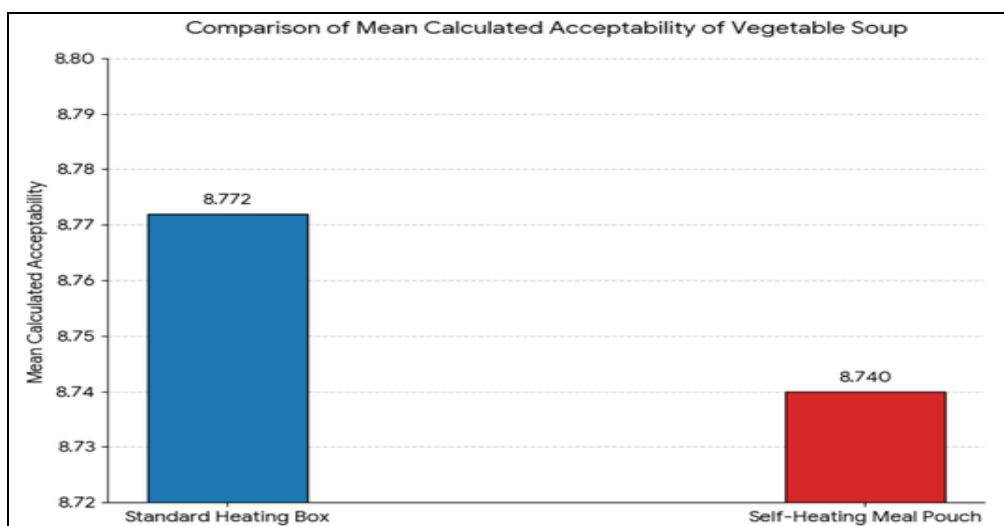


Fig 6 Comparison of Mean Calculated Acceptability of Vegetable Soup Heated with Standard Heating Box and Double Layer Self-Heating Meal Pouch

Table 6 Comparison of Sensory Attributes for Chapatti Heated with Standard Heating Box (C-S) and the Double Layer Self-Heating Meal Pouch (C-P)

Attributes	Mean $\pm$ Standard Deviation		t- Value
	C-S	C-P	
Appearance	8.72 $\pm$ 0.46	8.8 $\pm$ 0.41	0.41 ^{NS}
Aroma	8.84 $\pm$ 0.37	8.8 $\pm$ 0.41	0.23 ^{NS}
Hotness	8.4 $\pm$ 0.5	8.4 $\pm$ 0.5	0.00 ^{NS}
Texture	8.72 $\pm$ 0.46	8.76 $\pm$ 0.44	0.2 ^{NS}
Taste	8.8 $\pm$ 0.5	8.8 $\pm$ 0.41	0.00 ^{NS}

NS = Non-Significant (at 1% significance level)

C-S = Chapatti Heated with Standard Heating Box

C-P = Chapatti Heated with Meal Pouch

The comparison of sensory attributes of chapatti heated using the standard heating box (C-S) and the double-layer self-heating meal pouch (C-P) are shown in the table 6 revealed that both methods achieved very high mean scores (8.4–8.84) across all parameters, indicating strong overall acceptability. The standard deviations were low ($\pm$ 0.37 to

$\pm$ 0.50), reflecting good consistency and agreement among panelists. The calculated t-values for all attributes were very low (ranging from -0.41 to 0.23) and were found to be non-significant (NS) at the 1% level of significance, indicating that there is no statistically significant difference between the two heating methods. Attributes such as hotness and taste showed identical mean scores, while minor variations in appearance, aroma, and texture were negligible and statistically insignificant.

Table 7 Comparison of Sensory Attributes for Vegetable Soup Heated with Standard Heating Box (S-S) and the Double Layer Self-Heating Meal Pouch (S-P)

Attributes	Mean $\pm$ Standard Deviation		t - Value
	S-S	S-P	
Appearance	8.92 $\pm$ 0.28	8.92 $\pm$ 0.28	0.00 ^{NS}
Aroma	8.84 $\pm$ 0.07	8.84 $\pm$ 0.07	0.00 ^{NS}
Hotness	8.6 $\pm$ 0.57	8.6 $\pm$ 0.57	0.00 ^{NS}
Consistency	8.8 $\pm$ 0.41	8.84 $\pm$ 0.71	0.15 ^{NS}
Taste	8.84 $\pm$ 0.71	8.72 $\pm$ 0.46	0.45 ^{NS}

NS = Non-Significant (at 1% significance level)

S-S = Vegetable Soup Heated with Standard Heating Box

S-P = Vegetable Soup Heated with Meal Pouch

The sensory evaluation of vegetable soup heated using the standard heating box (S-S) and the double-layer self-heating meal pouch (S-P) is shown in the table 7 revealed that high mean scores (8.6–8.92) for all attributes, indicating excellent overall acceptability. The standard deviation values were low, suggesting high consistency and uniformity in panelist responses. Attributes such as appearance, aroma, and hotness recorded identical mean scores for both methods, reflecting the ability of the self-heating pouch to maintain sensory quality comparable to the conventional system. The t-values for all attributes ranged from 0.00 to 0.45 and were found to be non-significant (NS) at the 1% level, indicating

that there is no statistically significant difference between the two heating methods. Although slight variations were observed in consistency and taste, these differences were minimal and did not influence overall acceptability.

