UNIVERSIDADE FEDERAL DO ESTADO DO RIO DE JANEIRO - UNIRIO

CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE - CCBS

PROGRAMA DE PÓS-GRADUAÇÃO EM ALIMENTOS E NUTRIÇÃO - PPGAN

EDILAINE SILVA LEMOS COSTA

OBTENÇÃO DE ANÁLOGO DE ARROZ FORTIFICADO EM VITAMINA D E MAGNÉSIO DESTINADO À POPULAÇÃO 60+

Rio de Janeiro

2025

EDILAINE SILVA LEMOS COSTA

OBTENÇÃO DE ANÁLOGO DE ARROZ FORTIFICADO EM VITAMINA D E MAGNÉSIO DESTINADO À POPULAÇÃO 60+

Dissertação de mestrado apresentada ao Programa de Pós-graduação em Alimentos e Nutrição da Universidade Federal do Estado do Rio de Janeiro, como requisito parcial para obtenção do título de Mestre em Alimentos e Nutrição.

Orientadora: Dra. Cristina Yoshie Takeiti

Coorientador: Dr. Carlos Wanderlei Piler de Carvalho

Rio de Janeiro

2025

FICHA CATALOGRÁFICA

Catalogação informatizada pelo(a) autor(a)

C837 Costa, Edilaine Silva Lemos
OBTENÇÃO DE ANÁLOGO DE ARROZ FORTIFICADO EM VITAMINA D E MAGNÉSIO DESTINADO À POPULAÇÃO 60+ / Edilaine Silva Lemos Costa. -- Rio de Janeiro : UNIRIO, 2025.
93

Orientador: Cristina Yoshie Takeiti.
Coorientador: Carlos Wanderlei Piler de Carvalho.
Dissertação (Mestrado) - Universidade Federal do Estado do Rio de Janeiro, Programa de Pós-Graduação em Alimentos e Nutrição, 2025.

1. análogo de arroz. 2. extrusão termoplástica. 3. pastificação. I. Takeiti, Cristina Yoshie, orient. II. Piler de Carvalho, Carlos Wanderlei , coorient. III. Título.

Edilaine Silva Lemos Costa

Obtenção de análogo arroz fortificado em vitamina D e magnésio destinado à população 60+

Dissertação de mestrado apresentada ao Programa de Pós-graduação em Alimentos e Nutrição da Universidade Federal do Estado do Rio de Janeiro, como requisito parcial para obtenção do título de Mestre em Alimentos e Nutrição.

Aprovada em: 28/04/2025

BANCA EXAMINADORA

Profª. Drª Cristina Yoshie Takeiti - Embrapa Agroindustria de Alimentos e Programa de Pós-Graduação em Alimentos e Nutrição PPGAN - Universidade Federal do Estado do Rio de Janeiro (UNIRIO)
Presidente

Profª: Drª Maria Teresa Pedrosa Silva Clerici - Programa de Pós-Graduação em Tecnologia de Alimentos - Universidade Estadual de Campinas (UNICAMP)
Membro externo ao PPGAN

Profª. Drª Francine Albernaz Teixeira Fonseca Lobo - Programa de Pós-Graduação em Alimentos e Nutrição PPGAN - Universidade Federal do Estado do Rio de Janeiro (UNIRIO)
Membro interno ao PPGAN

Defesa Nº 100

ATA DE DEFESA DE DISSERTAÇÃO DE MESTRADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ALIMENTOS E NUTRIÇÃO PARA CONCESSÃO DO GRAU DE MESTRE EM ALIMENTOS E NUTRIÇÃO

DATA DA DEFESA: 28 de abril de 2025
CANDIDATO:EDILAINE SILVA LEMOS COSTA
ORIENTADORA: Profa. Dra. Cristina Yoshie Takeiti

BANCA EXAMINADORA:
Profa. Dra. Cristina Yoshie Takeiti (PPGAN)- PPGAN/Embrapa
Profa. Dra. Francine Albernaz Teixeira Fonseca Lobo (PPGAN)
Profa. Dra. Maria Teresa Pedrosa Silva Clerici (UNICAMP)

TÍTULO DA DISSERTAÇÃO: OBTENÇÃO DE ANÁLOGO ARROZ FORTIFICADO EM VITAMINA D E MAGNÉSIO DESTINADO À POPULAÇÃO 60

LOCAL: videoconferência disponível no link (https://meet.google.com/aus-xfmi-iwv).

HORA DE INÍCIO: 14h

Em sessão pública, após exposição de cerca de 35 minutos, a candidata foi arguida oralmente pelos membros da banca tendo como resultado:
(x) APROVADO(A)
( ) NÃO APROVADO(A)

Em acordo com o capítulo VIII, artigo 62 do Regulamento do PPGAN, o candidato no prazo máximo de 30 (trinta) dias para Dissertações/Tese aprovadas deve entregar as cópias exigidas pelo Regulamento do PPGAN da versão final à secretaria como condição final para a expedição do diploma.
Esta ata vai assinada digitalmente por todos os participantes

Rio de Janeiro, 28 de abril de 2025

gov.br Documento assinado digitalmente
CRISTINA YOSHIE TAKEITI
Data: 30/04/2025 15:43:06-0300
Verifique em https://validar.iti.gov.br

gov.br Documento assinado digitalmente
FRANCINE ALBERNAZ TEIXEIRA FONSECA LOBO
Data: 01/05/2025 07:50:33-0300
Verifique em https://validar.iti.gov.br

gov.br Documento assinado digitalmente
MARIA TERESA PEDROSA SILVA CLERICI
Data: 04/05/2025 19:22:00-0300
Verifique em https://validar.iti.gov.br

AGRADECIMENTOS

À Deus, pela oportunidade de fazer esse mestrado e por todos os dias ter sido minha paz, minha coragem, minha força e minha motivação.

A Alexandre e Lívia, minha gratidão por estarem sempre presentes, me apoiando e me ajudando com carinho e dedicação.

Ao meu pai, minha mãe (in memoriam) e minhas irmãs, por terem me ensinado a ser resiliente e corajosa.

À minha orientadora Cristina, pelo apoio e disponibilidade, pelo ensinamento, pela compreensão e paciência em minhas dificuldades.

Ao meu coorientador Carlos, por me orientar sempre que precisei.

Aos colegas da Embrapa Jhony, Monique, Thuane, Adriana, Maria Eugenia por me ajudarem sempre que precisei.

A todos os funcionários da Embrapa que de alguma forma contribuíram para esse projeto em especial a Mariana, Adriana, Silmara, Neuri, Sidney Pacheco.

Agradeço a todas as minhas amigas por todo o carinho e palavras de motivação.

À Empresa Brasileira de Pesquisa Agropecuária (Embrapa) por me permitir ter acesso à toda estrutura física, laboratórios e pessoal qualificado durante esses anos.

Ao Programa de Pós-Graduação em Alimentos e Nutrição (PPGAN) da Universidade Federal do Estado do Rio de Janeiro (UNIRIO) pela oportunidade e à Fundação de Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pelo auxílio concedido sob forma de bolsa de mestrado.

RESUMO GERAL

O envelhecimento populacional é um fenômeno global em rápida expansão, especialmente na América Latina. Até 2050, espera-se que haja 2,1 bilhões de pessoas com 60 anos ou mais no mundo. O processo de envelhecimento traz mudanças fisiológicas e condições que afetam a autonomia, como a sarcopenia e a disfagia, aumentando os riscos de desnutrição e de doenças associadas. A Assembleia Geral da Organização das Nações Unidas (ONU) declarou 2021-2030 como a década do envelhecimento saudável, que tem o objetivo de unir esforços de governos, sociedade e pesquisadores na criação de estratégias que promovam qualidade de vida para essa população. No Brasil, o envelhecimento da população abrirá novas oportunidades de negócios, tornando os idosos o principal grupo de consumidores até 2046, quando atingirá 28 % da população total (IBGE). Produtos voltados para idosos devem atender às necessidades nutricionais dessa fase, como a vitamina D e o magnésio, que auxiliam no metabolismo ósseo e muscular. O análogo de arroz é um substituto ao arroz com formato e desempenho semelhantes, produzido a partir de diferentes ingredientes, quando fortificado pode contribuir para as necessidades nutricionais dos idosos. O objetivo desse estudo foi (i) obter um análogo de arroz enriquecido com vitamina D e magnésio usando o processo de extrusão termoplástica e pastificação a partir de 9 formulações com diferentes ingredientes, como farinha de arroz crua (RF), farinha de feijão-caupi (*Vigna unguiculata*) crua (BF), emulsificante (estearoil lactato de cálcio, CSL) e mix de vitaminas e minerais, e (ii) avaliar as propriedades físico-químicas e a qualidade nutricional dos análogos de arroz obtidos. Os resultados mostraram que os processos e as formulações utilizados foram capazes de produzir dois protótipos finais que podem ser classificados como "*rico em vitamina D e magnésio*" (4,53 - 8,52 µ/100 g de vitamina D e 278 - 286 mg/100g de magnésio), com tempo de cozimento reduzido (35 - 53% menores que arroz branco polido) e sob a denominação de "*grão longo"* (7,86 - 7,91 mm de comprimento e 2,73 - 2,75 mm de largura). A composição centesimal (7,65 - 8,03% de proteínas; 0,68 - 0,79% de lipídios; 0,81 - 1,20% de fibras alimentares), o teor de amido resistente (0,47 – 0,89%), o teor de amilose (21,78 – 23,76%), o índice de brancura (88,29 - 89,86), o perfil de textura (8,72-9,51 N de dureza), as características térmicas (83,21 – 87,81 ºC de temperatura de conclusão de cozimento) e as propriedades de pasta (59,83 – 62,50 ºC de temperatura de pasta, Tp e 454,66 – 512,33 cP de pico de viscosidade, PV) são comparáveis ao arroz branco polido, que é um alimento tradicional e diariamente consumido. Os resultados deste estudo podem ser úteis para a produção de novos produtos fortificados com vitamina D e magnésio destinados à população sênior, ampliando a oferta de produtos sólidos, nutritivos e com tempo reduzido de preparo.

