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Effects of cheese ingestion on muscle mass and strength in possible sarcopenia women: an open-label, parallel-group study

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Abstract

Background Nutrient-rich cheese supplements were demonstrated to have improvements in markers of sarcopenia in healthy elders. However, the potential effects of cheese in individuals with possible sarcopenia remain unknown.

Method This 90-day randomized controlled trial (RCT) included 68 women aged 60–80 years with possible sarcopenia in China, who were randomly assigned to three groups: Control group (CG), Original cheese group (OG: 9.0 g protein; 322.8 mg calcium), and Golden cheese group (GG: 12.7 g protein; 802.1 mg calcium). OG and GG were instructed to consume their habitual diet along with 4 slices of supplied cheese, while CG was directed to maintain their usual dietary habits. Face-to-face interviews, anthropometric measurements, and blood sample collection were conducted at baseline, midway (60 days), and the end of the trial.

Result At the end of the trial, the primary outcome, changes of Skeletal Muscle Mass Index (SMI) were found to be higher in OG (0.18 ± 0.02 kg/m^2) and GG (0.14 ± 0.02 kg/m^2) compared to CG (0.09 ± 0.02 kg/m^2). The secondary outcome, changes of handgrip strength were higher in GG (1.82 ± 4.16 kg) than CG (-0.61 ± 3.78 kg). There were no significant differences in makers for muscle function between three groups ($P > 0.05$). In the self-comparison, Creatinine/Cystatin C significantly increased in both OG and GG. In addition, OG had a significant increase in changes of free and total carnitine compared to CG.

Conclusion Both golden and original cheese supplementation enhanced muscle strength and mass in older women with possible sarcopenia. The mechanism behind this effect may be linked to muscle cell energy metabolism.

Trial registration The present study was registered in the Chinese Clinical Trial Registry with the registration number ChiCTR2300078720 (retrospectively registered, 20231215).

Keywords Possible sarcopenia, Cheese, Muscle strength, Muscle function, Muscle mass

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Introduction

Sarcopenia is a syndrome marked by the age-related reduction of skeletal muscle mass and the concurrent decline in muscle strength, which is linked to an elevated risk of negative outcomes, including falls, fractures, physical disability, and mortality [1]. Globally, the prevalence of sarcopenia ranges from 8 to 36% in individuals under 60 years and from 10 to 27% in those aged 60 years and above [2]. In community-dwelling Chinese older adults, the prevalence is 12.9% for men and 11.2% for women, respectively [3]. With the global aging trend, sarcopenia imposes a significant burden on individuals and society [4]. Therefore, it is imperative to identify potential risk factors and initiate early interventions.

Sarcopenia involves numerous complex and interactive mechanisms, none of which can fully explain its underlying pathophysiology. Except for advancing age, several risk factors contribute to sarcopenia, including malnutrition, sedentary lifestyle, chronic diseases, and iatrogenic factors [5–7]. Given that sarcopenia is characterized by the loss of skeletal muscle, poor nutritional status has recently been proposed to play a crucial role in its development, making it a primary non-pharmacological target for intervention [8].

According to the Report on Nutrition and Chronic Diseases in China (2020), residents aged ≥ 60 years in China had an average protein intake of 52.9 g/d [9], significantly lower than the recommended levels (72 g/d for men, 62 g/d for women) [10]. Additionally, calcium intake was also below the recommended value at 333.2 mg [9]. Previous studies have reported that a protein-poor diet triggers a compensatory response characterized by a reduction in lean mass [11, 12]. Certain dietary approaches, such as ensuring adequate intake of protein, vitamin D, antioxidant nutrients, and long-chain polyunsaturated fatty acids, have been shown to have positive effects against sarcopenia [13], which suggested that nutrient-rich foods may play a role in preventing and reversing the loss of skeletal muscle.

Dairy products, known for their high-quality protein content and nutrient richness (such as calcium), have been recognized as valuable contributors to a healthy diet [14]. In a previous study, the addition of 210 g of ricotta cheese was found to improve appendicular skeletal muscle mass (TASM) and balance-test scores, while also attenuating the loss of muscle strength in healthy individuals aged over 60 years [15]. However, when the same randomized controlled trials were conducted in individuals with sarcopenia, the results were converse, showing no significant changes in TASM after the intervention period [16]. Individuals who have experienced accelerated loss of muscle mass may be less responsive to the anabolic stimulus of protein supplementation [17], potentially explaining the inconsistent results. In 2020, the Asian Working Group for Sarcopenia introduced the concept of 'possible sarcopenia,' characterized by low muscle strength with or without diminished physical performance [18]. Lifestyle interventions were recommended for this target reversible population. Considering the challenges of intervening in sarcopenia and its severe disease burden, it is worthwhile to investigate the potential effects of cheese intervention in individuals with possible sarcopenia.

In this study, our aim was to evaluate the effects of cheese intervention on markers for sarcopenia in women aged 60–80 years with possible sarcopenia. Notably, previous studies were confined to healthy or specifically defined sarcopenic elders. To the best of our knowledge, this is the first randomized controlled trial (RCT) reporting dairy intervention in a population with possible sarcopenia.

