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Effect of encapsulated egg white noodles as a meat substitute on weight management in overweight and obese participants: a controlled trial

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Abstract

High-protein diets have gained popularity for weight management; however, concerns persist regarding increased meat protein intake. This study explored the potential of egg white noodles (EWN) as a novel meat substitute, utilizing advanced encapsulation techniques to enhance their functional properties. An isocaloric diet with a high protein proportion including a 30% meat replacement by EWN was provided to overweight and obese participants for 6-week intervention period, and 2-week follow-up period without test meals. The results demonstrated significant reductions in body weight, Body Mass Index (BMI), waist and hip circumferences, and fat mass in the EWN group while maintaining muscle mass compared to baseline. However, these effects did not significantly differ from those observed in the control group. By week 6, the change in body weight was notably greater in the EWN group (-2.64 ± 0.45 kg) than in the control group (-1.48 ± 0.26 kg). The waist-to-hip ratio in the EWN group was significantly lower than the control group in week 3. Additionally, at week 6, the EWN group had significantly lower total cholesterol (201.82 ± 6.46 mg/dL) and LDL cholesterol (127.18 ± 6.59 mg/dL) levels compared to the control group (220.05 ± 6.98 mg/dL and 148.55 ± 6.58 mg/dL, respectively). Despite these benefits, inflammatory markers (IL-1, IL-6, and TNF-α) and antioxidant parameters (MDA, thiol, and FRAP) showed no significant changes. These findings suggest that replacing meat with EWN in an isocaloric, high-protein proportion diet can yield effects comparable to those of meat protein consumption. This indicates that EWN may present a promising and sustainable alternative for weight management. This study contributes to our understanding of weight management strategies and addresses consumer concerns regarding high meat protein intake.

Trial registration Identifier TCTR20230427004 (27 April 2023).

Keywords Egg white noodle, High protein proportion, Weight management, Obesity, Overweight, Isocaloric diet

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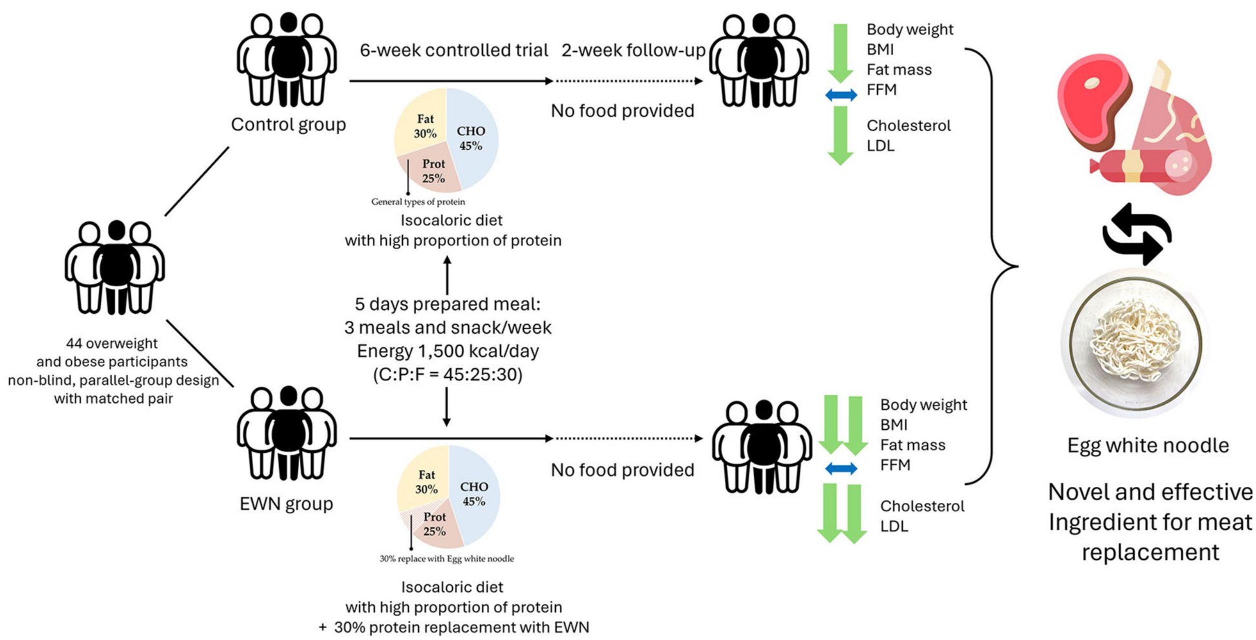
Graphical Abstract



Background

Overweight and obesity are major contributors to metabolic diseases, causing disruptions in normal metabolism and leading to non-communicable conditions such as diabetes and cardiovascular disease. The increasing prevalence of overweight and obesity each year adds to societal and economic burdens (Coutinho & Halpern, 2024). Research indicates that obesity is a significant public health concern associated with a decrease in life expectancy. Overweight and obesity promote fat accumulation, leading to a cascade of physiological changes that induce a state of inflammation within the body. This inflammatory response is characterized by the infiltration of immune cells, particularly macrophages, into adipose tissue. As these immune cells accumulate, they trigger the release of inflammatory cytokines such as Tumor Necrosis Factor Alpha (TNF-α), Interleukin 1 (IL-1), and Interleukin 6 (IL-6) (Henning, 2021). These inflammatory markers, along with acute-phase proteins like C-reactive protein (CRP), are upregulated in both preclinical obesity and advanced vascular damage, potentially contributing to various health complications (Jin et al., 2023). The consequences of excess body fat include issues such as insulin resistance, dyslipidaemia, and inflammation (Vekic et al., 2023). Addressing these issues is vital for improving overall public health.

Current recommendations for weight management emphasize lifestyle modifications, increased physical activity, and the adoption of healthy dietary practices (Enright et al., 2023). Various alternative eating plans, such as the dietary approaches to stop hypertension diet (DASH diet), Mediterranean diet, and high protein strategies, offer diverse approaches to weight management (Castro-Barquero et al., 2020; Hwalla & Jaafar, 2020). Specifically, a high protein diet, defined by comprising 20–30% of daily energy intake from protein, has proven effective in weight loss and maintenance (Castro-Barquero et al., 2020).

Research indicates that high-protein diets significantly enhance satiety and energy expenditure. Specific amino acids, particularly arginine, lysine, leucine, and glutamic acid, contribute to an anorexigenic response, which leads to appetite suppression and reduced food intake (Moris et al., 2022). When proteins are broken down into their basic components—amino acids—gut hormones respond to these nutrients. Studies have shown that proteins and amino acids effectively increase feelings of fullness, likely through their impact on satiety hormones (Dericioglu et al., 2022). The digestive system features a complex nutrient-sensing system comprised of various chemoreceptors located in specialized enteroendocrine cells. These receptors can identify and respond to specific nutrients in the digestive tract after a meal. For instance, L cells—specialized enteroendocrine cells primarily found in the large intestine—play a crucial role in producing and releasing glucagon-like peptide 1 (GLP-1) and peptide YY (PYY). The release of these hormones triggers a response that suppresses appetite after eating, which can have beneficial effects on weight management (Rigamonti et al., 2020). The thermic effect of food resulting from protein consumption can increase diet-induced thermogenesis by approximately 30%, thereby boosting daily energy expenditure (Moon & Koh, 2020). Rapidly digestible proteins stimulate postprandial protein synthesis, supporting the preservation of lean body mass (Waliłko et al., 2021). A study found that partially replacing the diet with protein-enriched meals in patients with metabolic syndrome led to greater weight loss over six months (change -7.0 ± 3.7 kg) and significantly improve biochemical markers, including glucose, triacylglycerol, total cholesterol, and very low-density lipoprotein cholesterol (VLDL cholesterol) levels, compared to a normal protein diet (Campos-Nonato et al., 2017). High-protein diets not only aid in weight reduction but also help maintain lean body mass during weight loss (-1.9 ± 0.3 kg) (Tang et al., 2013) and muscle mass during weight maintenance (Hsu et al., 2021). However, concerns remain regarding high protein intake, with consumers raising issues about animal welfare, environmental sustainability, and potential health risks, including cardiovascular disease and cancer (Ewy et al., 2022; Nezlek & Forestell, 2022; Thavamani et al., 2020).