Palavras-chave: análogo de arroz, extrusão termoplástica, pastificação, sarcopenia, disfagia

ABSTRACT

Population aging is a rapidly expanding global phenomenon, especially in Latin America. By 2050, it is expected to reach 2.1 billion people aged 60 or over in the world. The aging process brings physiological changes and conditions that affect autonomy, such as sarcopenia and dysphagia that increase the risks of deficiencies and disease-related malnutrition. The United Nations General Assembly declared 2021-2030 as the decade of healthy aging, which aims to unite the efforts of governments, society and researchers in the creation of strategies that promote quality of life for this population. In Brazil, the population aging will drive towards to new business opportunities, since the elderly is the main consumer group by 2046, reaching 28 % of the total population (IBGE). Products aimed to the older people must deliver the nutritional requirements in terms of vitamin D and magnesium, which are adjuvants in bone and muscle metabolism. Rice analogue is a rice substitute with similar shape and performance, produced from different ingredients, when fortified it can contribute to the nutritional needs of the elderly. This study aimed to (i) obtain a rice analogue enriched with vitamin D and magnesium using the thermoplastic extrusion and pastification process from 9 formulations containing different ingredients, such as raw rice flour (RF), raw cowpea (*Vigna unguiculata*) flour (BF), emulsifier (calcium stearoyl lactate, CSL) and vitamin and mineral mix, (ii) evaluate the physicochemical properties and nutritional quality. The results showed that process type and formulations used were able to produce two final prototypes that can classified as "enrich in vitamin D and magnesium" (4.53 - 8.52 µ/100g of vitamin D and 278 - 286 mg/100g of magnesium), with reduced cooking time (35 - 53% reduction in relation to polished white rice) and "long grain" designation (7.86 - 7.91 mm in lenght and 2.73 - 2.75 mm in widht). The proximate composition (7,65 - 8,03% proteins; 0,68 - 0,79 % lipids; 0,81 - 1,20% dietary fiber), resistant starch (0.47 – 0,89%), amylose (21.78 – 23.76%), whiteness index (88.29 -89.86), texture profile (8.72 – 9.51 N hardness), thermal properties (83.21 - 87.81 ºC conclusion temperature, Tc) and pasting properties (59.83 – 62.50 ºC of pasta temperature, PT and 454.66 – 512.33 of peak viscosity, PV) were comparable to polished white rice that is a Brazilian daily consumed traditional food. The results of this study may be useful to produce new products fortified with vitamin D and magnesium for the senior population, expanding the supply of nutritious solid foods with reduced preparation time appeal.

Keywords: analoge rice, thermoplastic extrusion, pastification, sarcopenia, dysphagia

List of Figures

List of Tables

Chapter I

Chapter II

List of abbreviations and acronyms

AACC	American Associates of Cereal Chemist
ANOVA	Analysis of variance
BF	Bean flour
CP	Centipoise
DRV	Daily reference value
DSC	Differential Scanning Calorimetry
DASH	Dietary Approach to Stop Hypertension
EERF	Extruded flour with emulsifier
ERF	Extruded rice flour
ESPEN	European Society for Clinical Nutrition and Metabolism
IDDSI	International Dysphagia Diet Standardization Initiative
K-AMYL	Amylose Amylopectin Assay Kit Test
K-RSTAR	Resistant Starch Assay Kit
K-TSTA	Total Starch Assay Kit
MG	Magnesium
MIX	Vitamin mix
PCA	Principal Components Analysis
RF	Rice flour
RVA	Rapid Visco Analyzer
SARC-F	Strength, assistance with walking, rising from a chair, climbing stairs, and falls

SDGs	Sustainable Development Goals
TPA	Texture profile analysis
UPLC	Ultra Performance liquid chromatographic
VDR	Daily reference value
WHO	World Heath Organization
ΔH	Enthalpy

Sumário

Introdução geral, estratégia e objetivo

O envelhecimento da população é um fenômeno mundial com crescimento constante e, em 2022, o número de pessoas com 60 ou mais no mundo chegou a 1,2 bilhão de pessoas com projeção estimada de 2,1 bilhões para o ano 2050 (OMS, 2025). No Brasil, o contingente de população idosa corresponde a 16,3 % da população total (aproximadamente 32,5 milhões de pessoas) e para o ano de 2050, a projeção é de 29,3 % (62,3 milhões de indivíduos) (IBGE, 2024).

A América Latina se destaca como líder na aceleração do envelhecimento global. Em 1950, os idosos correspondiam a 5,6 % da população, índice que subiu para 8,3 % na década de 2000 e que deverá atingir 25 % até 2050. Com isso, o número de pessoas acima de 60 anos superará a quantidade de indivíduos entre 0 e 19 anos, alcançando cerca de 190 milhões de idosos. Esses dados indicam que a região está vivenciando a maior transformação demográfica acelerada no cenário global (OPAS, 2023).

No Brasil segundo o Estatuto do Idoso (BRASIL, 2022), considera-se idoso todo indivíduo com mais de 60 anos. O Estatuto do Idoso (Lei nº 10.741/2003) regulamenta os direitos das pessoas com 60 anos ou mais, mas negligência aspectos importantes da nutrição para idosos. Embora o Estatuto declare que a alimentação adequada é um direito essencial, a abordagem é superficial e genérica, sem detalhar diretrizes específicas sobre nutrição na terceira idade. Por exemplo, não há um plano de ações de segurança alimentar e nutricional para a população idosa, considerando as particularidades dessa faixa etária.

Esse aumento contínuo da população idosa foi determinante para que a Assembleia Geral das Nações Unidas declarasse 2021-2030 como a década do envelhecimento saudável. Essa é uma ação para orientar e juntar esforços dos governos, da sociedade, e dos pesquisadores para juntos criar ações e estratégias com o objetivo de proporcionar uma sociedade melhor para todas as idades (OMS, 2020).

Esta sociedade envelhecida trará novas oportunidades de negócios e os idosos indubitavelmente se tornarão o principal grupo de consumidores do futuro. De acordo com estatísticas da Associação Americana de Pessoas Aposentadas (AARP), em 2020, o grupo de pessoas com 50 anos ou mais representou 50 % do consumo global, totalizando 35 trilhões de dólares. Até 2050, estima-se que esse número chegue a 96 trilhões de dólares, representando quase 60% do consumo global distribuídas em três categorias principais de consumo que incluem habitação, alimentação e transporte. Portanto, esse aumento impulsiona o desenvolvimento de novos produtos para atender as demandas nutricionais desse mercado crescente.

Esta dissertação de mestrado foi desenvolvida no Programa de Pós-Graduação em Alimentos e Nutrição (PPGAN-UNIRIO) dentro da linha de pesquisa "Alimentos funcionais". A parte experimental deste estudo foi realizada na Empresa Brasileira de Pesquisa Agropecuária (Embrapa Agroindústria de Alimentos) financiada pelo projeto do Sistema Embrapa de Gestão (SEG 20.20.03.051.00.00) intitulado "Desenvolvimento de alimentos para a manutenção da vitalidade e qualidade de vida de adultos a partir dos 60 anos". Esta pesquisa contempla dois dos 17 Objetivos de Desenvolvimento Sustentável (ODS) das Nações Unidas, a saber: (i) ODS 3. Saúde e bem-estar e (ii) ODS 12. Consumo e produção responsáveis.

Deste modo, o objetivo geral desse trabalho foi produzir análogos de arroz fortificado com vitamina D e com magnésio destinado a população 60+ utilizando como ferramentas tecnológicas a extrusão termoplástica seguida da pastificação, estudando-se variações das condições de contorno do processo como: (i) utilização de parafusos com diferentes configurações (para extrusão úmida e para extrusão seca), (ii) utilização de misturas contendo farinhas cruas e farinhas extrudadas, (iii) formulações com uso de emulsificantes e (iv) uso de farinha de feijão caupi cru e (v) ordem de adição do mix vitamínico.

A presente dissertação está dividida em dois capítulos, dos quais o primeiro capítulo consiste em um artigo de revisão bibliográfica que visa enfatizar alguns aspectos importantes do envelhecimento como a sarcopenia, a disfagia, a comensalidade, incluindo a relevância da nutrição para um envelhecimento saudável, uma visão sobre políticas públicas e estratégias para a sua promoção. O artigo é intitulado "Aging and health: challenges in nutrition and strategies for a healthy life" e foi submetido para publicação à revista "Appetite".

O segundo capítulo apresenta o artigo original de dados que será submetido para publicação à revista "ACS Food Science & Technology". O artigo é intitulado "Development of rice analogue with magnesium and vitamin D for population aged 60". Neste artigo, os análogos obtidos foram analisados quanto as propriedades físicas (RVA, DSC, MEV, textura instrumental, cor instrumental, dimensões dos análogos, teste de qualidade do cozimento), físico-químicas (composição centesimal, fibras alimentares, perfil de microelementos) e nutricionais (vitamina D, teor amilose e teor amido resistente).

Referências

Brasil. Lei nº 10.741, de 1º de outubro de 2003. Estatuto do Idoso. Disponível em: <https://www.gov.br/mdh/pt-br/centrais-de-conteudo/pessoa-idosa/estatuto-da-pessoa-idosa.pdf/view>.

Instituto Brasileiro de Geografia e Estatística. Projeção da população: Brasil e unidades da federação: Revisão 2024. IBGE, 2024. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html. Acesso em: 31 mar. 2025.

Instituto Brasileiro de Geografia e Estatística. (2024). Projeção da população: Brasil e unidades da federação: Revisão 2024. IBGE. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html

Perspectivas demográficas do envelhecimento populacional na Região das Américas. Organização Pan-Americana da Saúde e Comissão Econômica para a América Latina e o Caribe. Washington, DC; (2023). Licença CC BY-NC-SA 3.0 IGO. Disponível em: https://doi. org/10.37774/9789275726792.