Method

Subjects

In this study, we enrolled elderly women aged sixty to eighty years who exhibited signs of possible sarcopenia. Recruitment took place within local communities from February to June 2023, employing convenient and snowball sampling methods. We utilized advertisements in local community and health service centers, along with telephone invitations for participant recruitment. We screened participants for possible sarcopenia using calf circumference. The target population was identified based on the criteria established by the Asian Working Group for Sarcopenia. Inclusion criteria comprised a calf circumference of < 33 cm or SARC-CalF ≥ 11, along with handgrip strength < 18 kg or/and a 5-time chair stand test ≥ 12 s. Exclusion criteria encompassed individuals who: (1) had recently participated in or were concurrently involved in other clinical trials; (2) had a BMI ≥ 28 kg/m^2; (3) suffered from diabetes, severe hypertension, liver decompensation, significantly impaired kidney function (CrCl < 30 mL/min), tumors, cardiopulmonary insufficiency, or gastrointestinal absorption dysfunction; (3) wore a pacemaker, stent, contraceptive ring, or steel nail; (4) had severe lactose intolerance or consumed cheese more than 3 times a week; (5) regularly took vitamin D, calcium tablets, protein powder, fish oil, or other nutritional supplementations; (6) engaged in more than 150 min of moderate-intensity aerobic activity or 75 min of vigorous-intensity aerobic activity per week; (7) were unwilling to adhere to prescribed diets or disagreed with maintaining their activity levels.

Study design

This study was a 90-day, single-site, RCT conducted in the Suzhou Industrial Park community, Jiangsu, China. During enrollment period, face-to-face interview and

Table 1 Study assessment procedures and timetable

Day	Enrollment	Intervention period		
	Day_{-120}-Day_{-0}	Baseline	Day_{60}	Day_{90}
Calf circumference	√	√	√	√
SARC-CalF	√			
24-hour dietary recall	√	√	√	√
IPAQ	√	√	√	√
Handgrip strength	√	√	√	√
SPPB	√	√	√	√
Muscle mass		√	√	√
Blood sample		√		√

SPPB: Short Physical Performance Battery;

Table 2 Nutrient composition (daily intake) of intervention cheese

	Original cheese(66.4 g)	Golden cheese(67.4 g)
Energy (Kcal)	223.4	218.9
Fat (g)	18.2	17.3
Carbohydrate (g)	6.3	3.5
Sodium (mg)	721.2	591.8
Calcium (mg)	322.8	802.1
Protein (g)	9.0	12.7
Essential Amino Acids (g)		
Isoleucine	0.47	0.63
Leucine	0.77	1.07
Valine	0.55	0.75
Lysine	0.44	0.71
Methionine	0.22	0.30
Phenylalanine	0.42	0.57
Threonine	0.41	0.54
Tryptophan	0.20	0.24
Non-Essential Amino Acids (g)		
Histidine	0.22	0.30
Alanine	0.29	0.39
Arginine	0.23	0.34
Aspartic acid	0.68	0.92
Cysteine/Cystine	0.06	0.09
Glutamic acid	1.85	2.52
Glycine	0.21	0.26
Proline	0.96	1.26
Serine	0.33	0.51
Tyrosine	0.44	0.60

anthropometric measurements were conducted. Then, participants were randomly assigned to one of three groups: the control group (CG), the original cheese group (OG), and the golden cheese group (GG). The randomization sequence was generated using computer software. The intervention period spanned 90 days, during which measurements were conducted at baseline, midway (60 days), and the end of the trial (Table 1).

All subjects received individual instructions from a dietitian to maintain their habitual diet and refrain from making any major lifestyle changes, especially in terms of exercise. Participants in the OG were instructed to consume 4 slices (66.4 g) of original cheese (Shanghai Milkground Food Tech Co., Ltd, China), containing 9.0 g of protein per 66.4 g. Meanwhile, participants in the GG were directed to consume 4 slices (67.4 g) of golden cheese (Shanghai Milkground Food Tech Co., Ltd, China), which contained 12.7 g of protein per 67.4 g. Cheese was selected because of its convenience, appeal (better tolerated than milk), affordability and acceptability among elderly adults. The chosen amounts of cheese were determined based on assessments for improvements of muscle strength from previous studies [15, 19] and selected to be within a range that participants could feasibly consume. The key nutrients of the intervention cheeses were presented in Table 2. The processing methods for golden cheese and original cheese are the same, but the ingredients and their proportions differe. Specifically, golden cheese contains 60% cheddar cheese, compared to 51% in original cheese, and includes additional calcium-containing phosphates. Thus, in comparison to the original cheese, golden cheese provided higher protein and calcium, and lower carbohydrate and sodium.

All participants in the intervention groups received brochures containing cheese recipes and were instructed to ingest 2 slices of intervention cheese at both breakfast and dinner. To enhance compliance, the required cheese and a record sheet (to track cheese intake) were provided every two weeks. Adherence to consumption of at least 80% of the product was considered acceptable. Additionally, participants were instructed to store the cheese in the freezer throughout the trial. Participants in the control group were given an additional requirement to avoid the two intervention cheeses, as well as similar cheeses.

Human ethics and consent to participate declarations

All participants provided their informed consent to participate in the study, which received approval from the Ethics Committee of Soochow University (Approval Code: SUDA20221005H01) and adhered to the ethical standards outlined in the Declaration of Helsinki. The present study was registered in the Chinese Clinical Trial Registry with the registration number ChiCTR2300078720.