➤ Field Testing

Field testing of the developed product was conducted using a 5-point rating scale, where 1 = very poor, 2 = poor, 3 = satisfactory, 4 = good, and 5 = excellent, to evaluate key performance attributes. The evaluation was carried out by 10 panel members, and the collected data were statistically analyzed using a one-sample t-test. The test value ($\mu = 3$) was taken as the reference (satisfactory level) to determine how significantly the developed product performed above the average is shown in the table 8.

Table 8 Statistical Evaluation of Functional Attributes for Self-Heating Meal Pouches in Field Test

Attributes	Mean $\pm$ Standard Deviation	t-Value	Level of Significance
	Meal Pouch		
Ease of carrying	4.6 $\pm$ 0.52	9.75	Highly significant
Leakage/spoilage	4.2 $\pm$ 0.63	6.03	Highly significant
Ease of activation	4.7 $\pm$ 0.48	11.18	Highly significant
Heating efficiency	5 $\pm$ 0.0	0.0	Not-significant
Safety during handling	4.4 $\pm$ 0.84	5.26	Highly significant

Significant (at 5% significance level)

The field evaluation of the developed self-heating meal pouch demonstrated high mean scores (4.2–5.0) across all performance attributes, indicating that the product was rated between good and excellent by the panelists. The standard deviation values were relatively low, reflecting consistency in responses among the 10 members. The t-test results showed that most attributes had very high t-values (ranging from 5.26 to 11.18), which are significant at the 5% level, indicating that the performance of the pouch is significantly higher than the reference mean ($\mu = 3$, satisfactory level). Among the attributes, ease of activation ($t = 11.18$) and ease of carrying ($t = 9.75$) exhibited the highest significance, highlighting the user-friendly nature of the product. Similarly, leakage/spoilage ($t = 6.03$) and safety during handling ($t = 5.26$) were also found to be highly significant, confirming the reliability and safety of the pouch. The attribute heating efficiency showed a mean score of 5 ± 0 , indicating perfect agreement among panelists, as all respondents rated it as excellent. Although the t-value is reported as 0.0 due to zero variation, it practically reflects maximum acceptability rather than lack of significance.

➤ Cost Calculation of the Self Heating Meal Pouch

The cost of producing one double-layer self-heating meal pouch was estimated based on the market price of raw materials and additional production expenses. The raw material cost was calculated to be approximately Rs. 90.91 per pouch. Additional costs including labour (Rs. 10), equipment depreciation (Rs. 5), and miscellaneous expenses such as electricity, water, and packaging (Rs. 4) were incorporated to estimate the overall production cost. Thus, the total estimated cost for producing one pouch was approximately Rs. 110.

IV. CONCLUSION

The developed CaO-based self-heating meal pouch effectively heats food (55–63°C) without external energy, making it suitable for field use. The use of biodegradable materials (starch, chitosan, CMC) ensures environmental sustainability. The pouch showed adequate mechanical strength and safe performance, with no contamination (pH within neutral range). Sensory and field evaluations confirmed high acceptability, safety, and user convenience. The system has strong potential for military, emergency, and outdoor food applications.

REFERENCES

- [1]. Ayeleru O. O, Dlova S, Akinribide O J, Ntuli F, Kupolati W. K, Facal Marina P, Blencowe A, and Olubambi P. A (2020), 'Challenges of plastic waste generation and management in sub Saharan Africa: A review', *Waste Management*, 110: 24–42.
- [2]. Cruz R. M. S, Krauter V, Krauter S, Agriopoulou S, Weinrich R, Herbes C, Scholten P. B. V, Uysal Unalan I, Sogut E, Kopacic S, Lahti J, Rutkaite R, and Varzakas T (2022), 'Bioplastics for food packaging: Environmental impact, trends and regulatory aspects', *Foods*, 11(19): 3087.

- [3]. Geyer R, Jambeck J. R, and Law K. L (2017), 'Production, use, and fate of all plastics ever made', *Science Advances*, 3(7): e1700782.
- [4]. Ho S, Rahman M. M, and Sunol A (2010), 'Analysis of thermal response of a food self-heating system', *Applied Thermal Engineering*, 30(14): 2109–2115.
- [5]. Nilsen-Nygaard J, Noriega Fernandez E, Radusin T, Rotabakk B. T, Sarfraz J, Sharmin N. J, Sivertsvik M, Sone I, and Pettersen M. K (2021), 'Current status of biobased and biodegradable food packaging materials: Impact on food quality and effect of innovative processing technologies', *Comprehensive Reviews in Food Science and Food Safety*, 20(2): 1333–1380.
- [6]. Rani A, Negi S, Fan C, Lam S. S, Kim H, and Pan S. Y (2024), 'Revitalizing plastic wastes employing bio-circular-green economy principles for carbon neutrality', *Journal of Hazardous Materials*, 472: 134394.
- [7]. Siddiqui S. A, Yang X, Deshmukh R. K, Gaikwad K. K, Bahmid N. A, and Castro-Munoz R (2024), 'Recent advances in reinforced bioplastics for food packaging – A critical review', *International Journal of Biological Macromolecules*, 263(Pt 2): 130399.
- [8]. Xu C, Hu J-l, Dong B, Lin Q-b, Wu S-l, Chen J, Wang J, Li D, and Zhong H-n (2024), 'Safety assessment of polypropylene self-heating food container: The release of microplastics and volatile organic compounds', *Food Packaging and Shelf Life*, 44: 101307.