Organização Mundial da Saúde (2025). Number of persons aged 60 years or over (thousands). WHO. Disponível em: https://platform.who.int/data/maternal-newborn-child-adolescent-ageing/indicator-explorer-new/MCA/number-of-persons-aged-over-60-years-or-over-(thousands)

Organização Mundial da Saúde. Década del Envejecimiento Saludable. Genebra: OMS; 2020. Disponível em: https://www.who.int/es/initiatives/decadeof-healthy-ageing.

ARRP. Global Longevity Economy Outlook: The economic contribution of people age 50 and olde, 2020. Disponível em: https://doi.org/10.26419/int.00052.001

CHAPTER 1 - AGING AND HEALTH: CHALLENGES IN NUTRITION AND STRATEGIES FOR A HEALTHY LIFE

Edilaine Silva Lemos Costa[1], Monique Barreto Santos[2], Carlos Wanderlei Piler de Carvalho[3], Renata Torrezan[3], Cristina Yoshie Takeiti[1, 3]

[1] Food and Nutrition Graduate Program, Nutrition School, Federal University of the State of Rio de Janeiro (UNIRIO), Rio de Janeiro, (RJ), 22290-250, Brazil

[2] Food and Nutrition Graduate Program, Federal Rural University of Rio de Janeiro (UFRRJ), Seropédica (RJ), 23890-000, Brazil

[3] Embrapa Agroindústria de Alimentos, Avenida das Américas, 2950501, Rio de Janeiro (RJ), 23020-470, Brazil

Abstract

Population aging is a growing global phenomenon. By 2025, the global population aged 60 or over will reach 1.2 billion with a projection of 2.1 billion by 2050. In Latin America, population aging is progressing rapidly, rising from 8 % in 2020 to over 30 % by the end of the century. Aging brings physiological changes, such as appearance of gray hair or its loss, loss of skin flexibility and the appearance of wrinkles, and reduction in height, called senescence, as well as conditions that lead to loss of autonomy, such as senility, which includes chronic diseases and frailty. Changes, such as difficulties in chewing and swallowing, make the elderly more susceptible to nutritional deficiencies and related diseases. Sarcopenia, characterized by loss of muscle mass, affects quality of life and daily activities. In addition, dysphagia, often associated with sarcopenia, can lead to malnutrition and increase the risk of comorbidities, such as pneumonia. Vitamins and minerals can help reduce the risk of certain diseases and physiological changes in the population over 60 years of age. In view of these points, the United Nations (UN) has declared 2021-2030 as the decade of healthy aging, aiming to improve the quality of life of older adults. In this scenario, age-related conditions are a growing problem and need to be studied and understood. Therefore, this review addresses essential aspects of aging, including sarcopenia, dysphagia, commensality, and the relevance of nutrition for healthy aging, as well as public policies and strategies for their promotion.

Keywords: Elderly, Aging, Vitamin D, Magnesium, Dysphagia, Sarcopenia

1 Introduction

The ageing of the population is a global phenomenon under constantly growing. The world population over 60 years old today has reached 1.2 billion people with a projection of 2.1 billion for 2050 (WHO, 2025). In comparative terms, the growth of the population aged 60+ in China for example will increase twice (39 %) until 2050. Likewise, the 60+ population in Brazil currently is 16.6 % and is projected to reach 29.3 % in 2050 (IBGE, 2024). Population aging is a demographic characteristic of the 21st century and one of the challenges is promoting health and well-being for this population (United Nations, 2023).

Latin America is the leader of global rate of aging. In 1950, older people represented 5.6 % of the population, a proportion that rose to 8.3 % in the 2000s and is expected to reach 25 % by 2050. As a result, the number of people aged 60 or over will surpass the population aged 0 to 19 of approximately 190 million. This scenario shows that this region is undergoing the highest global accelerated demographic transformation, highlighting the need for new policies and strategies to deal relating to this change (PAHO, 2023).

In Brazil, an elderly person is considered someone over 60 years old, according to the Elderly Statute (BRASIL, 2022). In order to understand the aging process, it is essential to comprehend some concepts. According to the Brazilian Society of Geriatrics and Gerontology, *senescence* refers to the natural aging process, characterized by physiological changes common to everyone, such as hair loss, loss of skin elasticity, wrinkles, gray hair, and functional changes that occur over the years in the body. On the other hand, *senility* is defined as aging associated with the loss of autonomy and independence, often accompanied by chronic diseases, such as diabetes, hypertension, osteoarthritis, as well as conditions such as frailty syndrome and sarcopenia (SBGG, 2025).

Some of the changes that occur with aging can interfere in relation to eating capacity, such as difficulty of chewing and swallowing, making the elderly more susceptible to complications with respect to eating, which include nutritional deficiencies, anemia, and diseases regarding lack of nutrients (BRASIL, 2006).

Reduced strength and muscle mass are also related to aging, and one of the reasons may be sarcopenia, which can be caused by aging itself, but also by a sedentary lifestyle and poor nutritional diet. Sarcopenia damages quality of life of the elderly by affecting simple activities such as climbing stairs and carrying suitcases, in addition to imbalance when walking causes constant falls (Cruz-Jentoft; Sayer, 2019).

In aging, dysphagia maybe is associated with sarcopenia as a consequence muscle mass loss related to the aging process that leads to lack of elasticity in the upper digestive tract, decreased saliva amount, loss of taste and reduced sense of smell (Barkoukis, 2016). In this sense, dysphagia can lead to malnutrition and, hence an increase in comorbidities in the elderly. It needs to be diagnosed as soon as possible to delineate the best strategy to ensure safe and effective feeding and adequate nutrition, diet adaptation to avoid problems with choking and bronchoaspiration, which commonly lead to pneumonia possibly culminating in hospitalizations (PEDE, 2015; BALET et al., 2019).

Some elderly people may have difficulty in producing vitamin D due to reduced liver or kidney functioning and low exposure to sunlight. Vitamin D is important for bone mineralization, calcium and phosphate homeostasis, and skeletal health. Vitamin D deficiency may be related to osteoporosis, osteomalacia, cardiovascular diseases, multiple sclerosis and lung diseases (HOLICK, 2007). The available forms to treat this deficiency are ergocalciferol (vitamin D_2), cholecalciferol (vitamin D_3) and calcifediol (25(OH)D) (Figure 1) (Jodar, 2023).

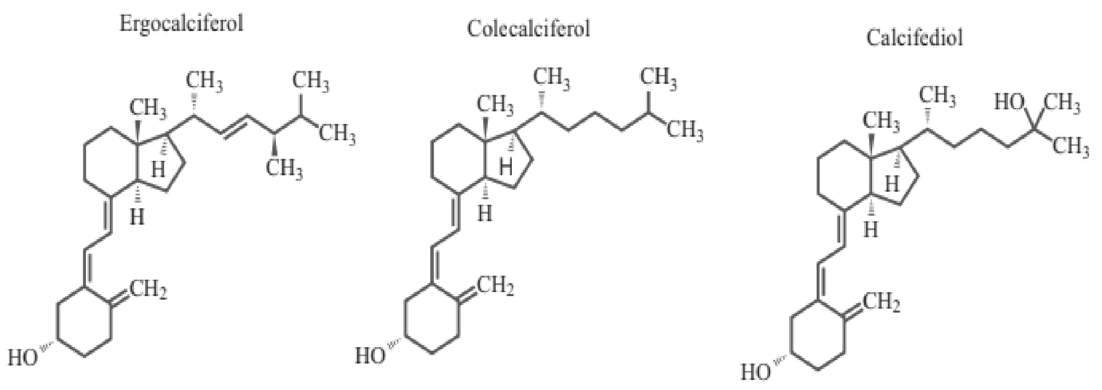


Figure 1. Chemical structures of ergocalciferol (vitamin D_2), cholecalciferol (vitamin D_3), and calcifediol (25-hydroxyvitamin D*3*)

The aging of the population changes the demands for public policies and social services. In Brazil and other countries, some initiatives have been delayed in carrying out actions. In 2020, with the aim of improving the lives of the elderly people, the United Nations General Assembly declared 2021-2030 as the decade for healthy aging. This represents an action to guide and unite forces between countries, governments, society and researchers in order to create actions and strategies together with the aim of creating a better society for all ages (United Nations, 2020).

The aging process is usually accompanied by an increase in physical dependence. In the Americas, data from 2019 indicate that as life expectancy increases, the period in which people live with health restrictions also increases. In most countries, men face greater dependency between the ages of 70 and 75, while for women this period generally occurs between the ages of 77 and 82 (GBD, 2019).

In this scenario, age-related conditions are a growing problem that needs to be studied and understood. Therefore, this review addresses some essential aspects of aging, including sarcopenia, dysphagia, commensality, and the relevance of nutrition for healthy aging, as well as public policies and strategies for its promotion.

2 Data search strategy

The studies that were included in this narrative review were found in the ScienceDirect, PubMed and Google Scholar databases, as well as on organizational websites with publication dates from January 2004 to February 2025. The searched keywords were *nutrition and aging, commensality, aging, vitamin D, magnesium, food security, family meals, elderly, happiness, malnutrition, dysphagia* and *sarcopenia* including the combinations among them.

Table 1 summarizes articles focusing on physiological changes that occur during aging process relating nutritious diet with better health conditions.