Outcome measures

Trained investigators conducted measurements of anthropometric variables following a standardized protocol. The principal investigator and staff involved in the recruitment and follow-up of participants were "blinded".

Primary outcome

The primary outcome of this study was the change in muscle mass at 60 days and 90 days. (A) Skeletal Muscle Mass Index (SMI): each participant, wearing light

clothing and devoid of metal objects, underwent body composition assessment during early morning fasting. Muscle mass was measured using the inBody 770 (Biospace Co., Ltd., Seoul, Korea). SMI was determined on the basis of the Bioelectrical Impedance Analysis (BIA). SMI=appendicular skeletal muscle mass (kg) / height^2 (m^2). (B) Calf Circumference: patients were instructed to assume a standing position, and the maximum diameter of the right calf was measured using a measuring tape.

Secondary outcome

The secondary outcomes were changes of muscle strength, muscle function, and biomakers for sarcopenia.

A) Maximum handgrip strength.

Measurements were conducted following the manufacturer's recommendations, utilizing an electronic handgrip dynamometer (Aopi Sporting Goods Co., Ltd., USA).

B) Physical performance.

Participants' physical performance was evaluated using the short physical performance battery (SPPB), which consisted of 3 components: (1) a 6-meter usual pace walk. Participants performed the walk component twice, and the average gait speed was calculated. (2) a five-repetition chair stand without using one's arms, assessing leg-power impairment. Volunteers were instructed to rise from a chair and return to a seated position five times as quickly as possible. Time was measured using a stopwatch with precision to the nearest 0.01 s, and the average of two trials was subsequently calculated. (3) a progressive Test of Standing Balance. Tests of standing balance included tandem, semi-tandem, and side-by-side stands. Categories of all physical performance components were established for each set of measures following the procedures published by Guralnik et al [20].

C) Biomakers for sarcopenia.

Venous blood samples were obtained at both baseline and the end of the study period. Collection was performed using a 5 mL serum separator tube, and serum was isolated through centrifugation. Insulin-like growth factor 1 (IGF-1) was quantified by Liquid Chromatography Tandem Mass Spectrometry (Waters Xevo TQ-S, Waters Corporation, Ltd., Framingham, USA). C-reactive protein (CRP) and Cystatin C were determined through immune transmission turbidity (Beckman AU5800 Automatic Analyzer, Beckman, Ltd., Fullerton, USA). Interleukin 6 (IL-6) levels were measured using chemiluminescence immunoassay (Hunan Kangqing biological technology Co., Ltd., Liuyang, China). The content of free L-carnitine and acylcarnitine in human serum was assessed by enzyme-linked immunoassay (Shanghai Yansheng Industrial Co., Ltd., Shanghai, China). Procedures and tests were conducted by the same group of nurses and research technicians to minimize methodological variations and ensure consistency across both individual subjects and the entire study cohort.

Blood pressure and biochemical variables

The participants were asked to sit quietly for at least 15 min, and blood pressure (BP) was measured on the right arm three times at 5 min intervals using an automatic BP monitor (Shenzhen Jiakang Technology Co., Ltd., Shenzhen, China). Triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), fasting blood glucose (FBG), and creatinine levels were determined using the Hitachi Automatic Analyzer 3100 (Hitachi, Ltd., Tokyo, Japan).

Dietetic, physical activity and comorbidities' data

Dietary intake was assessed using two-day (one weekday and one weekend day) 24-hour dietary recalls. Experienced dietitians administered the recalls through face-to-face interviews, utilizing valid forms. The macronutrient and mineral (calcium and sodium) content of the diet at baseline, midway (60 days), and the end of the trial were calculated based on the China Food Composition Table (2019) to establish a measure of dietary control, ensuring that habitual nutritional intake did not significantly impact the study findings. To account for any variations in physical activity during the entire trial, a physical activity metabolic equivalent of task (MET) was determined using the International Physical Activity Questionnaire Short Form (IPAQ-SF) at three points (0, 60, 90 days).

Statistical analysis

The sample size of 22 subjects in each group was determined through power analysis, targeting 80% power at a 5% significance level, based on SMI as the desired effect size. Baseline continuous variables were summarized using mean (standard deviation) or median (interquartile range), while categorical parameters were expressed as numbers and proportions. Group differences in participant characteristics were assessed using either one-way ANOVA or the Kruskal–Wallis test.

A general linear model was employed to compare differences in markers of muscle and sarcopenia, serum biomarkers, blood lipid, and glucose among the three groups, adjusting for age, BMI, drinking habits, physical activity, and current main nutrient intake (protein and calcium). Furthermore, between-group comparisons were conducted using either LSD or the Mann-Whitney U test. A general linear model-repeated measures

approach was developed to assess differences in self-comparison before and after the intervention, with additional adjustments made for changes in calcium and protein intake, as well as physical activities.

Statistical significance was set at a two-tailed *P*-value < 0.05. All statistical analyses were performed using SPSS version 26.0 (IBM SPSS, USA).

Result

Recruitment and study population

Initially, 150 potential patients were screened for enrollment, but only 81 met the inclusion and exclusion criteria and were subsequently randomized. The participant flow diagram was presented in Fig. 1. Thirteen participants withdrew from the study for personal reasons, refusal to continue participation, or hospitalization.