Eggs, known for their convenience, cost-effectiveness, and rich protein content, particularly in the form of egg whites, emerge as a favourable choice for high protein diets. Egg white is commonly consumed due to its complete essential amino acid profile and lower content of carbohydrates and fat. Notably, they are rich in amino acids such as arginine, leucine, and phenylalanine (Hida et al., 2012; Matsuoka & Sugano, 2022). Research highlights that egg whites may support muscle mass development, primarily attributed to the presence of branched-chain amino acids (BCAAs), which are associated with muscle repair and hypertrophy (Myers & Ruxton, 2023). Beyond muscle-related benefits, egg whites exhibit antioxidant properties. Ovalbumin, the major protein in egg whites, plays a role in redox regulation through its disulfide bonds and free sulfhydryl groups (Benede & Molina, 2020; Nakamura et al., 2002). Additionally, ovotransferrin, another abundant egg white protein, helps prevent iron-induced lipid peroxidation, offering further protective benefits (Nimalaratne & Wu, 2015; Rathnapala et al., 2021). Incorporating egg whites into a high protein diet may have beneficial effects on weight management strategies. Although many studies have explored the effects of egg consumption on weight management by substituting whole eggs or egg white powder, more research is needed to clarify their practical applications in real-life dietary settings (Liu et al., 2020; Matsuoka et al., 2017; Wright et al., 2018).

In recent years, EWN has emerged as an innovative food alternative produced using encapsulation techniques (Ngamukote et al., 2022). This product is notable for its flour-free composition, low-fat content, and convenience as a ready-to-eat option. Its popularity stems from its high protein content, positioning it as a potentially effective choice for individuals aiming to reduce body weight, particularly those with overweight or obesity. However, it is important to note that research on the clinical application of EWN in body weight management remains in its early stages within the scientific community.

The primary objective of our study is to investigate the short-term effects of EWN consumption on body composition and biochemical profiles in individuals with overweight and obesity, within the framework of high-protein diets for weight management. This clinical trial seeks to provide valuable insights into the benefits of incorporating EWN into high-protein diets, compared to an isocaloric diet, in achieving weight management goals. Therefore, this study aims to deepen our understanding of alternative food choices, with a specific focus on exploring the impact of egg white protein and its potential role in promoting a healthy weight.

Materials and methods

Participants

This study recruited office workers from Chulalongkorn University in Bangkok, Thailand, who predominantly spent their time in an office environment. Inclusion criteria of sample were: (1) male or female aged 20–60 years old, and (2) BMI between 25.0–29.9 kg/m^2, (3) total cholesterol level > 200 mg/dL, (4) LDL cholesterol level > 130 mg/dL, (5) no dietary restriction, (6) be able to pick up meal, and (7) intend to lose weight. Exclusion criteria included participants with a known allergy to eggs and egg products, those who were pregnant or lactating, regular smokers, regular alcohol consumers, individuals diagnosed with chronic diseases such as diabetes, chronic kidney disease, cancer, etc., those with co-morbidities (hypertension ≥ 140/90 mmHg), those with a history of bariatric or other gastrointestinal surgeries, users of protein supplements, and those who had used medications affecting body weight, energy expenditure, or glucose in the last 3 months. The study was approved by the Ethics Review Committee for Research Involving Human Research Subjects at Chulalongkorn University (COA No. 239/65), and written informed consent was obtained from all participants prior to enrolment. The study protocol was retrospectively registered at Thaiclinicaltrials.org as TCTR20230427004 (27 April 2023).

Experimental design

The current study employed a non-blind, parallel group, randomized controlled trial with matched pairs. Following eligibility screening and blood profile assessment, a total of 66 overweight or obese participants, both males and females, were enrolled in an 8-week study, consisting of a 6-week intervention period and a subsequent 2-week follow-up. The research was conducted at Chulalongkorn University, Bangkok, Thailand, spanning from January 2023 to August 2023. The determination of the total sample size was based on a prior study that documented a significant change in body weight (1.86) and the standard deviation of change (2.2), aiming for a study power of 80% and an alpha of 0.05 (Wright et al., 2018). Accounting for a potential 30% dropout rate, the study aimed to recruit a minimum of 58 participants. The primary focus of this study was on body weight as the primary outcome, while secondary outcomes encompassed anthropometric measures, including waist and hip circumferences, along with body composition. Additionally, biochemical profiles, including glucose, cholesterol, and triacylglycerols as well as functional properties such as inflammatory cytokine levels and malondialdehyde (MDA) levels indicating lipid peroxidation, were also evaluated. In the present study, a total of 79 participants were initially recruited for screening, but only 66 participants successfully completed the screening process and enrolled in this study.

These participants were then paired based on age, gender, BMI, fasting blood glucose, and total cholesterol levels. Subsequently, they were randomly assigned to either the control group or the EWN group. Both groups received three prepared meals and snacks on weekdays, ensuring isocaloric diets. Over the 6-week intervention period, participants made scheduled visits for assessments, which included evaluations of anthropometry, biochemistry, dietary intake, and physical activity. Participants were instructed to strictly adhere to the guidelines of this study, which were provided to them daily along with their prepared meals. Additionally, all participants received basic nutrition education through online classes conducted by a registered dietitian. Throughout the study, an infographic outlining weekend food selections for maintaining a high protein diet was shared via the LINE official account every Friday. To monitor treatment adherence, participants received weekly phone calls, updates through the LINE official account, and assessments during regularly scheduled appointments. Throughout the study, participants were encouraged to maintain their usual levels of physical activity. At the end of the study, the physical activities recorded in the self-reported activity logs during the intervention were reviewed by a registered dietitian using metabolic equivalent scores (METs) to confirm their consistency.

Dietary interventions

EWN for all interventions were provided by Thandee Innofood Co., Ltd, Bangkok, Thailand. The products were approved by the Food and Drug Administration (FDA no. 74–2–00157–5–0036). Noodles have been manufactured from egg white (58%), Kelp (INS401) at 1.8%, and water at 40.2%. Noodles have a nutritional composition of 4 g of carbohydrates, 8 g of protein, 0 g of fat, and 2 g of fiber, resulting in a total calorie content of 50 kcal per 100-g serving. The meals, with EWN, were meticulously crafted by Dr. Dish (Doctor Dish Co., Ltd., Bangkok, Thailand), in collaboration with other restaurants. Repackaging was conducted in adherence to specified portion calculations, encompassing three main meals (breakfast, lunch, and dinner), as well as snacks. These prepared meals, adhering to isocaloric diets (1,500 kcal/day) and maintaining a consistent macronutrient ratio of 45:25:30 (carbohydrate: protein: fat), were provided to participants in both groups. In the control group, participants received a diet comprising general protein sources such as red meat, poultry, and fish. Conversely, the EWN group had their meals designed with a 30% replacement of protein through EWN to ensure optimal compliance. This adjustment aimed to align with Thai Dietary Reference Intakes (DRI) for 2020, which recommends around 70 g of protein per day for a normal protein diet, prioritizing animal protein. In the context of a high protein diet, incorporating a 30% replacement with EWN, equivalent to 28 g of protein, maintained the prescribed caloric distribution (Bureau of Nutrition, 2020). Participants in the EWN group received noodles made from egg whites, while the control group was given regular noodles supplemented with additional animal protein to ensure sufficient protein intake. In addition to the three main meals, researchers also provided side dishes that incorporated EWN. Examples included EWN salad and EWN Zaru ramen (chilled noodles served with dipping sauce). The study spanned two periods: a 6-week intervention followed by a 2-week follow-up (Fig. 1). During the intervention, participants received prepared meals that included lunch, dinner, and a snack for the current day, as well as breakfast for the following day. These meals were provided on weekdays, with a fresh set delivered each day. Participants were instructed to refrigerate the meals throughout the day and to follow an instruction card outlining the daily meal plan and behavioral guidelines for the intervention. They were also required to record their food intake and photograph any leftovers to ensure adherence