Table 1. Main disorders of age-related morbidities, senescence and health maintenance

Authors	**Objective**	**Main findings**	**Country**
Bruins et al. (2019)	Highlight the role of nutrients in reducing the risk of chronic non-communicable diseases prevalent in population aging.	Adequate nutrient levels can help to improve the health and well-being of older populations and to reduce the progression of chronic non-communicable diseases.	Swtizerland

		The promotion of nutrient-rich diets for healthy aging should be considered as a health policies.	
Papadopoulou (2020)	Report the prevalence of sarcopenia in elderly, etiology, prevention and treatment techniques.	Malnutrition and low physical activity seem to be the main factors associated with sarcopenia. Therapies including supplementation and diet are recommended for sarcopenic individuals.	Greek
Norman et al. (2021)	Describe the challenges in understanding, identifying and treating malnutrition in elderly.	Adequate protein with energy intake is crucial to prevent malnutrition and sarcopenia. Furthermore, since micronutrient deficiencies are common in older age, targeted micronutrient supplementation may be useful if diet by itself is not sufficient to delivery age-specific needs.	Germany
Raheem et al. (2021)	Raise awareness in order to modify the texture of foods offered to dysphagic patients.	Older people and people with dysphagia need nutritious and tasty foods that should be soft, easy and safe to swallow. Food industries need to consider important criteria such as texture when developing new products for dysphagic patients.	Portugal
de Sire et al. (2022)	Describe the overlapping characteristics of sarcopenia, sarcopenic dysphagia, malnutrition and oral fragility in older people, their correlations, and define good	Individualized treatment based on patient characteristics should be proposed by pursuing etiological causes, which includes oral fragility, malnutrition and sarcopenia.	Italy

	management of these conditions.	Furthermore, appropriate treatment should also include oropharyngeal rehabilitation, oral health treatment, and nutritional supplementation to neutralize age-related functional decline and improve of quality life.	
Duan et al. (2022)	Compare the effects of dietary patterns and supplements on aging process.	Traditional diets and dietary supplements are profitable options for delaying aging.	China
Walker-Clarke et al. (2022)	Identify and evaluate evidence for specific psychological (intrapersonal) and social (interpersonal) factors that have positive and negative eating results.	The research identified eight psychosocial factors: eating behaviors in adulthood, health awareness and attitudes, food decision-making, perceived dietary control, mental health and mood, emotions and eating pleasure, eating arrangements (commensality), and social support.	United Kingdom
Zeppa et al. (2022)	Compare young and old microbiota in order to suggest a supposed microbial characteristic of aging. Discuss the effects of physical activity, dietary interventions, and supplements for maintaining good health in aging progress.	This research reported that the composition of the microbiota of the elderly differs significantly from that of young and middle-aged people. A healthy lifestyle, with a balanced diet rich in unrefined foods of natural origin, combined with adequate physical exercise, sustained for sufficiently long periods, allows the restoration and maintenance of a healthy microbiota even	Italy

		in old age, promoting healthy aging. The use of supplements should be advised, individualized and calibrated according to the needs of the individual.	
Aguilera; Covacevic (2023)	Discuss the main factors involved in the design of foods for the elderly considering the perspective of body process and the relevant properties involved.	Rational design of foods for the elderly should be based on a multidisciplinary knowledge toolbox (including physiology, nutrition, food technology, social sciences and AI experts).	Chile
Phulkerdi et al. (2023)	Investigate the association between happiness and food-related behaviors, sociodemographic and economic conditions among the elderly in Thailand.	The three main reasons associated with a greater likelihood of being happy are financial satisfaction, sharing a family meal and food security.	Thailand
Galarrequi et al. (2024)	Evaluate the effects of a personalized strategy based on the inclusion of individualized foods and digital tools on the general health status and quality of life in a 3-month follow-up in overweight or obese elderly people.	The precision strategy reduced body weight in 3 months with significant improvements in body fat percentage, blood pressure, and overall metabolic health compared to standard recommendations. The precision approach significantly improved the quality of life of individuals, with additional improvements in emotional well-being and vitality. Adherence to the Mediterranean diet was significantly associated with	Spain

		greater quality of life and vitality.	

3 What factors can influence nutrition in the old-aged people?

Many studies focus on physiological and biological changes and at lesser extent on the social influences of elderly's diet. But, in addition to the physiological processes, that occur naturally and diseases, social issues have a great influence on the general health of the elderly. Changes in routine, use of medication, and psychological illnesses are also important factors to be evaluated in the elderly's diet.

Food ingestion can be reduced by physiological and anatomical changes such as reduced masticatory strength, tooth loss, reduced perception of sensory properties and lack of coordination during eating. Elderly people also have less autonomy in preparing their meals and making food choices. Because of these changes, nutrient ingestion can be reduced and lead elderly people to malnutrition and other diseases (de Sire et al., 2022).

Therefore, this session will discuss terms such as commensality, dysphagia and sarcopenia, which are the most reported problems observed in elderly people.

3.1 Commensality

Commensality can be defined as shared meals and this practice refers to the way we eat in terms of the duration of meals, concentration, location and company. This practice is also associated with greater pleasure during eating act (Moreira, 2010).

Eating meals with the family has a positive relationship in terms of health and well-being, but urbanization, social media addiction and fast-paced lifestyles are harming families' ability to sustain this habit. Mealtime brings benefits such as strengthening family bonds and resolving family problems (Middleton et al., 2020).

If elderly people live alone, they no longer have shared meals, which may result in less interest in preparing meals and food is no longer a priority. They feel free from the commitment of *commensality,* some of them just abandon regular meals and simplify meal preparation strategies. The absence of commensality can make the seniors even more vulnerable and have implications for health (Moreira, 2010).

In this scenario, the Brazilian Ministry of Health launched the Dietary Guidelines for the Brazilian Population (BRASIL, 2014) that provides recommendations for an adequate and healthy diet, in which commensality appears as an important practice for greater pleasure in eating, better food digestion and more efficient control of how much we eat, in addition to increasing social interaction with friends and family.

The study conducted in Thailand with 1,197 elderly people aged 60 and over in different regions (center, north, northeast and south) regarding sociodemographic characteristics, health status, domestic tasks, gardening, financial situation, family meals and food security, concluded that sharing family meal is an important component for happy aging. This study found that seniors who ate all their meals with their family were probably happier than those who did not eat any meals with their family (Phulkerd et al., 2023).

3.2 Sarcopenia

Muscle mass decreases by about 6 % per decade after middle age (Janssen, 2010). Therefore, sarcopenia is defined as the loss of muscle mass and function, that lead the elderly to decline in functionality, frailty and mortality. This status can happen due to illness, inactivity, malnutrition and mainly due to aging process, in which skeletal muscle homeostasis is altered with an imbalance between anabolic and catabolic processes in terms of protein production pathway. Changes in the muscle occur due to the reduction in the size and number of muscle fibers and the infiltration of intramuscular and intermuscular fat. Furthermore, there is a reduction in cells that replaces and repair damaged muscle fibers (Cho, Lee, Song, 2022).

The diagnosis of sarcopenia is achieved by using SARC-F questionnaire, which asks simple questions about difficulty getting up from a chair, walking, climbing stairs and carrying weights, measuring pressure strength and muscle mass (Malmstrom, 2016). There are three categories of sarcopenia: (i) the primary sarcopenia is related to aging, (ii) second, it is attributable to disease, inactivity, and malnutrition, (iii) chronic sarcopenia that presents for more than 6 months (Sayer; Cruz-Jentoft, 2022).

Options for treating sarcopenia should be based on an understanding of the pathophysiology and the inclusion of pharmacological and non-pharmacological approaches, which include strength exercise and adequate nutrition, such as adequate intake of proteins, vitamin D, antioxidant nutrients and fatty acids (Cho et al., 2022; Papadopoulou, 2020).

3.3 Dysphagia and the management diet of the elderly

Dysphagia is defined as difficulty of swallowing that generally occurs as a result of diseases such as esophageal cancer, stroke and Parkinson's disease. Dysphagia can also occur due to changes in some stage of the swallowing process, which is divided into oral, pharyngeal and esophageal. These changes can make it difficult and reduce eating habits for individuals (Chen et al., 2021).

Elderly dysphasic patients need soft and moist foods due to these products are easy and safe to swallow, but also nutritious and tasty. This is vital for them in order to meet their nutritional needs (Raheem et al., 2021).

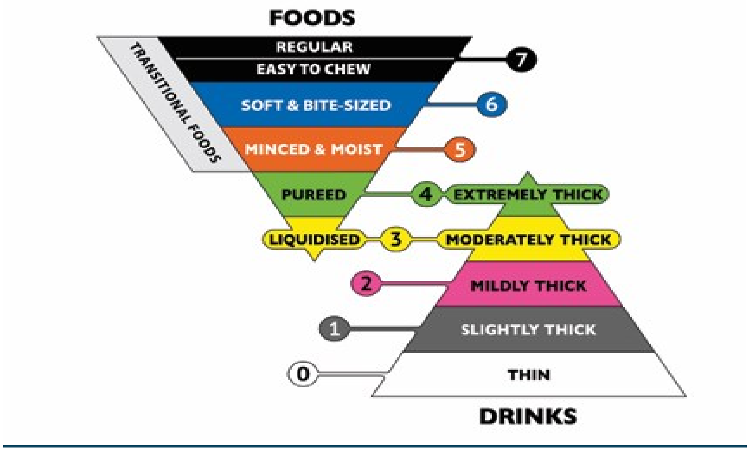
Reducing oral intake increases the risk of malnutrition, dehydration, respiratory infections, pneumonia, increased hospitalizations and mortality. Decreased nutritional support also leads to weight loss and reduced skeletal muscle synthesis, which consequently results in the development of sarcopenia. Therefore, a vicious cycle of sarcopenia and dysphagia ends up becoming unavoidable. Dysphagia caused by sarcopenia is classified as sarcopenic dysphagia and is related to the decline in muscle mass and strength related to swallowing (Chen et al., 2021).