Consequently, a total of sixty-eight subjects completed the full 90-day intervention period (CG: 21 subjects; OG: 25 subjects; GG: 22 subjects), and only sixty-four consented to provide blood samples (CG: 21 subjects; OG: 23 subjects; GG: 20 subjects). In the analysis, we used the data from 68 participants (sample set 1) to examine relative changes in markers of sarcopenia and diet. For the analysis of changes in serum biomarkers, as well as indicators for blood lipid and glucose, we utilized data from 64 participants (sample set 2).

Baseline characteristics

The mean age of participants was 71.57 ± 5.08 years. 50% of participants were illiterate, 45.6% had completed primary school education, and only 4.4% had completed middle/high school education. Table 3 presented the baseline characteristics and demographics of participants. No statistically significant differences were observed in demographic and anthropometric variables, as well as makers for sarcopenia among three groups ($P > 0.05$).

On the basis of daily completed cheese diaries, compliance in 2 intervention groups was considered good (> 95%) with regard to adherence to assigned cheese. There were no significant differences in compliance between the 2 intervention groups in amount of test cheese consumed (OG: 97.6% ± 4.4%; GG: 97.2% ± 5.1%).

The daily nutrient intake for the study population was calculated based on the 24-hour recall data, as summarized in Supplementary Table 1. The mean of protein intake increased from 0.82 g/kg·bw to 1.01 g/kg·bw for the OG and from 0.84 g/kg·bw to 1.10 g/kg·bw for the GG after intervention. Total energy, protein, fat, carbohydrate, and calcium intake did not differ at baseline and the end, while participants in the OG and GG had a higher carbohydrate and energy intake in the 60-day survey. Participants of three groups had a significant decrease in physical activity (Supplementary Table 2).

Muscle strength, muscle function, and muscle mass

The changes of muscle strength, function, and mass from baseline and between three groups were showed in Table 4. The handgrip strength of the GG exhibited a significant increase from 11.52 ± 3.52 kg at baseline to 13.65 ± 3.13 kg at the end of the trial, with a noticeable but non-significant increase to 13.34 ± 4.10 kg at midway

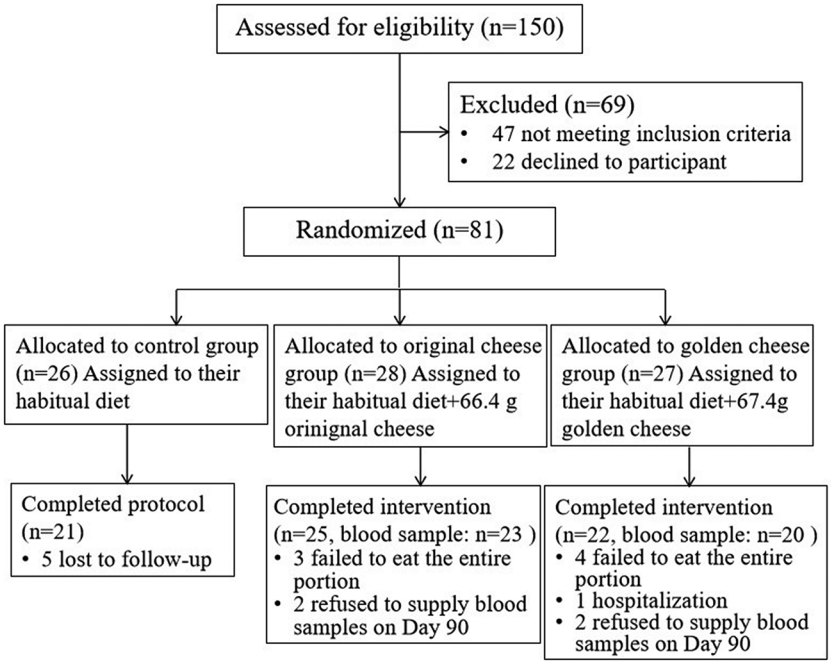

Fig. 1 Study flowchart

Table 3 Baseline characteristics and demographics of each study group (*N* = 68)