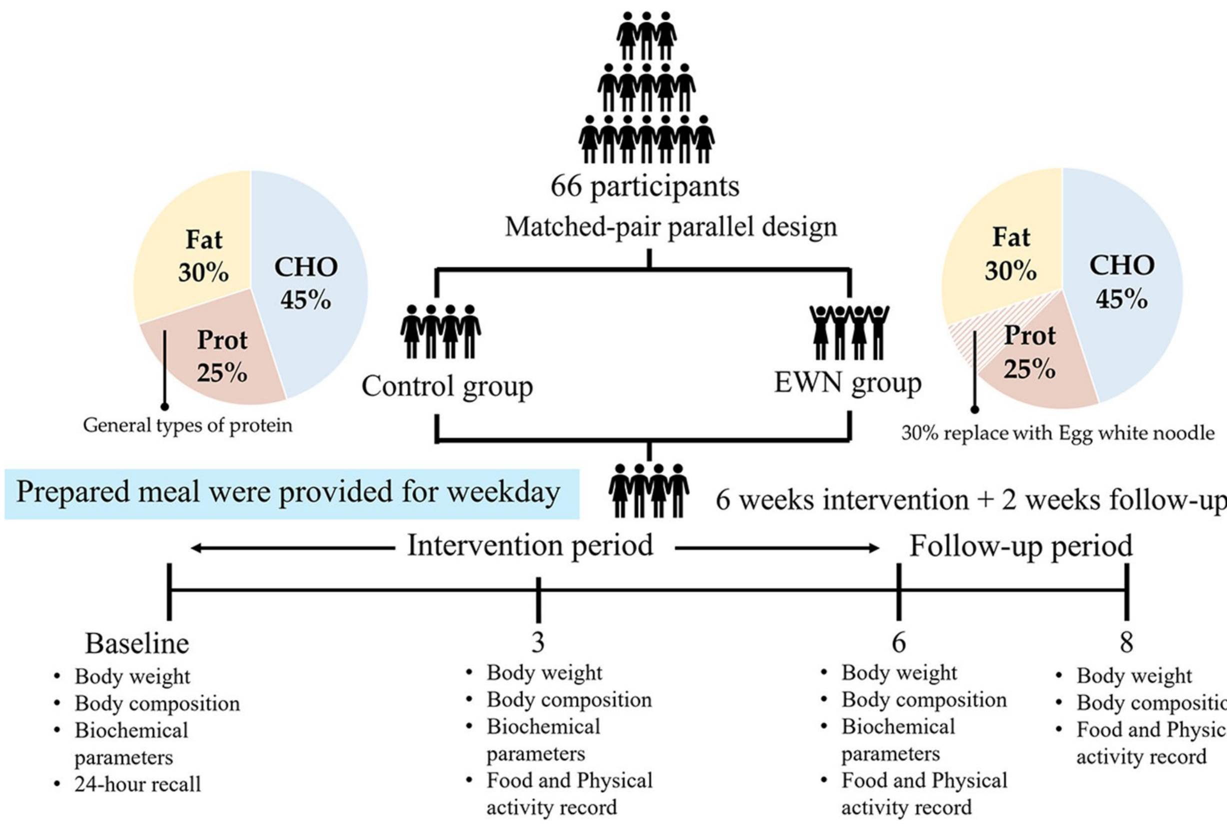


Fig. 1 Schematic representation of this study. EWN; egg white noodle, CHO; carbohydrate, Prot; protein

to the prescribed plan. Additionally, participants were asked to maintain this regimen for five consecutive days. At the weekends, participants were required to adhere to a provided infographic outlining their food choices and capture a picture of their food and any leftovers to be sent via the LINE official account, ensuring control over their energy intake. In the follow-up period, participants were not supplied meals by the researchers. However, they were asked to record their food intake and maintain their usual lifestyle.

Anthropometry and body composition assessment

Participants were measured for body weight, height, waist circumference, hip circumference, and body composition at the initiation of the experiment, weeks 3 and 6, and the conclusion of the follow-up period (week 8). Body composition analysis employed bioelectrical impedance analysis with Tanita MC-980MA (Tokyo). Waist circumference measurements were taken at the superior border of the iliac crest and the midpoint between the lowest rib and the iliac crest, using a waist tape under the supervision of the registered dietitian. Anthropometric characteristics, including body weight, BMI, waist circumference, hip circumference, waist-to-hip ratio (W/H ratio), fat mass, fat-free mass (FFM), and muscle mass, were tracked at these specific intervals to monitor changes throughout the study.

Biochemical assessment

Blood samples were collected using blood collecting tubes with sodium fluoride (2 ml), EDTA (5 ml), and a clot activator tube (5 ml) as anticoagulants at the beginning, after 3 weeks, and at the conclusion of the study, administered by a registered nurse. Plasma samples were obtained by centrifugation at 3,000 rpm for 15 min at 4 °C and preserved at − 20 °C for subsequent analysis.

Blood chemical profiles, including glucose, cholesterol, triacylglycerol, HDL cholesterol, LDL cholesterol, BUN, creatinine, ALT, AST, and uric acid were determined by the Health Science unit at the Faculty of Allied Health Sciences, Chulalongkorn University.

For the quantification of MDA, a lipid peroxidation product, a thiobarbituric acid reactive substances (TBARS) assay was employed (Wright et al., 2018). In this assay, 200 µL of plasma sample was mixed with trichloroacetic acid (10% w/v) and 50 mM 2,6-Di-tert-butyl-4-methylphenol (BHT) from Sigma-Aldrich Co., St. Louis, MO, USA. The mixture was then centrifuged at 12,000 rpm for 10 min. The resulting supernatant (200 μL) was separated and combined with 0.67% TBA (Sigma-Aldrich Co., St. Louis, MO, USA) before being boiled for 10 min at 100 °C. After cooling to room temperature, the absorbance of the pink-colored reaction was measured at 532 nm. Plasma MDA concentration was determined from the calibration curve of MDA (Sigma-Aldrich Co., St. Louis, MO, USA) and expressed as μmol/L MDA.

The ferric reducing ability of plasma (FRAP) assay, a redox-linked colorimetric reaction, was performed by mixing 10 μL of plasma sample with 90 μL of freshly prepared FRAP reagent (Chusak et al., 2020). The FRAP reagent consisted of 0.3 M sodium acetate buffer (pH 3.6), 10 mM 2,4,6-Tri(2-pyridyl)-*S*-triazine (TPTZ) (Sigma-Aldrich Co., St. Louis, MO, USA) in 40 mM HCl, and 20 mM $FeCl_3$, prepared in a 10:1:1 ratio. After a 30-min incubation at room temperature, the absorbance was read at 595 nm, and the results were expressed as μmol of $FeSO_4$ equivalents obtained from a standard curve of $FeSO_4$.

Plasma thiol levels were measured using an Ellman's assay with some modifications (Ellman, 1959). In this assay, 90 μL of plasma sample was mixed with 130 μL of 2.5 mM 5,5′-dithiobis-(2-nitrobenzoic acid) (DTNB) (Merck KGaA, Darmstadt, Germany) in 0.1 M PBS, pH 7.4, and incubated for 15 min at room temperature. The absorbance was then measured at 410 nm, and the plasma thiol level was calculated and expressed as μM L-cysteine (Sigma-Aldrich Co., St. Louis, MO, USA) equivalent.

For the determination of inflammatory cytokines (IL-1, IL-6, and TNF-α), an immunoassay kit from SunLong Biotech Co.,Ltd., China, was used according to the manufacturer's instructions. Briefly, 40 μl of sample dilution buffer and 10 μl of sample were added to wells, followed by a 30-min incubation at 37 °C. The solution was aspirated, and wells were washed with wash solution. Subsequently, 50 μl of HRP-conjugate reagent was added and incubated at 37 °C for another 30 min. After incubation, washing was repeated, and for coloring, Chromogen A and B were added, followed by a 15-min incubation at 37 °C. The reaction was terminated by adding 50 μl stop solution, causing the color to change from blue to yellow. The absorbance was then read at 450 nm using microplate reader spectrophotometer (BioTek Instruments, Winooski, VT, USA).