Dysphagia can be classified into seven levels, according to the Dysphagia Outcome Severity Scale (DOSS): (i) Level 1: Severe dysphagia, with severe retention and aspiration, (ii) Level 2: Moderate-severe dysphagia, with severe aspiration, (iii) Level 3: Moderate dysphagia, with significant difficulties and possible aspiration, (iv) Level 4: Mild-moderate dysphagia, food retention in the pharynx, (v) Level 5: Mild dysphagia, with possible aspiration of liquids, (vi) Level 6: Mild difficulty swallowing, but without aspiration, and (vii) Level 7: Normal swallowing. These levels help determine the severity of the condition and the appropriate diet for the patient (Fransson et al., 2025; O'Neil et al., 1999)

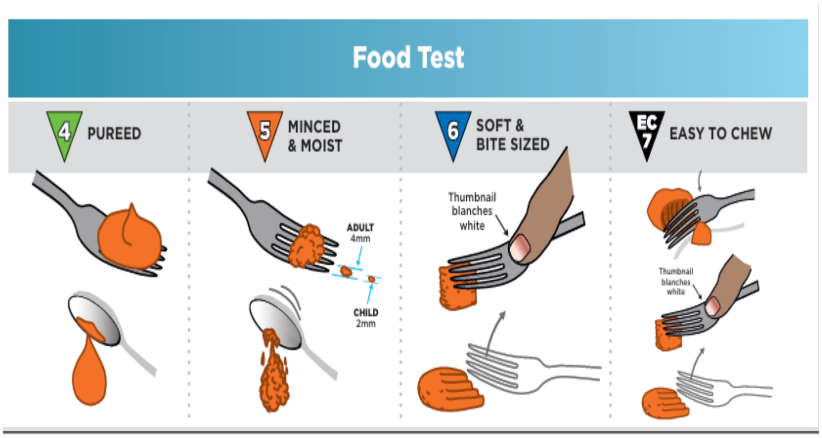
Regarding dysphagia, it is important to evaluate the texture and viscosity of food (Figure S3). Texture involves characteristics such as firmness, elasticity, chewiness and adhesiveness, and is essential for safe swallowing. Viscosity refers to the resistance of the liquid to flow, and is essential to prevent aspiration, especially in patients with reduced oral control. Liquids can be classified into four types of viscosity: thin, nectar, honey and pudding. In addition to defining the texture and viscosity, it is important to adjust the diet according to the type of dysphagia for the purpose of ensure safe swallowing (Christmas, 2019).

Therefore, in order to systematize diets for people with dysphagia, the *International Dysphagia Diet Standardization Initiative* (IDDSI, 2019) created a diagram that describes the appropriate consistencies for each level of dysphagia (Figure 2a) for individuals of all ages and all cultures. This initiative brought information in a simple way, using everyday hospital and residential equipment, in which texture can be measured using a spoon and fork and thickness of drinks using a common syringe.

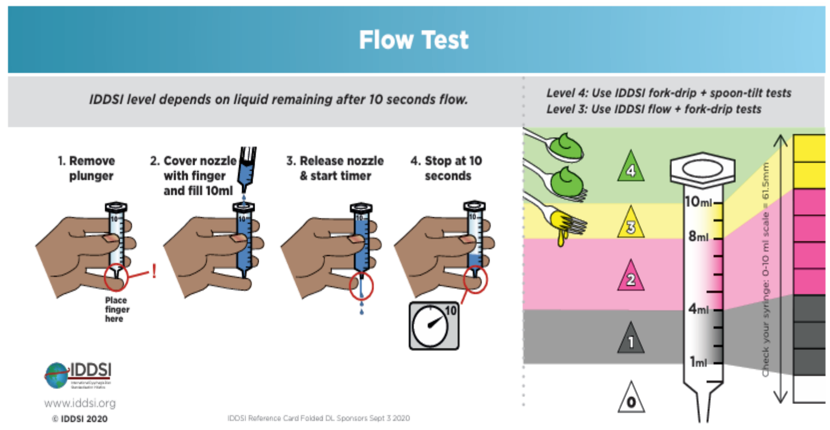
This diagram also presents simple and common terminology to describe the textures and consistencies of beverages such as *thin liquid*, *very slightly thickened, slightly thickened, slightly thickened liquid, extremely thickened pasty, wet and smooth, soft and chewy, easy to chew and normal.* Besides, it has developed a test method to confirm the flow or texture characteristics for use in beverages and foods (Figure 2b and Figure 2c).



(a)



(b)



(c)

Figure 2. The International Dysphagia Diet Standardization Initiative (IDDSI) diagram containing terminologies for consistency and flow of food (a), test method for solid food (b) and flow test method for beverages and liquefied foods (c) (IDDSI, 2019).

4 The role of nutrition on healthy aging

The elderly population is the fastest growing, therefore, strategies focusing on efforts on their nutritional and food requirements are urgent. At this stage of life, important nutrients include vitamin D, vitamin K, calcium, magnesium, phosphorus, proteins and fatty acids that act on the bone and the muscle metabolism. It is important to comprehend that vitamin and mineral deficiencies (Table 2) throughout life can harm the health of the elderly and lead to some chronic clinical symptoms (Bruins; Dael; Eggersdorfer, 2019).

Table 2. Nutrients deficient in older people

	Micronutrient	Signs and symptoms of deficiency
Vitamins	B_1 (Thiamine)	Risk factor for heart failure, peripheral neuropathy and encephalopathy.
	B_6	Role in reducing elevated homocysteine, a cardiovascular risk factor. It is related to vitamin B_{12} and folate.
	B_9 (Folate)	It is also among the common causes of anemia in older adults, leading to weakness and fatigue. Deficiency is linked to depression and dementia.
	B_{12} (Cobalamin)	Important role in reducing elevated homocysteine. It is a common cause of anemia in older adults, leading to weakness and fatigue. Low status increases the risk of cardiovascular disease and cognitive impairment.
	C	May help seniors maintain immune cells and function. Smoking increases the need.
	D	Risk factor for low bone mass, rapid bone loss, high fracture rates and muscle weakness.
Minerals	Calcium	Associated with low bone mass, rapid bone loss and high fracture rates.
	Iron	Deficiencies are seen mainly among hospitalized elderly people or those with chronic illnesses. Common symptoms of anemia in the elderly include weakness and fatigue.
	Magnesium	Often deficient in the elderly. Maintains muscle integrity and function.
	Selenium	Deficiency can increase the risk of diseases of aging, such as cardiovascular disease, reduced immune response and cognitive decline.
	Zinc	Risk factor for immune deficiency and susceptibility to infection in the elderly.

In: FRANCO, G. (2005)

According to the Ministry of Health (Brazil, 2009), healthy diet is among the daily health cares that contribute to a favorable aging process. This guideline also recommends (i) encourage preparations with whole grains or the use of products made with whole grain flours, including six portions of the cereal, root or tuber group in daily meals, (ii) when the elderly person has limitations in chewing and swallowing, the way of preparation in terms of consistency, texture, size of the food and the size of portion should be adapted to the degree of the limitation, (iii) distribute the daily diet into five or six meals, (iv) eat beans and rice every day or at least five times a week.

Food intake can be reduced by physiological and anatomical changes such as reduced masticatory strength, tooth loss, reduced perception of sensory properties and lack of coordination during eating process. Elderly people also have less autonomy in preparing their meals and making food choices. Because of these changes, nutrient intake can be decreased and lead to malnutrition and other diseases (de Sire et al., 2022).

Malnutrition in the elderly can be caused by difficulty eating, reduced mobility, psychological stress, less access to oral health, and is associated not only with increased mortality and disease, but also with physical decline that affects daily activities and quality of life (de Sire et al., 2022). If elderly people have oral health problems, these individuals usually should avoid foods, such as raw vegetables, hard fruits, animal protein due to the difficulty of chewing. This deprives them from essential sources of proteins, vitamins and minerals. Aging also reduces the perception of taste and smell (Raheem et al., 2021).

Protein requirements are higher at older ages, and adequate energy and protein intake are important to prevent malnutrition and sarcopenia. The European Society for Clinical Nutrition and Metabolism (ESPEN) recommends an energy intake of 30 kcal/kg body weight/day and a protein intake of at least 1.0 g/kg body weight/day in older adults. However, protein intake can reach 1.2-1.5 g/kg body weight/day in acute or chronic diseases such as sarcopenia and malnutrition (Volkert et al., 2019).

Dietary intervention is a safe, effective, and low-cost preventive strategy to increase life expectancy. The most popular diets that promote longevity and healthy life expectancy are the Okinawan, Mediterranean, and Dietary Approach to Stop Hypertension (DASH) diets. The Okinawan diet is characterized by low calories (approximately 10–20 % energy restriction) and high carbohydrates with a protein to carbohydrate ratio of 1:10. The Mediterranean diet is associated with high fish intake containing n-3 polyunsaturated fatty acids. The Dietary Approach to Stop Hypertension (DASH) diet emphasizes sodium reduction to lower blood pressure (Duan et al., 2022).

Some micronutrients have important functions in aging, such as vitamin D and magnesium. These micronutrients can contribute to better musculoskeletal health and contribute to reducing the number of hospitalizations related to osteoporosis, femur fractures, and among others. In Brazil, it was recorded 573,741 hospitalizations of elderly people due to fractures in body regions and osteoporosis cases reported between 2022 and 2024, accounting for 5 % of the total hospitalizations in the period (BRASIL, 2024). Deficiency of these substances in elderly people increases the risk of falls that can also lead to hospitalizations and surgeries. Prevention involves physical activity, a safe environment, and adequate levels of vitamin D and magnesium. Vitamin D is part of the treatment recommendation and can also prevent or delay the development of osteoporosis (Brasil, 2018). Considering the importance in the prevention and treatment of sarcopenia and dysphagia, vitamin D and magnesium will be discussed in the next topic.

4.1 Vitamin D in the elderly health panorama

Vitamin D is classified as lipid-soluble and belongs to the group of calciferols, in which there are two most important compounds named as vitamin D_3 (cholecalciferol) and vitamin D_2 (ergocalciferol) (Figure1) (Remelli et al., 2019).

About 90 % of this vitamin are produced in the skin by sun exposure and 10 % through dietary intake. Vitamin D_2 can be found in some mushrooms, such as champignon, shiitake, shimeji, funghi, portobello and vitamin D_3 is present in animal food products such as eggs, cod liver oil, fish fat such as salmon, sardines, mackerel and tuna. In the skin, vitamin D occurs from sun exposure and depends on age, ethnicity, skin pigmentation, time and duration of sun exposure, area of exposed skin, use or not of sunscreen and clothing (Remelli et al., 2019).

The recommended dietary intake of vitamin D in Australia is 600 IU /day (15 μg/day) for people over 70 years old, whereas in the UK it is 800 IU/day (20 μg/day) for all age groups (Australian Dietary Guidelines, 2013; Dawson, 2010). In Brazil, governamental normative instruction recommends a daily intake of 600 IU/day for all people (ANVISA, 2020).