	CG(*N* = 21)	OG(*N* = 25)	GG(*N* = 22)	*P*
Ages, years	75 (70, 77)	71 (67, 73)	73 (67, 76)	0.140
Marital status, n (%)				0.389
Married	14 (66.7)	21 (84)	17 (77.3)	
Divorced or widowed	7 (33.3)	4 (16)	5 (22.7)	
Education, n (%)				0.890
Illiteracy	11 (52.4)	13 (52.0)	10 (45.5)	
Primary school	9 (42.9)	11 (44.0)	21 (50.0)	
Middle/high school	1 (4.8)	1 (4.0)	1 (4.5)	
BMI, kg/m^2	23.45 ± 2.41	22.07 ± 2.54	22.77 ± 2.81	0.157
Waist circumference, cm	82.67 ± 8.63	77.72 ± 6.03	79.36 ± 6.56	0.196
Hip circumference, cm	96.90 ± 5.74	93.44 ± 6.12	93.64 ± 5.15	0.097
SBP, mmHg	129 (117, 146)	129 (126,138)	132 (121, 142)	0.978
DBP, mmHg	73 (79, 88)	80 (71, 86)	79 (76, 85)	0.928
MET	1386 (693, 5799)	940 (222, 2646)	1386 (587, 3467)	0.734
Handgrip strength, kg	12.40 (8.25, 14.55)	13.70 (8.70, 15.75)	12.60 (7.63, 14.20)	0.715
Gait speed, m/s	0.96 ± 0.22	1.05 ± 0.22	1.01 ± 0.24	0.452
Chair stand test, s	15.00 ± 2.61	13.38 ± 3.23	14.6 ± 2.98	0.140
Balance, score	3.76 ± 0.63	3.80 ± 0.50	3.68 ± 0.57	0.568
SPPB, score	8.24 ± 1.84	9.28 ± 1.79	8.64 ± 1.94	0.245
SMI, kg/m^2	5.60 ± 0.57	5.38 ± 0.52	5.50 ± 0.44	0.245
Calf circumference, cm	31.00 ± 1.58	30.56 ± 1.45	30.50 ± 1.54	0.400
IGF-1, ng/mL	83.71 (70.39, 120.51)	99.05 (72.29, 126.94)	87.56 (73.80,119.52)	0.779
Free L-carnitine, μmol/L	247.84 ± 28.50	243.95 ± 22.27	251.71 ± 28.68	0.669
Total carnitine, μmol/L	332.39 ± 30.58	327.59 ± 24.01	336.29 ± 32.55	0.664
hs-CRP, mg/L	1.20 (0.60, 2.60)	0.80 (0.40, 2.10)	0.90 (0.48, 1.55)	0.580
IL-6, PG/mL	2.10 ± 0.87	2.71 ± 3.78	2.36 ± 1.45	0.281
Creatinine/Cystatin C	64.66 (56.17, 77.74)	59.25 (50.27, 67.89)	61.48 (45.96, 67.75)	0.364

BMI: Body Mass Index; SBP: Systolic blood pressure; DBP: diastolic blood pressure; MET: SPPB: Short Physical Performance Battery; SMI: Skeletal Muscle Mass Index; Metabolic equivalent; IGF-1: Insulin-like growth factor 1; hs-CRP: high-sensitivity C reactive protein; IL-6: interleukin 6;

(Supplementary Table 3, Table 4) (P=0.063). Compared to CG, both of OG and GG had a significant increase of handgrip strength at midway, but only GG was observed a positive change at the end of trial (P=0.039). In the component of SPPB, positive changes in gait speed and negative changes in five-chair rise time were observed at both midway and end of trial in GG, while only at the end in OG. Relative changes of balance in GG significantly increased compared to CG at midway. There were no significant changes of muscle function between three groups during intervention period. Three groups had significant increases in SMI at midway, whereas, at the end of the trial, only original (change: 0.19±0.21 kg/m^2) and golden groups (change: 0.14±0.23 kg/m^2) had significantly increases.The relative changes of SMI were higher in GG and OG than CG at end of the trial, and GG was additionally found to have a higher change than CG at midway. The change in calf circumference was significant in control group at midway, whereas at the end of trial, positive and significant changes were observed in golden cheese group (Table 4). The calf circumference did not differ between three groups (P>0.05).

Biomakers for sarcopenia

Over the course of the study, the OG demonstrated a positive change in free L-carnitine (18.12±33.05 μmol/L) and total carnitine (15.59±34.83 μmol/L)(P<0.05). A significant increase in relative changes of free and total carnitine was observed in OG compared to CG. Creatinine/Cystatin C significantly increased in both the OG and GG (Table 5). However, no significant changes were observed for IGF-1, hs-CRP, and IL-6.

Possible adverse effects

At the end of the intervention, there was a significant decrease in HDL-C in the control group. In contrast, the consumption of original cheese influenced the level of LDL-C, resulting in a decrease of 0.27±0.97 mmol/L (Table 6). Furthermore, there were no significant changes in any markers for the two intervention groups when compared to the control group (P>0.05).

Discussion

The present 90 days, randomized, open-label, 3-parallel-group trial study demonstrated that the addition of nutrient-rich dairy proteins, particularly 67.4 g of golden cheese over the course of 90 days, resulted in enhancements in handgrip strength and SMI. Additionally, both intervention groups exhibited a significant increase in Creatinine/Cystatin C. Positive and significant changes were also found in free L-carnitine and total carnitine in the original cheese group.

The amelioration of skeletal muscle loss and decline in muscle strength observed in the intervention groups in this study may be attributed to the protein content added to the participants' habitual diets. Currently, there is widespread recognition that dietary protein supplementation promotes muscle protein synthesis and overall skeletal muscle increase [21]. In line with our findings, a RCT conducted by Helidoro et al. demonstrated that the addition of 210 g of ricotta cheese improved markers of

Table 4 Changes in makers of sarcopenia at baseline, 60 days and 90 days of follow-up (Self-comparison, $N=68$)