Dietary and physical assessment

Initially, dietary intake was evaluated using the 24-h dietary recall method, conducted by a registered dietitian. Subsequent assessments involved collecting 3-day food records at each visit and at the conclusion of both the intervention and follow-up periods. Additionally, participants were instructed to photograph leftover food and share it via the LINE official account dedicated to this project. The data from the food records were analyzed using the INMUCAL-Nutrients V.4.0 program developed by the Institute of Nutrition at Mahidol University in Nakhon Pathom, Thailand. In this study, all participants were instructed to strictly maintain their usual lifestyle. Regarding physical activity, participants self-reported the type and duration of their exercises, which a registered dietitian then converted to metabolic equivalent (MET) scores to ensure data consistency.

Statistical analysis

To confirm the normal distribution of variables, the histogram and Kolmogorov-Smirnov tests were employed. Data were presented as mean ± standard error of mean (SEM) for normally distributed variables. A significance level of $p < 0.05$ was considered statistically significant. Intra-group comparisons before and after the intervention were assessed using the repeated-measures ANOVA while inter-group differences were determined through an independent sample *t*-test. All statistical analyses were conducted using SPSS (version 28.0, SPSS Inc., Chicago, IL, USA).

Results

Participant characteristics

This study initially enrolled 79 participants (Fig. 2), but only 66 participants met the inclusion criteria. However, three participants were excluded from the EWN group due to personal reasons. Consequently, 63 participants successfully completed the study, while eight matched pairs were excluded from the analysis in each group due to incomplete data. Therefore, the total number of participants for analysis was 44. At the commencement of this study, participants exhibited no significant differences in gender, BMI, blood pressure, fasting blood glucose, and total cholesterol, as presented in Table 1.

Anthropometry and body composition assessment

The results of EWN consumption during the intervention period revealed significant reductions relative to baseline in various parameters (Table 2): body weight ($p < 0.001$), BMI ($p < 0.001$), waist circumference ($p < 0.05$), hip circumference (week 6, $p < 0.05$), and waist-to-hip ratio (week 3, $p < 0.05$). Additionally, fat mass significantly decreased ($p < 0.001$), while muscle mass remained consistent in the EWN group. During the follow-up period, EWN consumption continued to demonstrate beneficial effects on maintaining body weight ($p < 0.001$), BMI ($p < 0.001$), waist circumference in males ($p < 0.001$), waist-to-hip ratio in males ($p = 0.001$), and fat mass

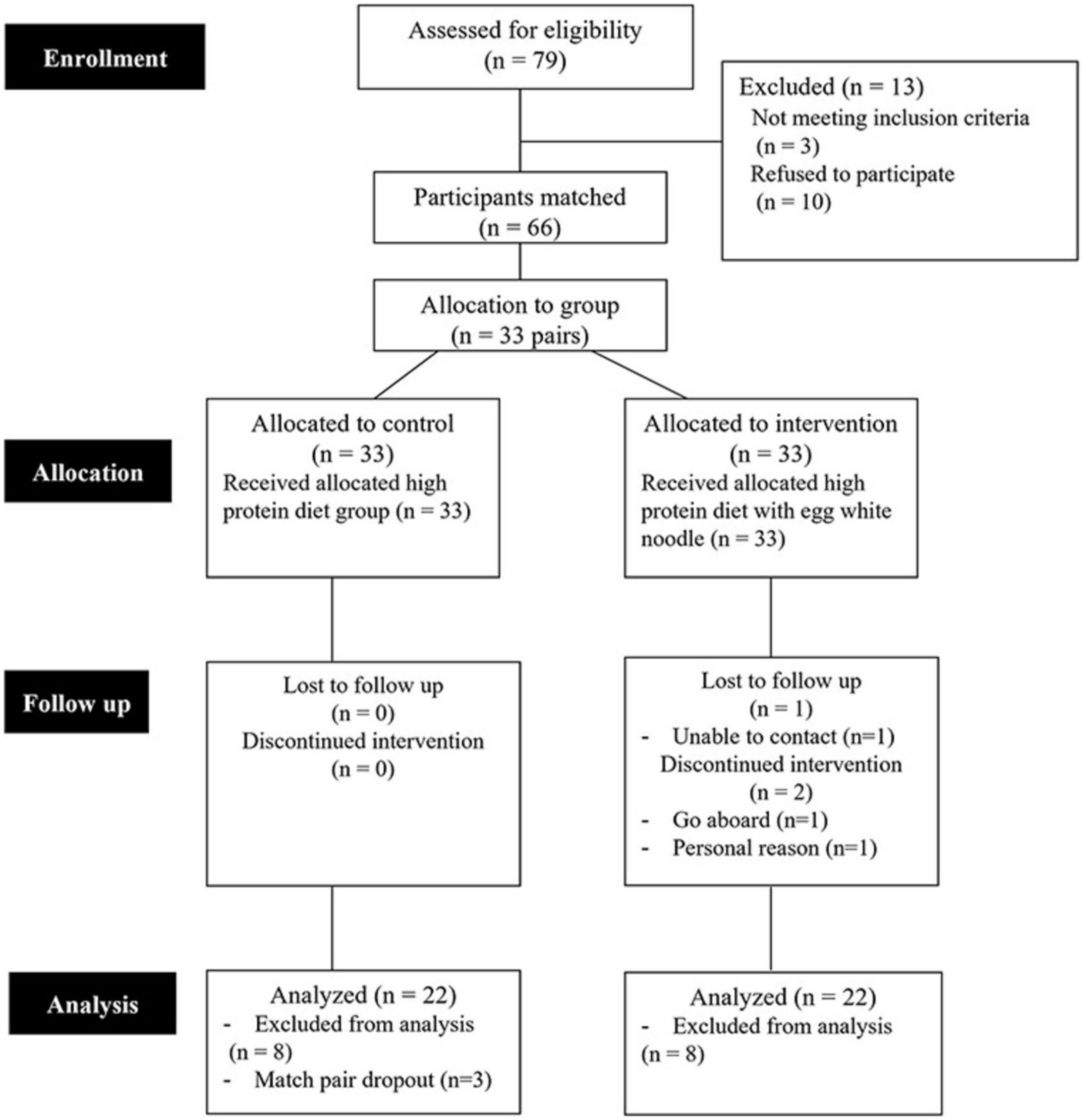


Fig. 2 The consort flow diagram of this study

($p<0.001$) relative to baseline. However, all these parameters showed similar alterations to those in the control group during the study. Remarkably, at week 6, the reduction in body weight was significantly greater in the EWN group (−2.64 ± 0.45 kg) compared to the control group (−1.48 ± 0.26 kg) ($p=0.031$) (Fig. 3). Moreover, the waist-to-hip ratio in males consuming EWN displayed a notable difference compared to the control group at weeks 3 and 6.

Biochemical blood profiles

The 6-week consumption of EWN led to a significant decrease in total cholesterol (week 3, $p=0.029$; week 6, $p=0.001$) and direct LDL cholesterol (week 3, $p=0.037$, week 6, $p<0.001$) compared to baseline. Furthermore, there were no notable changes in kidney and liver functions, including BUN, creatinine, eGFR, uric acid, AST, or ALT levels in the EWN group at the conclusion. Furthermore, the results revealed that EWN significantly decreased cholesterol levels compared to the control group by week 6. Additionally, it led to lower LDL cholesterol levels in both weeks 3 and 6, as depicted in Table 3.