After dietary ingestion or synthesis in the skin after sun exposure, vitamin D binds to a protein (Vitamin D-Binding Protein — DBP), which transports it to the liver, where it is metabolized by 25-hydroxylase enzymes into 25-hydroxyvitamin D (25(OH)D). Afterwards, it is transported to the kidney, metabolized by the enzyme 1-alpha-hydroxylase into the biologically active form 1,25-dihydroxyvitamin D (1,25(OH)2D) or calcitriol (Wintermeyer et al., 2016).

Serum 25-hydroxyvitamin D is the most used indicator of the level of vitamin D in the blood, and its active form is 1,25-dihydroxyvitamin D. The recommendation is to maintain vitamin D levels in the upper normal range from middle-aged to older adults. The Washington Institute of Medicine (2010) established as inadequate values below 20 ng/mL, while values of 20 ng/mL or more are adequate (Looker, 2011). Some studies suggest that the greatest benefits of serum 25(OH)D concentration would be around 75 nmol/L, and concentrations between 90 and 100 nmol/L showed greater benefits (Bruins; Dael; Eggersdorfer, 2019).

Holick et al. (2011) published a guideline for the assessment, treatment, and prevention of vitamin D deficiency, reviewed and supported by the Endocrinological Society of the United States. This guideline considers below 50 nmol/L serum concentrations of 25(OH)D as vitamin D deficiency, between 50 and 74.9 nmol/L to be insufficient and sufficiency between 75 and 250 nmol/L (Bischoff-Ferrari et al., 2006).

Since there are few naturally rich foods in vitamin D and the content contained in these foods can vary greatly, an efficient alternative would be food fortification. In Canada, vitamin D fortification is mandatory for milk (2 μg/100 mL) and margarine (26 μg/100 g) (Health Canada, 2022). In other countries, such as United States of America, vitamin D fortification is optional for products such as milk, breakfast cereals, and plant-based beverages (FDA, 2015). Another strategy to enrich food is to supplement fish and cattle feed with vitamin D, thus these animals will produce vitamin D enriched foods (Guo et al., 2017).

4.2 Magnesium in aging hallmarks

Magnesium (Mg) has important role in human metabolism. Its presence in the body is mainly located in bones, muscles and inside cells. The adult human body has approximately 28 g of Mg, in which 99 % is in the intracellular compartment and 1 % is extracellular. Serum magnesium is divided into a protein-bound part (25 % of albumin and 8 % of globulins), a chelated part (12 %) and an ionized part (ion Mg 55 %) (Barbagallo, 2007).

Magnesium ingested in the diet is absorbed mainly in the small intestine, colon and a small proportion in the stomach. Factors that can reduce the absorption of Mg are the high consumption of sodium, calcium, protein, alcohol, caffeine, diuretics, proton pump inhibitors, whereas the presence of lactose and vitamin D can favor absorption. Excretion is fecal, urinary or biliary routes and the kidney helps to control and balance of Mg. Some hormones maintain the Mg balance and transport. Among them, parathyroid and calcitonin play an important role, and catecholamines influence the Mg metabolism (Barbagallo, 2021; Delva, 2004).

According to the U.S. Department of Agriculture and the U.S. Department of Health and Human Services (2020), Mg consumption in food should be 420 mg/day for men and 320 mg/day for women. In Brazil, the recommendation is 420 mg/day according to Government Normative Instruction No. 75/2020 (ANVISA, 2020).

Magnesium deficiency in the elderly is associated with reduced intake of food sources, increased urinary excretion, reduced kidney function, and age-related diseases and comorbidities, such as gastrointestinal problems. Polypharmacy also reduces the absorption of magnesium, and the list of medications includes antiacids, proton pump inhibitors, antihistamines, antibiotics, antiepileptic and antiviral medications, among others (Barbagallo, 2021).

Magnesium is essential for genomic stability, participating in DNA repair mechanisms and defense against oxidative stress. Its deficiency compromises cellular integrity, promotes mitochondrial dysfunction, reduces cell viability and accelerates senescence (Hartwig, 2001). In addition, low levels of Mg are associated with telomere shortening, a process linked to aging. Mg also acts in the modulation of protein synthesis, apoptosis and membrane repair. Changes caused by Mg deficiency resemble those observed in cellular senescence (Killilea; Ames, 2008). Thus, its balance is important for the maintenance of cellular function and can positively influence longevity.

Studies indicate that magnesium may work synergistically with vitamin D by acting as a cofactor for vitamin D receptors, activating enzymes and vitamin D-binding proteins. Magnesium deficiency has been associated with reduced vitamin D levels, and magnesium supplementation may increase vitamin D status (Dall et al., 2022; Stokic et al., 2018; Qi et al., 2018).

5 Healthcare and government policies for older persons

The world's population is aging and many people do not have access to the basic resources needed to have a good quality of life. The World Health Organization (WHO) defines healthy aging as the process of developing and maintaining functional capacity that enables well-being in old age. Different health factors can influence mobility, vitality, psychological, cognitive and sensory capacities (Beard et al., 2016).

This demographic change has created some movements around the world. In 2020, the United Nations General Assembly declared 2021-2030 as the decade for healthy aging, which brought together previous guidelines and the sustainable development goals (SDGs). In this point of view, the aging progress are related to SDGs that include (i) promotion of gender equality in employment and adoption of family-friendly policies that can improve labor force participation and lead to faster economic growth (SDGs 5 and 8); (ii) elimination of age-related discrimination, including age barriers in employment, which can reduce inequality, increase productivity and promote economic growth (SDGs 8, 10 and 16); and (iii) promotion of health and preventive care throughout the life to maintain individuals' maximum functional capacity, which can improve health and well-being (SDG 3) (WHO, 2020).

The Pan American Health Organization (PAHO) is leading this agenda in the Americas and has set the following goals: (i) changing the way we think, feel and act in relation to age; (ii) developing communities to promote the capabilities of older people; (iii) providing integrated person-centred care; (iv) providing primary health services that serve older people; and (v) providing quality long-term care services, a strategy that aims to improve the lives of older people and their families (WHO, 2021). Besides, these are the lines of action that efforts must be pursued: promote public policies and partnerships for healthy aging in the Region of the Americas; support the development of friendly environments adapted to all older people; align health systems to meet the specific needs of older people; develop sustainable and equitable systems for providing long-term care; improve measurement, monitoring and research on aging (PAHO, 2024).

In Brazil, the Statute of the Elderly People (Law No. 10.741/ 2003) regulates the rights of people aged 60 and over, but neglects important aspects of nutrition for older people. Although the Statute declares states that adequate nutrition is an essential right, the approach is superficial and generic, without detailing specific guidelines on nutrition in old age. For example, there is an absence of plan for food and nutritional security actions for the older population, considering the particularities of this group age.

Aging should be a process of experiencing health throughout life. In order to ensure healthy aging, it is essential to provide adequate care services that meet the individual needs of this population. Access to qualified professionals and support structures contributes to maintaining autonomy and well-being. In addition, public policies focused on health and social assistance are essential to minimize the impacts of physical limitations.

Demographic change also brings demands for care services. The massive presence of women in the labor market has led to the term “Care Economy”, which can be used to explain all types of work, paid or unpaid, with the purpose of improving the lives of others, such as preparing meals, cleaning and organizing the house, buying groceries and washing, hanging and storing clothes. There is also care for children and the elderly, which involves a series of other tasks that can be part of the lives of those responsible for many years. Data from the International Labour Organization (ILO, 2019) show that in the 64 countries surveyed, women dedicate, on average, 3.2 times more time than men to unpaid care work, i.e. 4 h and 25 min per day, compared to 1 h and 23 min spent daily by men (Queiroz, 2021). The family is still the predominant place of care with little or no government support. It is the responsibility of its members, especially women, who perform free of charge, this task as an extension of domestic work. It is important to support families and create strategies addressed to those that have dependent elderly people (Hirata, 2019).

6 Conclusions

Population aging is a growing global phenomenon and, until 2050, the global population aged 60 or over will increase by 75 %. Likewise, population aging in Latin America is progressing rapidly, demonstrating the highest rate of global aging. Concerning this scenario, this review showed the importance of the nutritional and dietary needs of the elderly people, and also that inadequate diets in old age can contribute to loss of function and diseases. Aging brings together several physiological and anatomical changes that can reduce food intake such as loss of chewing strength, difficulties in swallowing and less autonomy in preparing meals increase the risk of malnutrition and sarcopenia that may be accompanied by dysphagia. Commensality or the practice of sharing meals, is associated with greater pleasure in eating and benefits for health and well-being. However, factors such as urbanization, social media and fast-paced lifestyles have weakened this habit and the reduced interest in eating, impact their health. Regarding nutritional deficiencies, the lack of vitamin D and magnesium are common due to (i) lower intake in case of magnesium and (ii) production since vitamin D is obtained mainly through sun exposure (90 %). Thus, there is an urgent need to create strategies to benefit older adults that must include public and/or private partnerships, health authorities, academics and the food sector that jointly should promote actions that benefit and encourage nutrition and healthy lifestyles for the older population besides long-term care facilities and professional caregivers for the elderly people.

Author statement

The authors declare that the submitted manuscript has not been published elsewhere and it is not under consideration for publication elsewhere.

Declaration of competing interest

The authors attest that there are no interests of competing with the objective, interpretation, and presentation of the results.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

vailability of data and material

Not applicable

Code availability

Not applicable

Bibliographic references

Aguilera José M, & Covacevich Leyla. (2023). Designing foods for an increasingly elderly population: a challenge of the XXI century, Current Opinion in Food Science, *Volume 51*, https://doi.org/10.1016/j.cofs.2023.101037

Aimee Walker-Clarke, Lukasz Walasek, & Caroline Meyer. (2022), Psychosocial factors influencing the eating behaviours of older adults: A systematic review, Ageing Research Reviews, Volume 77, 101597, ISSN 1568-1637, https://doi.org/10.1016/j.arr.2022.101597.