	CG		OG		GG		*P*	
	Change from baseline	***P***	**Change from baseline**	***P***	**Change from baseline**	***P***	**CG vs OG**	**CG vs GG**
				2 months				
Muscle strength								
Handgrip strength, kg	-0.61 ± 3.78	0.523	1.17 ± 4.89	0.250	1.82 ± 4.16	0.063	**0.050**	**0.043**
Muscle function								
Gait speed, m/s	0.14 ± 0.25	**0.035**	0.09 ± 0.28	0.127	0.13 ± 0.26	**0.007**	0.452	0.695
Chair stand test, s	-3.42 ± 2.45	**< 0.001**	-1.42 ± 2.83	0.054	-2.68 ± 3.43	**0.002**	0.090	0.192
Balance, score	-0.44 ± 0.70	**0.013**	0.00 ± 1.48	0.885	0.05 ± 0.84	0.812	0.311	0.112
SPPB, score	0.00 ± 1.85	1.000	0.05 ± 0.84	0.812	0.18 ± 2.32	0.627	0.247	0.478
Muscle mass								
SMI, kg/m^2	0.29 ± 0.36	**0.005**	0.23 ± 0.17	**< 0.001**	0.19 ± 0.20	**< 0.001**	0.508	0.514
Calf circumference, cm	1.11 ± 1.70	**0.015**	0.29 ± 2.77	0.724	0.41 ± 1.50	0.183	0.170	0.466
				End				
Muscle strength								
Handgrip strength, kg	0.12 ± 3.89	0.889	0.12 ± 3.89	0.889	2.13 ± 3.83	**0.021**	0.118	**0.039**
Muscle function								
Gait speed, m/s	0.08 ± 0.17	0.050	0.09 ± 0.19	**0.032**	0.09 ± 0.19	**0.032**	0.878	0.664
Chair stand test, s	-1.03 ± 2.94	0.116	-1.03 ± 2.94	0.116	-2.16 ± 3.81	**0.015**	0.894	0.769
Balance, score	-0.33 ± 0.58	**0.020**	-0.28 ± 0.61	**0.043**	0.32 ± 0.72	0.059	0.844	0.520
SPPB, score	-0.57 ± 1.29	0.065	-0.48 ± 1.66	0.191	-0.48 ± 1.66	0.191	0.700	0.414
Muscle mass								
SMI, kg/m^2	0.09 ± 0.02	0.083	0.18 ± 0.02	0.083	0.14 ± 0.02	0.083	**0.024**	**0.006**
Calf circumference, cm	0.57 ± 1.29	0.067	0.57 ± 1.29	0.067	1.27 ± 1.75	**0.004**	0.574	0.386

CG: control group; OG: original cheese group; GG: golden cheese group. SPPB: Short Physical Performance Battery; SMI: Skeletal Muscle Mass Index. Between-group comparisons were conducted based on the value of relative change

Table 5 Changes in serum biomakers at baseline and 90 days of follow-up (*N* = 64)

	Change from baseline	*P*	Difference from control (95% CI)	*P*
IGF-1, ng/mL				
CG	2.09 ± 34.77	0.788		
OG	-6.20 ± 29.24	0.320	-8.29 (-26.92, 10.35)	0.377
GG	-2.44 ± 28.23	0.725	-4.53 (-23.82, 14.75)	0.640
Free L-carnitine, μmol/L				
CG	-12.9 ± 44.16	0.179		
OG	18.12 ± 33.05	**0.018**	31.02 (8.11, 53.94)	**0.009**
GG	-6.00 ± 36.07	0.515	6.90 (-17.14, 30.974)	0.568
Total carnitine, μmol/L				
CG	-12.20 ± 47.88	0.239		
OG	15.59 ± 34.83	**0.045**	27.80 (2.15, 53.44)	**0.034**
GG	-6.33 ± 44.54	0.574	5.87 (-21.03, 32.77)	0.664
hs-CRP, mg/L				
CG	-0.13 ± 0.87	0.530		
OG	0.34 ± 2.82	0.578	0.47 (-1.02, 1.96)	0.528
GG	1.26 ± 3.08	0.081	1.39 (-0.15, 2.93)	0.076
IL-6, PG/mL				
CG	-0.09 ± 0.84	0.610		
OG	-0.10 ± 2.14	0.827	-0.01 (-1.46, 1.44)	0.988
GG	0.61 ± 3.54	0.370	0.070 (-0.80, 2.20)	0.355
Creatinine/Cystatin C				
CG	3.04 ± 20.35	0.509		
OG	8.31 ± 14.69	**0.018**	5.26 (-4.67, 15.20)	0.293
GG	8.51 ± 12.7	**0.013**	5.46 (-4.70, 15.63)	0.287

IGF-1: Insulin-like growth factor 1; hs-CRP: high-sensitivity C reactive protein; IL-6: interleukin 6; CG: control group; OG: original cheese group; GG: golden cheese group

Table 6 Changes in some makers of adverse effects at baseline and 90 days of follow-up

	CG (*N* = 21)	OG (*N* = 23)	GG (*N* = 20)	*P*
TC, mmol/L				
Baseline	1.26 ± 0.67	1.40 ± 0.89	1.27 ± 0.84	0.405
End	1.62 ± 0.80	1.51 ± 1.03	1.26 ± 0.53	0.533
P	0.148	0.836	0.800	
TG, mmol/L				
Baseline	5.12 ± 0.86	5.40 ± 0.88	5.20 ± 0.96	0.669
End	4.74 ± 0.82	5.03 ± 0.69	5.12 ± 0.94	0.306
P	0.194	0.092	0.578	
HDL-C, mmol/L				
Baseline	1.74 ± 0.35	1.72 ± 0.39	1.74 ± 0.38	0.986
End	1.41 ± 0.38	1.55 ± 0.31	1.57 ± 0.40	0.236
P	**0.003**	0.248	0.113	
LDL-C, mmol/L				
Baseline	2.78 ± 0.68	3.03 ± 0.69	2.86 ± 0.83	0.567
End	2.53 ± 0.66	2.69 ± 0.61	2.78 ± 0.61	0.428
P	0.263	**0.049**	0.577	
FBG, mmol/L				
Baseline	5.21 ± 0.42	5.25 ± 0.71	5.12 ± 0.51	0.594
End	5.21 ± 0.66	5.08 ± 0.67	5.02 ± 0.61	0.417
P	0.959	0.518	0.362	
SBP, mmHg				
Baseline	135.14 ± 21.03	131.96 ± 12.92	132.59 ± 16.82	0.978
End	125.90 ± 24.98	129.60 ± 18.05	130.00 ± 15.54	0.409
P	0.031	0.588	0.461	
DBP, mmHg				
Baseline	80.62 ± 10.85	79.64 ± 8.84	83.64 ± 19.23	0.928
End	81.62 ± 16.93	81.44 ± 13.65	76.86 ± 10.20	0.865
P	0.770	0.541	0.226	