Table 4 outlines the effects of EWN consumption on inflammatory and antioxidant parameters. While there was a tendency towards decreased inflammatory parameters, no significant differences were observed, except for TNF-α, which significantly increased from baseline in both the control and EWN groups. Additionally, the

Table 1 Baseline characteristics of participants

Parameters	Control group ($n=22$)	EWN group ($n=22$)	p-value
Gender (male/female)	6/16	6/16	
Age (years)	39.23 ± 1.94	42.09 ± 1.68	0.273
BMI (kg/m^2)	29.12 ± 0.55	28.83 ± 0.55	0.712
Systolic blood pressure (mmHg)	125.64 ± 3.30	126.87 ± 2.66	0.773
Diastolic blood pressure (mmHg)	80.14 ± 2.03	76.87 ± 1.60	0.213
Fasting blood glucose (mg/dL)	90.95 ± 1.19	95.91 ± 4.68	0.315
Total cholesterol (mg/dL)	223.09 ± 6.21	216.91 ± 6.71	0.503
BUN (mg/dL)	12.82 ± 0.56	10.91 ± 0.63	0.092
Creatinine (mg/dL)	0.83 ± 0.04	0.77 ± 0.03	0.233
AST (U/L)	21.45 ± 1.18	18.50 ± 1.20	0.086
ALT (U/L)	27.45 ± 3.33	19.55 ± 2.82	0.077

Data are presented as Mean ± SD, and p value < 0.05 was considered statistically significant

EWN egg white noodle, *BMI* body mass index, *W/H ratio* waist to hip ratio, *BUN* blood urea nitrogen, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase

Table 2 Effects of EWN replacing in an isocaloric diet with a high protein proportion on body composition

Parameters	Group	Baseline	Week 3	Week 6	Follow-up
Weight (kg)	Control	76.42 ± 11.89^{Aa}	75.32 ± 11.87^{Ab}	74.94 ± 12.08^{Ab}	75.74 ± 12.8^{Aa}
	EWN	75.96 ± 12.21^{Aa}	74.20 ± 12.07^{Ab}	73.32 ± 11.92^{Ab}	73.80 ± 12.03^{Ab}
BMI (kg/m^2)	Control	29.12 ± 2.60^{Aa}	28.67 ± 2.60^{Ab}	28.57 ± 2.57^{Ab}	28.82 ± 2.72^{Aa}
	EWN	28.83 ± 2.59^{Aa}	28.25 ± 2.67^{Ab}	27.84 ± 2.55^{Ab}	28.01 ± 2.62^{Ab}
Waist (cm)	Control	95.86 ± 1.79 ^{Aa}	93.61 ± 1.77 ^{Ab}	92.99 ± 1.68 ^{Ab}	93.9 ± 1.63 ^{Ab}
	EWN	92.74 ± 1.89 ^{Aa}	90.56 ± 1.90 ^{Ab}	89.82 ± 1.76 ^{Ab}	89.88 ± 1.80 ^{Bb}
Hip (cm)	Control	108.01 ± 1.12 ^{Aa}	107.60 ± 1.20 ^{Aa}	106.79 ± 1.20 ^{Ab}	107.43 ± 1.33 ^{Aa}
	EWN	107.23 ± 1.66 ^{Aa}	106.06 ± 1.58 ^{Aa}	105.01 ± 1.53 ^{Ab}	105.15 ± 1.65 ^{Ab}
W/H ratio	Control	0.89 ± 0.01 ^{Aa}	0.87 ± 0.01 ^{Ab}	0.87 ± 0.01 ^{Ab}	0.87 ± 0.01 ^{Aa}
	EWN	0.87 ± 0.02 ^{Aa}	0.85 ± 0.01 ^{Bb}	0.86 ± 0.01 ^{Ab}	0.86 ± 0.02 ^{Aa}
Fat mass (kg)	Control	28.74 ± 5.25^{Aa}	27.77 ± 5.08^{Ab}	27.51 ± 5.22^{Ab}	27.90 ± 5.53^{Ab}
	EWN	27.91 ± 7.01^{Aa}	26.70 ± 7.09^{Ab}	25.44 ± 6.99^{Aa}	26.05 ± 7.10^{Aa}
FFM (kg)	Control	47.92 ± 10.29^{Aa}	47.73 ± 10.30^{Aa}	47.65 ± 10.41^{Aa}	48.15 ± 10.75^{Aa}
	EWN	47.58 ± 10.37^{Aa}	47.18 ± 10.16^{Ab}	47.54 ± 10.55^{Aa}	47.46 ± 10.38^{Aa}
Muscle mass (kg)	Control	45.16 ± 9.89^{Aa}	45.01 ± 9.89^{Aa}	44.95 ± 9.98^{Aa}	45.38 ± 10.34^{Aa}
	EWN	44.86 ± 9.95^{Aa}	44.50 ± 9.77^{Ab}	44.95 ± 10.09^{Aa}	44.76 ± 9.96^{Aa}

Data are expressed as Mean ± SEM. Means with different uppercase letters at the same time point (A-B: treatment effects) and lowercase letters at the same treatment (a-b: time effects) are significantly different ($p < 0.05$)

EWN egg white noodle, *BMI* body mass index, *W/H ratio* waist to hip ratio, *FFM* Fat free mass

antioxidant marker FRAP showed a significant increase in both groups at the conclusion of the intervention period (control, $p = 0.002$; EWN, $p < 0.001$).

Dietary assessment

In Table 5, the dietary assessment conducted in this study is presented. Data were collected through a 24-h recall at baseline and a 3-day food record during subsequent visits. An increase in protein consumption was observed during the intervention period compared to baseline in both groups, although it was not significantly different during the follow-up period in the control group. However, total energy consumption did not show a significant difference between either group compared to the baseline.

Discussion

This study represents the initial attempt to investigate the effects of incorporating EWN, as alternative food choices, into an isocaloric diet with a high protein proportion over a 6-week period for weight management in overweight and obese participants. The findings suggest

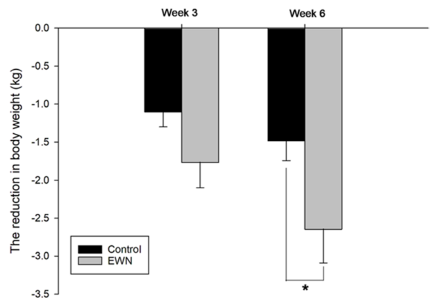


Fig. 3 The reduction in body weight following consumption of an isocaloric diet with a high protein proportion, including a 30% meat replacement by EWN, at weeks 3 and 6 is shown. Data are expressed as Mean ± SEM. *Significant difference ($p < 0.05$) compared to the control. EWN; egg white noodle

that substituting EWN for meat products leads to significant reductions in body weight, BMI, waist circumference, hip circumference, and fat mass. Additionally, improvements were noted in blood profile parameters, including total cholesterol, LDL cholesterol, and the antioxidant marker (FRAP), when compared to the baseline. A notable finding is that substituting 30% of the dietary protein with EWN proved to be more effective than the isocaloric diet control group, which featured a high protein content from meat products. Our findings suggest that this substitution led to more significant reductions in body weight change, total cholesterol, and LDL cholesterol compared to the control group.