Ames, B. N. Prolonging healthy aging: longevity vitamins and proteins. *Proceedings of the National Academy of Sciences*, v. 115, n. 43, p. 10836-10844, 2018. Disponível em: https://doi.org/10.1073/pnas.1809045115.

Arnim C.A.F. (2017) Nutrition security in older adults: Status quo and future development. In: Biesalski H.K., Drewnowski A., Dwyer J.T., Strain J.J., Weber P., Eggersdorfer M., editors. *Sustainable Nutrition in a Changing World.* Springer International Publishing; Basel, Switzerland: pp. 61–73.

Australia. (2025, January 27) Australian Dietary Guidelines: Nutrient Reference Values for Australia and New Zealand. *Eat for Health*, 2013. Disponível em: https://www.nhmrc.gov.au/guidelines-publications/n55.

Balet, S. (2019) et al. Rapid Visco Analyser (RVA) as a Tool for Measuring Starch-Related Physiochemical Properties in Cereals: a Review. Food Analytical Methods, v. 12, n. 10, p. 2344–2360.

Barbagallo M, & Dominguez LJ. (2007) Magnesium metabolism in type 2 diabetes mellitus, metabolic syndrome and insulin resistance. Arch Biochem Biophys. 2007 Feb 1;458(1):40-7. doi: 10.1016/j.abb.2006.05.007. Epub. PMID: 16808892.

Barbagallo, M., Veronese, N., & Dominguez, L.J. (2021) Magnesium in Aging, Health and Diseases. *Nutrients*, *13*, 463. https://doi.org/10.3390/nu13020463

Bischoff-Ferrari HA, Giovannucci E, Willett WC, Dietrich T, & Dawson-Hughes B. (2006) Estimation of optimal serum concentrations of 25-hydroxyvitamin D for multiple health outcomes. Am J Clin Nutr.

Brasil, (2024) Ministério da Saúde. Datasus. Tabnet. Brasília, DF: Ministério da Saúde.

Brasil. (2025). Lei nº 10.741, de 1º de outubro de 2003. Estatuto do Idoso. Disponível em: <https://www.gov.br/mdh/pt-br/centrais-de-conteudo/pessoa-idosa/estatuto-da-pessoa-idosa.pdf/view>.

Brasil. Ministério da Saúde. Secretaria de Atenção à Saúde. Departamento de Atenção Básica. (2014) *Guia alimentar para a população brasileira.* 2. ed., 1. reimpr. Brasília: Ministério da Saúde

Brasil. Ministério da Saúde (2009). Secretaria de Atenção à Saúde. Departamento de Atenção Básica. Alimentação saudável para a pessoa idosa: um manual para profissionais de saúde / Ministério da saúde, Secretaria de Atenção à Saúde, Departamento de Atenção Básica. – Brasília: Editora do Ministério da Saúde, 2009. 36 p.

Brasil. (2018). Comissão Nacional de Incorporação de Tecnologias no Sistema Único De Saúde (CONITEC). Protocolo Clínico e Diretrizes Terapêuticas de Osteoporose. Brasília: Ministério da Saúde.

Bruins, Maaike J., Van Dael, Peter, & Eggersdorfer, Manfred. (2019) The role of nutrients in reducing the risk for noncommunicable diseases during aging. Nutrients, v. 11, n. 1, p. 85.

Chen, K.-C.et.al. Sarcopenic Dysphagia: A Narrative Review from Diagnosis to Intervention. *Nutrients, 13*, 4043. https://doi.org/10.3390/nu13114043

Christmas, C. and Rogus-Pulia, N. (2019), Swallowing Disorders in the Older Population. J Am Geriatr Soc, 67: 2643-2649. https://doi.org/10.1111/jgs.16137

Cho mr, Lee s, & Song sk (2022, may 18). A Review of Sarcopenia Pathophysiology, Diagnosis, *Treatment and Future Direction. J Korean Med Sci. 37*. https://doi.org/10.3346/jkms.2022.37.e146

Cruz-Jentoft AJ, Sayer AA. Sarcopenia. Lancet. 2019 Jun 29;393(10191):2636-2646. doi: 10.1016/S0140-6736(19)31138-9. Epub 2019 Jun 3. Erratum in: Lancet. 2019 Jun 29;393(10191):2590. doi: 10.1016/S0140-6736(19)31465-5. PMID: 31171417.

Dawson-Hughes, B.; Mithal, A., Bonjour, J. P., Boonen, S., Burckhardt, P., Fuleihan, G. E., Josse, R. G., Lips, P, Morales-Torres, J., & Yoshimura, N. IOF position statement: Vitamin D recommendations for older adults. *Osteoporosis International*, v.21, n. 7, p. 1151-1154, 2010. DOI: 10.1007/s00198-010-1285-3.

De Sire, A. et al. Sarcopenic Dysphagia, Malnutrition, and Oral Frailty in Elderly: A Comprehensive Review. *Nutrients*, *14*, 982. https://doi.org/10.3390/nu14050982

Delva, P., Pastori, C. & Degan, M. (2004) *et al.* Catecholamine-induced Regulation in Vitro and ex Vivo of Intralymphocyte Ionized Magnesium. *J Membrane Biol* 199, 163–171. https://doi.org/10.1007/s00232-004-0686-7

Duan, H; Pan, J, Guo, M, Li,J, Yu, l, & Fan, L. (2022). Dietary strategies with anti-aging potential: Dietary patterns and supplements, Food Research International, *Volume 158*. https://doi.org/10.1016/j.foodres.2022.111501.

Fransson J, Thorén S, Selg J, Bergström L, Hägglund P. Validity and Reliability of Dysphagia Outcome Severity Scale (DOSS) When Used to Rate Flexible Endoscopic Evaluations of Swallowing (FEES). Dysphagia. 2025

Apr;40(2):343-352. doi: 10.1007/s00455-024-10732-z. Epub 2024 Jul 24. PMID: 39046477; PMCID: PMC11893719.

Galarregui, C., Navas-Carretero, S., Zulet, M. A., González-Navarro, C. J., Martínez, J. A., de Cuevillas, B., ... & Abete, I. (2024). Precision nutrition impact on metabolic health and quality of life in aging population after a 3-month intervention: A randomized intervention. *The Journal of nutrition, health and aging*, *28*(7), 100289. https://doi.org/10.1016/j.jnha.2024.100289.

Guo J, Lovegrove Ja, & Givens Di. (2017, November 27). 25(OH)D3-enriched or fortified foods are more efficient at tackling inadequate vitamin D status than vitamin D3. Proc Nutr Soc. 2018 Aug;77(3):282-291. doi: 10.1017/S0029665117004062. Epub. PMID: 29173203; PMCID: PMC6088524.

Hartwig, Andrea Role of magnesium in genomic stability, Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, Volume 475, Issues 1–2, 2001, Pages 113-121, ISSN 0027-5107, https://doi.org/10.1016/S0027-5107(01)00074-4.

Health Canada. (2022). *Consolidation Food and Drugs Regulation*. Ottawa, ON: The Minister of Justice Canada.

Hirata, Helena, & Kergoat, Danièle. (2007) Novas configurações da divisão sexual do trabalho. Cadernos de pesquisa, v. 37, p. 595-609.

Hirata, Helena. (2016). O trabalho de cuidado. *Sur: Revista Internacional de Direitos Humanos*, v. 13, p. 53-64.

Holick MF, Binkley NC, & Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP, & Murad MH. (2011), Weaver CM; Endocrine Society. Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. J Clin Endocrinol Metab

Instituto Brasileiro de Geografia e Estatística. (2024). Projeção da população: Brasil e unidades da federação: Revisão 2024. IBGE. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html

Institute of Medicine. (2010). Food and Nutrition Board. *Dietary reference intakes for calcium and vitamin D.* Washington, DC: National Academy Press.

Institute for Health Metrics and Evaluation (IHME). (2020). Global Burden of Disease Study 2019 (GBD 2019) Results. IHME. Disponível em: https://www.healthdata.org/gbd/2019

IPEA – Instituto de Pesquisa Econômica Aplicada. (2016) Economia dos cuidados: Marco teórico-conceitual. Relatório do Ipea.

Janssen I. (2010) Evolution of sarcopenia research. Appl Physiol Nutr Metab. 35(5):707-12. DOI: 10.1139/H10-067. PMID: 20962927 https://doi.org/10.1007/s00394-023-03103-1

Jodar, E., Campusano, C., De Jongh, R. T., & Holick, M. F. (2023). Calcifediol: a review of its pharmacological characteristics and clinical use in correcting vitamin D deficiency. *European journal of nutrition*, *62*(4), 1579-1597. https://doi.org/10.1007/s00394-023-03103-1

Killilea, D.W., & Ames, B.N. (2008) Magnesium deficiency accelerates cellular senescence in cultured human fibroblasts, Proc. Natl. Acad. Sci. U.S.A. 105 (15) 5768-5773, https://doi.org/10.1073/pnas.0712401105.

Looker, A. C., Johnson, C. L., Lacher, D. A., Pfeiffer, C. M., Schleicher, R. L., & Sempos, C. T. (2025) Vitamin D status: United States, 2001-2006. *NCHS Data Brief*, n. 59, p. 1-8, mar. 2011. Disponível em: https://pubmed.ncbi.nlm.nih.gov/21592422/.

Malmstrom TK, Miller DK, Simonsick EM, Ferrucci L, Morley JE. SARC-F: a symptom score to predict persons with sarcopenia at risk for poor functional outcomes. J Cachexia Sarcopenia Muscle. 2016 Mar;7(1):28-36. doi: 10.1002/jcsm.12048. Epub 2015 Jul 7. PMID: 27066316; PMCID: PMC4799853.

Middleton G, Golley R, Patterson K, Le Moal F, & Coveney J. (2020). What can families gain from the family meal? *A mixed-papers systematic review. Appetite*.153:104725.

Norman K, Haß U, & Pirlich M. (2021) Malnutrition in Older Adults-Recent Advances and Remaining Challenges. Nutrients. 13(8):2764. doi: 10.3390/nu13082764. PMID: 34444924; PMCID: PMC8399049.