TG: Triglycerides; TC: total cholesterol; HDL-C: high-density lipoprotein cholesterol low density; LDL-C: lipoprotein cholesterol; FBG: fasting blood glucose; SBP: Systolic blood pressure; DBP: diastolic blood pressure; CG: control group; OG: original cheese group; GG: golden cheese group

sarcopenia in healthy older adults [15]. Another intervention study also noted that nutrient-rich dairy proteins induced greater protein synthesis and skeletal muscle gain in a healthy young population [22]. However, some clinical intervention studies using milk proteins failed to find an effect on muscle mass and function in individuals with polymyalgia rheumatica and sarcopenia [16, 23]. The literature suggested that the skeletal muscle's response to protein supplementation may be contingent upon the initial stage of muscle mass, which implied the impact of dairy protein intervention might differ based on the characteristics of the chosen population [17]. Therefore, we selected a population at high risk of sarcopenia, though not conclusively diagnosed, to conduct our intervention. This study presented new evidences supporting the consideration of such supplementation as a promising strategy for restoring muscle mass and strength in individuals with possible sarcopenia, thereby contributing to the promotion of healthy aging. In addition, our finding may indicate cheese intervention can be used as an adjunct to the clinical treatment of sarcopenia.

Although improvements in some markers of muscle function (such as gait speed and chair stand test) were observed in self-comparisons, no significant differences were found between three groups. This finding may be explained by the fact that dietary supplementation alone improved muscle mass but did not significantly enhance muscle function without concurrent physical training. Similar findings were reported by Bo et al., indicating that a high whey protein, vitamin D, and E supplement preserved muscle mass and strength but did not improve muscle function [24]. The relatively small sample size may also contribute to these results. Further studies with larger sample sizes, longer intervention periods, and more comprehensive interventions were needed to thoroughly evaluate the effectiveness of cheese in improving muscle function.

Dietary protein plays a crucial role in providing the necessary amino acids for synthesizing muscle protein [25]. Current protein consumption recommendations were based on the minimum protein mass required to maintain a neutral nitrogen balance [26]. Rand et al. conducted a review of 19 studies on nitrogen balance in adults, resulting in the current dietary protein recommendations of 0.66 g/kg/day and 0.80 g/kg/day as the estimated average requirement (EAR) and recommended dietary allowance (RDA), respectively [27]. However, recent discussions have arisen about the suitability of these recommendations for the elderly population. The Chinese Nutrition Society established the current DRIs for protein in 2023, which indicated the reference intake of protein for elders aged over 65 (male: 72 g/d; female:62 g/d). The Expert Consensus on the Diagnosis and Treatment of Sarcopenia in the Elderly in China (2021) suggested that individuals aged 60 years and above without sarcopenia should consume 1.0–1.2 g/kg of protein daily to prevent sarcopenia [28]. For those with a definite diagnosis of sarcopenia, it is recommended to consume 1.2–1.5 g/kg of protein daily. In this study, the habitual protein intakes at baseline in the three groups were 0.82 g/kg (CG), 0.82 g/kg (OG), and 0.84 g/kg (GG), respectively, which were above the recommended dietary allowance of 0.8 g/kg for adults but below the recommended range of 1.0–1.2 g/kg for individuals aged over 60. The inclusion of 4 slices of cheese in both the original cheese group (protein intake after intervention: 1.01±0.21 g/kg per day) and the golden cheese group (protein intake after intervention: 1.10±0.21 g/kg per day) seemed to be a suitable strategy for enhancing the prevention of muscle mass and function loss in individuals with possible sarcopenia. Moreover, the golden cheese group showed even greater improvements. These findings revealed the quantity of protein intake is crucial for muscle mass and strength, indicating higher doses resulted in better effects.

In addition to quantity, the quality of protein, as indicated by essential amino acid (IAA) content and protein digestibility, plays a crucial role in influencing changes in muscle protein synthesis and skeletal muscle mass [29]. A comprehensive review delved into the myoprotective benefits of various whole foods, including meat, fish, eggs, fruits, vegetables, and non-liquid dairy, for aging muscles and sarcopenia in adults aged 50 years and above [30]. While this study demonstrated the effectiveness of non-liquid dairy foods in promoting muscle health, evidence for the benefits of other whole foods was either limited or inconclusive. Prospective data from the Calcium Intake Fracture Outcome Study/CAIFOS Aged Extension Study (CAIFOS/CARES) cohort revealed that women in the third tertile of dairy consumption (including milk, yogurt, and cheese) exhibited significantly greater appendicular bone mass (7.1%) and skeletal muscle mass (3.3%) compared to those in the first tertile [31]. These studies highlighted the positive impact of dairy consumption on maintaining muscle health. Despite these evidence, dairy consumption in China remains relatively low at 24.7 g/d, particularly in the case of nutrient-rich cheese. Our findings provide additional support for the importance of promoting higher dairy consumption among the elderly population in China.