Caloric restriction is a primary strategy for weight reduction. However, only energy restriction can lead to subsequent weight regain due to heightened hunger and reduce fullness. Even though it can reduce fat mass, the fat free mass and muscle mass also decrease, which is related to continuous negative energy balance (Moon & Koh, 2020). In this study, we formulated the prepared meals with 1,500 kcal, implementing a 500-kcal restriction from the recommended 2,000 kcal/day according to Thai DRI, and ensured they contained 25% protein (Bureau of Nutrition, 2020). Based on the results from food records (Table 5), participants consumed a daily total energy intake of 1,200–1,300 kcal, with approximately 23–24% protein, closely aligning with the targeted proportion within the designed isocaloric diet framework. Notably, our study supports the potential benefits of a high protein diet, with 20–30% of energy intake from protein, 45–65% from carbohydrates, and 10–35% from fat, as a promising therapeutic approach for preserving muscle mass during weight management (Castro-Barquero et al., 2020). The MEASUR-UP trial strategically focusing on obese individuals implemented an isocaloric design, with a 500-kcal restrictions and high protein intake. The high protein group with a daily

Table 3 Effects of EWN replacement in an isocaloric diet with a high protein proportion on blood biochemical profiles

Parameters	Group	Baseline	Week 3	Week 6
Glucose (mg/dL)	Control	90.95 ± 1.19 ^{Aa}	88.95 ± 1.29 ^{Ab}	89.09 ± 1.31 ^{Ab}
	EWN	95.91 ± 4.68 ^{Aa}	90.00 ± 4.35 ^{Ab}	91.73 ± 3.69 ^{Ab}
Triacylglycerol (mg/dL)	Control	118.36 ± 9.32 ^{Aa}	98.05 ± 9.37 ^{Ab}	111.64 ± 8.31 ^{Aa}
	EWN	101.86 ± 6.98 ^{Aa}	91.09 ± 6.54 ^{Aa}	99.23 ± 7.03 ^{Aa}
Cholesterol (mg/dL)	Control	226.86 ± 5.93 ^{Aa}	217.73 ± 7.58 ^{Aa}	220.05 ± 6.98 ^{Aa}
	EWN	216.91 ± 6.71 ^{Aa}	202.5 ± 7.99 ^{Ab}	201.82 ± 6.46 ^{Bb}
HDL cholesterol (mg/dL)	Control	50.45 ± 1.64 ^{Aa}	48.95 ± 1.49 ^{Aa}	51.45 ± 1.68 ^{Aa}
	EWN	52.77 ± 1.59 ^{Aa}	48.68 ± 1.60 ^{Ab}	52.18 ± 1.81 ^{Aa}
LDL cholesterol (mg/dL)	Control	156.86 ± 5.74 ^{Aa}	151.14 ± 7.38 ^{Aa}	148.55 ± 6.58 ^{Aa}
	EWN	142.41 ± 6.64 ^{Aa}	131.14 ± 7.37 ^{Bb}	127.18 ± 6.59 ^{Bb}
BUN (mg/dL)	Control	12.82 ± 0.56 ^{Aa}	13.14 ± 0.51 ^{Aa}	12.64 ± 0.46 ^{Aa}
	EWN	10.91 ± 0.63 ^{Aa}	11.82 ± 0.55 ^{Aa}	12.41 ± 0.61 ^{Aa}
Creatinine (mg/dL)	Control	0.83 ± 0.04 ^{Aa}	0.81 ± 0.03 ^{Aa}	0.78 ± 0.03 ^{Aa}
	EWN	0.77 ± 0.03 ^{Aa}	0.75 ± 0.03 ^{Aa}	0.78 ± 0.03 ^{Aa}
eGFR (ml/min/1.73m^2)	Control	97.23 ± 2.93 ^{Aa}	97.27 ± 2.72 ^{Aa}	101.41 ± 2.46 ^{Ab}
	EWN	98.50 ± 2.82 ^{Aa}	101.50 ± 2.20 ^{Aa}	99.14 ± 2.31 ^{Aa}
Uric acid (mg/dL)	Control	6.75 ± 0.33 ^{Aa}	6.16 ± 0.31 ^{Aa}	6.26 ± 0.36 ^{Aa}
	EWN	6.20 ± 0.23 ^{Aa}	5.73 ± 0.26 ^{Aa}	6.05 ± 0.23 ^{Aa}

Data are expressed as Mean ± SEM. Means with different uppercase letters at the same time point (A-B: treatment effects) and lowercase letters at the same treatment (a-b: time effects) are significantly different ($p < 0.05$)

EWN egg white noodle, *BUN* blood urea nitrogen, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase

Table 4 Effects of EWN replacement in an isocaloric diet with a high protein proportion on inflammatory and antioxidant parameters

Parameters	Group	Baseline	Week3	Week6
Inflammatory markers				
IL-1 (pg/mL)	Control	100.03 ± 1.76 Aa	97.44 ± 2.05 Aa	97.92 ± 1.26 Aa
	EWN	97.07 ± 0.83 Aa	96.5 ± 1.71 Aa	96.32 ± 1.53 Aa
IL-6 (pg/mL)	Control	32.59 ± 0.62 Aa	30.38 ± 0.60 Aa	32.43 ± 0.70 Aa
	EWN	31.35 ± 0.32 Aa	30.17 ± 0.38 Ab	32.39 ± 0.39 Aa
TNF-α (pg/mL)	Control	97.16 ± 2.35 Aa	102.95 ± 3.35 Aa	106.09 ± 3.59 Aa
	EWN	95.82 ± 1.23 Aa	99.96 ± 2.17 Aa	107.98 ± 2.43 Aa
Antioxidant parameters				
MDA (μM)	Control	1.28 ± 0.17 Aa	3.09 ± 0.51 Ab	1.55 ± 0.34 Aa
	EWN	1.37 ± 0.15 Aa	3.13 ± 0.24 Ab	1.79 ± 0.45 Aa
Thiol (μM)	Control	659.41 ± 9.18 Aa	622.01 ± 9.36 Ab	644.49 ± 8.58 Ab
	EWN	652.71 ± 7.03 Aa	606.64 ± 6.99 Ab	634.90 ± 6.75 Ab
FRAP (mM $FeSO_4$equivalent)	Control	0.45 ± 0.05 Aa	0.55 ± 0.04 Ab	0.65 ± 0.05 Ab
	EWN	0.48 ± 0.04 Aa	0.52 ± 0.03 Aa	0.70 ± 0.04 Ab

Data are expressed as Mean ± SEM. Means with different uppercase letters at the same time point (A-B: treatment effects) and lowercase letters at the same treatment (a-b: time effects) are significantly different ($p < 0.05$)

EWN egg white noodle, *FRAP* ferric ion reducing antioxidant power, *IL-1* interleukin 1, *IL-6* interleukin 6, *MDA* malondialdehyde, *TNF-α* tumor necrosis factor alpha

protein proportion of 1.2 g/kg BW/day demonstrated a remarkable 7% reduction in body weight at the study endpoint ($p < 0.001$) (Porter Starr et al., 2019). Moreover, the State of Slim weight management program incorporates an isocaloric diet with diverse protein content—21% and 40%, excluding red meat to explore the effects of weight loss on diabetes management in participants with type 2 diabetes. Results reveal notable weight loss of 9.4% and 11.8% for participants adhering to the respective high protein isocaloric diets (Clina et al., 2023). These findings emphasize the potential efficacy of a high protein, isocaloric approach in achieving both weight management goals.

One proposed mechanism for the weight loss-promoting effect of high protein diets is an increase in diet-induced thermogenesis. In a study investigating the impact of high protein consumption on satiety in a respiration chamber compared to adequate protein diet in healthy participants, the findings revealed that a diet with 30% of energy intake from protein significantly increased diet-induced thermogenesis, in contrast to a normal protein diet with only 10% of energy derived from protein. The notable thermic effect of protein is thought to be influenced by the high ATP costs associated with postprandial protein synthesis (Lejeune et al., 2006). Moreover, the quality of protein, including factors such as digestibility and the composition of amino acids, particularly leucine, which plays a crucial role in muscle protein synthesis, may play a significant role in preventing and managing obesity (Ellinger et al., 2024). In a 12-week open-randomized clinical trial involving a 750-kcal restriction and 30% protein intake to examine the effects of dietary protein and obesity on energy-restriction-induced changes in weight management and cardiometabolic markers, a remarkable 11% weight loss was achieved, highlighting a more substantial impact on preserving lean body mass compared to a normal protein diet in obesity (Leidy et al., 2007). Our results are consistent with these research findings, indicating that an isocaloric diet with a higher protein proportion led to reduced body weight, with no significant difference in changes to FFM and muscle mass observed in both the control and EWN groups when compared to the initial

Table 5 The three-day food record in control and EWN groups during the study

Parameters	Group	Baseline[c]	Week 3	Week 6	Follow-up
Energy (kcal)	Control	1413.4 ± 37.61 Aa	1355.1 ± 40.70 Aa	1311.99 ± 52.70 Ab	1313.34 ± 69.70 Aa
	EWN	1503.22 ± 35.21 Aa	1340.89 ± 52.38 Ab	1351.62 ± 48.60 Ab	1454.35 ± 82.87 Aa
Protein (g)	Control	56.82 ± 5.06 Aa	81.42 ± 2.93 Ab	75.06 ± 3.23 Ab	60.61 ± 3.32 Aa
	EWN	61.64 ± 6.03 Aa	74.99 ± 2.79 Ab	79.89 ± 3.43 Ab	72.26 ± 4.59 Ba
Carbohydrate (g)	Control	158.72 ± 5.29 Aa	154.28 ± 5.69 Aa	157.52 ± 7.71 Aa	156.6 ± 10.59 Aa
	EWN	167.06 ± 5.59 Aa	161.10 ± 6.81 Aa	159.4 ± 5.61 Aa	172.52 ± 10.07 Aa
Fat (g)	Control	48.42 ± 2.18 Aa	45.54 ± 2.26 Aa	42.11 ± 1.94 Ab	49.41 ± 3.21 Aa
	EWN	53.07 ± 1.75 Aa	44.41 ± 3.00 Ab	44.44 ± 3.23 Ab	52.77 ± 3.70 Aa

Data are expressed as Mean ± SEM. Means with different uppercase letters at the same time point (A-B: treatment effects) and lowercase letters at the same treatment (a-b: time effects) are significantly different ($p < 0.05$)

[c] Baseline food record was collected by 24-h recall

EWN egg white noodle

values. Importantly, our study also indicates that the substantial EWN diet promotes greater weight change than the control group, while still preserving FFM and muscle mass, as shown in Table 2. The observed reduction in body weight in this study may be attributed to changes in fat intake. Fat positively influences energy balance more than other macronutrients. Previous study suggested that lower fat intake in a high-protein diet could lead to greater reductions in body fat (Wycherley et al., 2010). This is correlated with the results in Table 5, which show a significant decrease in fat intake from baseline in the EWN group.

Contrary to our initial hypothesis, which suggested that EWN consumption might exhibit greater muscle mass preservation than the control group, our findings deviated from this expectation. Wright et al. (2018) confirmed the positive effects of a 12-week high-protein diet with eggs on age-related alterations in muscle composition in overweight and obese participants. They demonstrated that consuming a high-protein diet with whole eggs promoted the retention of lean mass during weight loss and reduced subcutaneous fat compared to a normal protein diet (Wright et al., 2018). Wycherley et al. (2010) demonstrated that combining a high protein diet with exercise in overweight and obese patients with type 2 diabetes resulted in higher FFM and muscular strength compared to a high protein diet alone. This supports the idea that the combined effects of reduced calorie intake and increased exercise have a positive impact on enhancing alterations in body composition, underscoring the benefits of maintaining higher protein consumption during calorie restriction (Layman et al., 2005; Wycherley et al., 2010). It is essential to recognize that our results differ from those of other studies, which may be attributed to the predominantly sedentary lifestyle of our participants, who were office workers with minimal physical activity. The lack of consistent physical activity probably contributed to the limited gains in muscle mass.

The study findings indicate a reduction in W/H ratio for both groups. Notably, the EWN group achieved a reduction that brought them close to the recommended normal range (0.9 for males and 0.8 for females) compared to their baseline (World Health Organization, 2011). Increased visceral fat mass, especially in abdominal obesity, is linked to ectopic lipid accumulation in crucial organs like the liver, skeletal muscle, and pancreas. This accumulation, in turn, is associated with metabolic changes that can contribute to dyslipidaemia, including elevated LDL cholesterol and the release of pro-inflammatory substances such as adipokines, IL-6, and TNF-α, contributing to systemic insulin resistance—a key factor in the onset of various health complications (Chon et al., 2020; Stefan, 2020).The substantial improvement in the W/H ratio observed in this study suggests that the high protein diet with EWN may effectively address and reduce abdominal obesity while improving metabolic markers.

Furthermore, this study observed improvements in blood profile parameters, including total cholesterol and LDL cholesterol. High-protein diets typically reduce carbohydrate intake and are frequently associated with increased saturated fatty acid consumption. This association can complicate the interpretation of results from studies aiming to assess the impact of protein intake on plasma lipid levels (Bergeron et al., 2019). In a previous study, the effect of various dietary protein sources on weight loss in abdominally obesity was studied over a 12-week period. The isocaloric distribution diet with 30% of soy replacement in 20% of protein distribution was provided for participants and indicated that both the soy and meat groups achieved an average weight loss of 8%, as well as a 10% decrease in total cholesterol and LDL cholesterol levels (Beavers et al., 2015). Moreover, Hill et al. (2015) found that individuals with overweight and obesity and metabolic syndrome could achieve a 5% reduction in weight and an 8–9% decrease in body fat by following a diet that consists of 60% plant-based protein instead of animal-based protein. This plant-based diet also resulted in better total cholesterol and LDL cholesterol levels. These improvements are linked to a controlled intake of saturated fatty acids (SFAs), which are associated with higher LDL cholesterol levels and increased cardiovascular risk (Hill et al., 2015). These factors may have contributed to the consistent findings observed in our study.

Proteins derived from animal sources, such as red meats and dairy products, often come with high levels of saturated fats and cholesterol, posing potential risks for heart disease, hyperlipidaemia, and hypercholesterolemia (Ko et al., 2020). In contrast, EWN serve as an excellent protein source, free from saturated fats and cholesterol. When individuals incorporate EWN into their diet instead of regular protein sources, there is evidence to suggest a reduction in total cholesterol and directed LDL cholesterol levels, Moreover, the cholesterol lowering effect from egg white might come from the physicochemical properties of ovalbumin and ovotransferrin in egg whites hinder the dissolution of dietary cholesterol in bile acid micelles, thereby suppressing the absorption of lipids, including cholesterol (Sugano & Matsuoka, 2021), aligning with previous studies. For example, Matsuoka et al. (2017) showed that daily consumption of an egg white drink for 8 weeks in hypercholesterolemic males led to a decrease in average total cholesterol levels by 11.0 ± 3.7 mg/dL and LDL cholesterol levels by 13.7 ± 3.1 mg/dL among those drinking an 8 g protein egg white beverage. Similarly, Asato et al. (1996) found that hypercholesterolemic females who consumed egg whites experienced a positive impact on serum cholesterol levels, reducing total cholesterol and LDL cholesterol compared to those consuming tofu and cheese over a 12-week period. Li et al. (2016) suggested that caloric restriction combined with a high-protein diet that includes egg-based foods may result in a greater reduction in total cholesterol levels compared to a conventional high-protein diet over 28 days in individuals with obesity. Because egg whites do not contain cholesterol, they can significantly reduce overall cholesterol intake when compared to other protein sources that do have cholesterol. Other studies have also indicated that reducing cholesterol intake and replacing it with egg whites or egg white-based alternatives can promote long-term health and longevity (Matsuoka et al., 2017; Zhuang et al., 2021). However, consuming 23 g of egg whites daily to reap health benefits can be challenging due to their unique flavor and texture (Sugano & Matsuoka, 2021). This issue could potentially be addressed by using egg white noodles (EWN).