Calcium supplementation from the intervention cheese could be another contributing factor to the improvement of muscle mass observed in this study. While findings on the relationship between calcium and sarcopenia have been contradictory [32–34], the role of calcium in the prevention and treatment of sarcopenia appeared to be more promising in older adults with low calcium intake. Seo et al. found a positive association between calcium and muscle mass in older adults with low calcium intake (<415 mg/d) [32]. In this study, the mean habitual calcium intake of subjects at baseline was 326.97 mg per day, significantly below the recommended dietary value of 800 mg, which indicated the calcium deficiency. Several previous studies have demonstrated positive effects of vitamin D and calcium supplementation on the risk of falls and sarcopenia, especially in populations with calcium deficiency [35, 36]. The underlying mechanism could be attributed to improved calcium absorption and altered calcium homeostasis, which has been suggested to be linked with muscle weakness in aging muscles [37–39].

Creatinine, a breakdown product of creatine phosphate in muscles, was typically produced at a relatively constant rate by the body, depending on the absolute amount of muscle mass under steady-state conditions and stable kidney function [40, 41]. As serum creatinine's role as a biomarker of muscle mass may be influenced by other factors, Cystatin C was often used in combination with creatinine to correct for these effects [42–44]. The significant increases in Creatinine/Cystatin C in both the original and golden cheese groups in present study further indicated the efficacy of cheese intervention on muscle mass.

Sarcopenia has been suggested to link with diverse mechanisms, encompassing heightened production of inflammatory cytokines, deficiency in IGF-1, dysfunctions in mitochondrial metabolic pathways, and irregular metabolism [1]. Our study revealed a significant increase in serum free and total carnitine content in the original cheese intervention group at the end of trial, suggesting that cheese may enhance muscle function by influencing muscle cell energy metabolism. However, no significant increases of carnitine were found in golden cheese group. The inconsistent results may be explained by the different fat content between two cheese, as original cheese

supplied more fatty acids. Carnitine, an amino acid derivative, played a crucial role in energy production within the mitochondria of skeletal and cardiac muscles, with 95% stored in these cells [45]. Free and acyl carnitine contribute to energy generation by oxidizing fatty acids and transporting them into mitochondria [46]. A previous RCT had demonstrated that carnitine supplementation significantly improved walking pace and distance in patients with claudication [47].

Our present study possessed both strengths and limitations that warrant acknowledgment. We investigated the impact of cheese consumption on markers of sarcopenia in Chinese elders, marking the first dairy proteins intervention in possible sarcopenia, to the best of our knowledge. However, our study had some limitations: (1) At the end of the trial, there was a significant decrease in the daily metabolic equivalent of subjects in all three groups with the rising temperatures, potentially influencing muscle function and mass. Consequently, the effect of the cheese intervention might be underestimated; (2) The study employed habitual diets instead of standardized meals. To address this, changes in protein and energy intake were included as covariates in the model for adjusting the dietary impact. (3) We calculated the sample size based on SMI. Apart from SMI, there were no significant relative changes in other variables between groups, although a clear tendency was evident. (4) Other pivotal factors that likely influenced results included sample size, resistance training, VD supplementation, intervention periods, and the amounts administered.

Conclusion

Overall, consuming 4 slices of cheese (both original and golden cheese) within the context of participants' habitual diets was effective for improving muscle strength and mass in 60-80-year-old women with possible sarcopenia. The significant increase of carnitine with the consumption of original cheese suggested the effect of this dairy product on muscle cell energy metabolism. Therefore, obtaining these nutrients through the consumption of cheese could have a potential role in improving the state of muscle health.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12986-024-00838-4.

Supplementary Material 1

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Author contributions

We thank all participants for their participation and kind assistance. Yingyao Wang and Liqiang Qin contributed to the conception and study design; Jingsi Chen, Yan Wang, Yilin Chen, Jing Yang, and Xiaofang Chen contributed to the acquisition of data; Jingsi Chen performed data analysis; Yifan Yang, Chenxi Su, and Mingquan Wang contributed to the interpretation of data; Jingsi Chen, Yingyao Wang and Liqiang Qin contributed to manuscript writing, and critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data availability

Data of this study has been deposited in http://www.medresman.org.cn/uc/projectsh/projectedit.aspx? proj=5540.

Declarations

Competing interests

The authors Yifan Yang, Chenxi Su and Mingquan Wang are affiliated with Shanghai Milkground Food Tech Co., Ltd. This study received funding from Shanghai Milkground Food Tech Co., Ltd. The funder had the following involvement with the study: conceptualization, investigation, methodology, and writing—review and editing. The authors Jingsi Chen, Yan Wang, Yilin Chen, Jing Yang, Xiaofang Chen, Yingyao Wang, Liqiang Qin state that they have no potential conflicts of interest.

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