Obesity is linked to a low-grade inflammatory state characterized by the increased infiltration of macrophages into adipose tissues, leading to the secretion of inflammatory cytokines such as TNF-α, IL-6, and leptin (Engin, 2017). Additionally, a high intake of red meat has been associated with elevated inflammation and oxidative stress (Ko et al., 2020). Caloric-restricted diets, inducing a negative energy balance, result in body fat loss, triggering lipolysis, reducing adipocyte size and metabolism, and inhibiting the secretion of specific inflammatory cytokines (Bianchi, 2018). Furthermore, specific egg white protein (ovotransferrin) has demonstrated potential in inhibiting nitric oxide (NO) production and the secretion and gene expression of cytokines (TNF-α, IL-6, and IL-10) (Zhou et al., 2022). However, the results showed no significant differences in the control and the EWN groups compared to baseline. This finding is consistent with the Metabolic Syndrome Reduction in Navarra diet (RESMENA diet), which compared energy-restricted diets with varying protein content on the inflammation state of obese individuals with metabolic syndrome. Despite the anticipated increase in inflammatory markers associated with higher animal meat consumption, no elevation was observed (Lopez-Legarrea et al., 2014). On the contrary, the lack of significant changes in both groups may be attributed to the percentage of weight loss, which might not have been sufficient to demonstrate the potential effect (approximately 2% weight reduction in both groups). These results align with a previous study exploring the relationship between moderate weight loss and inflammatory cytokine levels in obesity, which reported that even a 19.6% weight loss in obese participants did not lead to significant changes in inflammatory markers (CRP, IL-6, and TNF-α) (Sola et al., 2009).

Additionally, specifying the duration of the study is a crucial aspect in research. Our objective was to assess the changes in body composition during the follow-up period after the 6-week intervention. This follow-up period is a critical phase in weight management as it allows the evaluation of behavioural modifications and the long-term sustainability of interventions (Montesi et al., 2016). During this follow-up period, noteworthy differences emerged between the EWN group and the control group. The EWN group demonstrated an increase in protein intake, maintaining the positive changes achieved during the intervention, while the control group returned to levels similar to the baseline. This divergence in behaviour may be attributed to the influence of nutritional classes and adjustments made based on the recommendations of the intervention recipe. An interesting aspect is that after a weight loss program, the consumption of a diet with a normal distribution often results in inadequate protein intake, leading to subsequent weight gain (Soenen et al., 2013). Westerterp-Plantenga et al. (2009) propose that a high protein diet following weight loss may support weight maintenance for several reasons: (1) its metabolic inefficiency due to the costs involved in sparing FFM, (2) a decrease in energy efficiency regarding regained body mass, and (3) an increase in satiety (Westerterp-Plantenga et al., 2009). The findings of our study align with this notion, suggesting that the EWN group was able to sustain their body weight, BMI, and FFM during the follow-up period. This implies potential benefits associated with the use of EWN for achieving lasting effects in weight management.

In this study, we chose a short-term consumption of an isocaloric diet, which sets it apart from other reports where studies often span a 12-week duration to detect significant shifts in weight reduction and improvements in metabolic indicators (Moon & Koh, 2020). Our approach involved a 6-week intervention followed by a 2-week monitoring period, along with providing nutritional education. This design aimed to facilitate the implementation of lifestyle modifications and achieve reductions in both body weight and body composition. An added advantage of incorporating EWN as a meat alternative lies in the potential to enhance participant satisfaction with meals. Participants in the EWN group received a flexible recipe plan that featured satisfying main dishes, side dishes, and snacks. For example, instead of simply increasing the meat portions in a salad, they could make a spicy egg white salad or add cold noodles as a side. These options not only increased protein intake without relying heavily on meat but also enhanced overall meal satisfaction. Large meat portions can lead to feelings of monotony, so the flexible meal options were designed to keep participants engaged and enjoying their meals, which is essential for sticking to dietary changes. Moreover, this approach allowed for healthier versions of traditional Thai desserts, further enriching the dining experience. Using meat as a protein source has limitations in versatility, as it is generally reserved for main courses and less adaptable for desserts or side dishes. The intention was to make the recipe more engaging and less mundane for participants. Generally, dropout rates in weight-loss diets can be influenced by the specific characteristics of the diet itself. Conventional diets may induce feelings of monotony, potentially contributing to an increased dropout rate in body weight reduction programs (Bazrafkan et al., 2021). In this current study, we initially anticipated a high rate of reluctance from participants to consistently consume EWN over a 6-week period. Contrary to expectations, all participants demonstrated 100% compliance in consuming the EWN. This suggests that the product could indeed serve as a viable meat alternative, introducing additional variety and appeal to culinary dishes.

A notable strength of this study is its ability to simulate real-world conditions by providing participants with prepared meals, including three major meals and snacks, utilizing EWN. Although meals were supplied only on weekdays, this study also offered nutritional guidance over the weekend and held nutritional classes. This could pose challenges for sustaining behavioural modifications. Furthermore, the investigation into EWN as a novel food through clinical trials adds a unique and valuable dimension, contributing insights into the practical application of innovative EWN in the context of weight management in both overweight and obese people. However, several limitations should be acknowledged. Firstly, the energy requirements were not individually calculated for participants, which could have been more appropriate for determining energy restrictions. Additionally, the duration of this study may not have been sufficient to clearly observe its effects. Moreover, certain confounding factors, such as the monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) content of the diet, were not considered, despite their potential impact on the lipid profile.

Conclusions

The study highlights the effectiveness of incorporating EWN into an isocaloric, high-protein diet for managing body weight and composition in overweight and obese individuals. Over the 6-week intervention, replacing 30% of meat with EWN led to significant reductions in body weight, total cholesterol, and LDL cholesterol, while preserving muscle mass and decreasing fat mass. These findings suggest that EWN could serve as a promising alternative to red meat in weight management strategies, providing consumers with a practical, evidence-based option for achieving healthier outcomes.

Abbreviations

ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
BCAAs	Branched-chain amino acids
BHT	Butylated hydroxytoluene
BMI	Body mass index
BUN	Blood urea nitrogen
CHO	Carbohydrate
DASH diet	Dietary approaches to stop hypertension diet
DRI	Dietary Reference Intakes
EDTA	Ethylenediaminetetraacetic acid
eGFR	Estimated glomerular filtration rate
EWN	Egg white noodle
FFM	Fat-free mass
FRAP	Ferric ion reducing antioxidant power
HDL cholesterol	High-density lipoprotein cholesterol
IL-1	Interleukin 1
IL-6	Interleukin 6
LDL cholesterol	Low-density lipoprotein cholesterol
MDA	Malondialdehyde
METs	Metabolic equivalent score
MUFA	Monounsaturated fatty acid
Prot	Protein
PUFA	Polyunsaturated fatty acid
SEM	Standard error of mean
SFA	Saturated fatty acid
TBA	Thiobarbituric acid
TBARS	Thiobarbituric acid reactive substances
TNF-α	Tumor necrosis factor alpha
TPTZ	2,4,6-Tri(2-pyridyl)-*S*-triazine
VLDL cholesterol	Very low-density lipoprotein cholesterol
W/H ratio	Waist-to-hip ratio

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Patents
The petty patent for the egg white noodles was obtained from Department of Intellectual Property (DIP), (Thailand), no. 19652, date 28 April 2022.

Institutional review board statement
The study was conducted in accordance with the Declaration of Helsinki and approved by the office of the Ethics Review Committee for Research Involving Human Research Subjects, Human Science Group, Chulalongkorn University for studies involving humans (COA No. 239/65).

Authors' contributions
Conceptualization, W.J., C.C., S.N., V.T., T.K., T.S., and S.A.; Data curation, W.J., and C.C.; Investigation, W.J., and C.C.; Methodology, W.J., C.C., S.N., V.T., T.K., T.S., and S.A.; Formal analysis, W.J., and C.C.; Supervisor, S.A.; Writing—original draft preparation and writing—review and editing, W.J., T.S., and S.A.; Project administration, C.C., S.N., T.S., and S.A.; Funding acquisition, S.N., T.S., and S.A. All authors have read and agreed to the published version of the manuscript.

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Data availability
Data are contained within the article.

Declarations

Consent for publication
All participants provided written informed consent, including consent for publication of the study findings.

Competing interests
The authors declare a potential conflict of interest related to the funding source for this manuscript. Specifically, S.N, T.S., and S.A. are affiliated with Thandee Innofood Co., Ltd, a company that emerged as a university spin-off, and contributed partial financial support to the research. However, S.N, T.S., and S.A. did not participate in data curation, investigation, or formal analysis. This disclosure aims to maintain transparency and recognize any potential influence that the university spin-off may have exerted on the study. It is important to note that the remaining authors have no conflicts of interest to declare.

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