O'Neil, K., Purdy, M., Falk, J. et al. The Dysphagia Outcome and Severity Scale. Dysphagia 14, 139–145 (1999). https://doi.org/10.1007/PL00009595

Papadopoulou, S.K. (2020) Sarcopenia: A Contemporary Health Problem among Older Adult Populations. *Nutrients*. *12*, 1293. https://doi.org/10.3390/nu12051293

Perspectivas demográficas do envelhecimento populacional na Região das Américas. Organização Pan-Americana da Saúde e Comissão Econômica para a América Latina e o Caribe. Washington, DC; (2023). Licença CC BY-NC-SA 3.0 IGO. Disponível em: https://doi. org/10.37774/9789275726792.

Phulkerd, S., Gray, R. S., Chamratrithirong, A., Pattaravanich, U., & Thapsuwan, S. (2023). Financial satisfaction, food security, and shared meals are foundations of happiness among older persons in Thailand. *BMC geriatrics*, *23*(1), 690. https://doi.org/10.1186/s12877-023-04411-1

Prestação de Cuidados (2019) Trabalho e Profissões para o Futuro do Trabalho Digno *Organização Internacional do Trabalho (OIT)*.

Queiroz, Cristina. (2019) Economia do cuidado. *Revista Pesquisa Fapesp*.

Qi Dai, Xiangzhu Zhu, JoAnn E Manson, Yiqing Song, Xingnan Li, Adrian A Franke, Rebecca B Costello, Andrea Rosanoff, Hui Nian, Lei Fan, Harvey Murff, Reid M Ness, Douglas L Seidner, Chang Yu, Martha J Shrubsole, Magnesium status and supplementation influence vitamin D status and metabolism: results from a randomized trial, The American Journal of Clinical Nutrition, Volume 108, Issue 6, 2018,Pages 1249-1258, ISSN 0002-9165, https://doi.org/10.1093/ajcn/nqy274.

Raheem, D., Carrascosa, C., Ramos, F., Saraiva, A., & Raposo, A. (2021). Texture-modified food for dysphagic patients: A comprehensive review. *International Journal of Environmental Research and Public Health*, *18*(10), 5125. https://doi.org/10.3390/ijerph18105125

Red Global de Colaboración Sobre la Carga De Enfermedad. (2019) Resultados del Estudio de la Carga Global de Enfermedad 2019 (GBD 2019). Seattle: Institute for Health Metrics and Evaluation (IHME).

Remelli F, Vitali A, Zurlo A, & Volpato S. (2019, November 21) Vitamin D Deficiency and Sarcopenia in Older Persons. Nutrients. 11(12):2861. doi: 10.3390/nu11122861.

Rosemary D. Dall, May M. Cheung, Patricia A. Shewokis, Asma Altasan, Stella L. Volpe, Renee Amori, Harpreet Singh, Deeptha Sukumar, Combined vitamin D and magnesium supplementation does not influence markers of bone turnover or glycemic control: A randomized controlled clinical trial, Nutrition Research, Volume 110, 2023, Pages 33-43, ISSN 0271-5317, https://doi.org/10.1016/j.nutres.2022.12.005.

Saúde, M. d. (s.d.). (2014) *Guia Alimentar Para a População Brasileira*. disponível em Ministério de saúde: http://www.foodpolitics.com/wp-content/uploads/Brazils-Dietary-Guidelines_2014.pdf

Sayer, Avan Aihie, & Cruz-Jentoft, Alfonso. Sarcopenia definition, diagnosis and treatment: consensus is growing; Age and Ageing; *volume 51*, Issue 10; https://doi.org/10.1093/ageing/afac220

Sociedade Brasileira de Geriatria e Gerontologia (SBGG). (2022). Manual de Recomendações para diagnóstico e tratamento da sarcopenia no Brasil.

Sociedade Brasileira de Geriatria e Gerontologia. (2024). Guia para jornalista na cobertura do envelhecimento. Disponível em: < https://sbgg.org.br/wp-content/uploads/2023/11/1700223168_Guia_para_jornalistas_na_cobertura_do_envelhecimento.pdf>.

Stokic, E., Romani, A., Ilincic, B., Kupusinac, A., Stosic, Z., & Isenovic, E. R. (2018). Chronic latent magnesium deficiency in obesity decreases positive effects of vitamin D on cardiometabolic risk indicators. *Current Vascular Pharmacology*, *16*(6), 610-617. https://doi.org/10.2174/1570161115666170821154841

United Nations. (2020) *World Population Ageing 2019 (ST/ESA/SER.A/444)*. New York: Department of Economic and Social Affairs, Population Division.

United Nations. (2023). *World population ageing 2023: Challenges and opportunities of population ageing in the least developed countries.* United Nations, Department of Economic and Social Affairs, Population Division. Disponível em https://desapublications.un.org/publications/world-population-ageing-2023-challenges-and-opportunities-population-ageing-least

United Nations, Department of Economic and Social Affairs, Population Division. (2025). *Data Portal: User Guide*. United Nations. https://population.un.org/dataportal/about/userguide

US Department of Health and Human Services. (2005). Dietary guidelines for Americans 2005. *http://www. health. gov/dietaryguidelines/dga2005/document/default. htm*.

U.S. Department of Health and Human Services & U.S. Department of Agriculture. (2015). *Dietary guidelines for Americans 2015–2020* (8th ed.). U.S. Government Printing Office. https://www.dietaryguidelines.gov

Volkert D, Beck AM, Cederholm T, Cruz-Jentoft A, Goisser S, Hooper L, Kiesswetter E, Maggio M, Raynaud-Simon A, Sieber CC, Sobotka L, van Asselt D, & Wirth R, Bischoff SC. (2019) ESPEN guideline on clinical nutrition and hydration in geriatrics. Clin Nutr.38(1):10-47. doi: 10.1016/j.clnu.2018.05.024. Epub 2018 Jun 18. PMID: 30005900.

Wintermeyer E, Ihle C, Ehnert S, Stöckle U, Ochs G, De Zwart P, Flesch I, Bahrs C, & Nussler AK. (2016). Crucial Role of Vitamin D in the Musculoskeletal System. Nutrients. 8(6):319. doi: 10.3390/nu8060319.

World Health Organization. (2025). *Number of persons aged 60 years or over (thousands)*. WHO. Disponível em: https://platform.who.int/data/maternal-newborn-child-adolescent-ageing/indicator-explorer-new/MCA/number-of-persons-aged-over-60-years-or-over-(thousands)

Zeppa, D S, Agostini, D., Ferrini, F., Gervasi, M., Barbieri, E., Bartolacci, A., Piccoli, G., Saltarelli, R., Sestili, P., & Stocchi, v. (2023) Interventions on Gut Microbiota for Healthy Aging. *Cells. 12*, 34. https://doi.org/10.3390/cells12010034

Perspectivas demográficas do envelhecimento populacional na Região das Américas. Organização Pan-Americana da Saúde e Comissão Econômica para a América Latina e o Caribe. Washington, DC; 2023. Licença CC BY-NC-SA 3.0 IGO. Disponível em: https://doi. org/10.37774/9789275726792.

CHAPTER 2 - DEVELOPMENT OF RICE ANALOGUE WITH VITAMIN D AND MAGNESIUM FOR POPULATION 60+

Edilaine Silva Lemos Costa[1], Thuane Tomé Alves[2], Monique Barreto Santos[3], Maria Eugenia Araujo Silva Oliveira[1], Carlos Wanderlei Piler de Carvalho[4], Rosemar Antoniassi[4], Renata Torrezan[4], Cristina Yoshie Takeiti[1,4]

[1] Food and Nutrition Graduate Program, Nutrition School, Federal University of the State of Rio de Janeiro (UNIRIO), Rio de Janeiro, (RJ), 22290-250, Brazil

[2]Food Technology Department, Technology Institute, Federal Rural University of Rio de Janeiro, Seropédica, (UFRRJ) Rio de Janeiro, (RJ), 23890-000, Brazil

[3] Graduate Program in Food Science and Technology, Technology Institute, Federal Rural University of Rio de Janeiro, (UFRRJ), Rio de Janeiro, (RJ), 23890-000, Brazil

[4] Embrapa Agroindústria de Alimentos, Avenida das Américas, 2950501, Rio de Janeiro (RJ), 23020-470, Brazil

Abstract

Population aging is a growing global phenomenon, with a projection of 2.1 billion people over 60 years of age by 2050. This group of people seeks strategies for healthy aging such as developing products that delivered their nutritional requirements. Nutrients particularly vitamin D and magnesium are essential at this stage of life, since affect bone and muscle health. However, deficiencies are common due to low intake and limited sun exposure. Food fortification emerges as an effective solution to solve these nutritional deficiencies. Rice, as a cereal widely consumed and well accepted worldwide, is a promising ingredient for fortified products. Extrusion is a technology that operates with shear and high temperatures and can be used to formulate fortified foods. Rice analogue can be enriched with pulses, such as cowpea flour since is rich in fibers and proteins that contain essential amino acids. Therefore, this study was conducted in order to obtain a rice analogue enriched with vitamin D and magnesium using thermoplastic extrusion and pastification process. Rice flour (RF), bean flour (BF), extruded rice flour (ERF) and emulsified extruded rice flour (EERF) were processed by milling and thermoplastic extrusion. The rice analogues (T1, T2, T4, T7, T7+, T8, T9, T9+) were formatted using pasta-making process from mixture of these flours in different proportions. The analogues showed 7.29 - 7.91 mm of lenght, 2.49 - 2.76 mm of width and 2.48 - 2.83 mg/grain and were classified as long grain. The cooking time was shorter (6 to 12 minutes) than the control rice (14 minutes), presenting a water uptake ratio of 59-152 % and 5.08 - 15.95 % of soluble solid loss. TPA texture profile revealed 8.72 - 46.48 N of hardness, 2.50 - 12.94 N of chewiness and 2.78-26.65 gumminess, comparable to polished rice. The colour measurements showed a whiteness index (WI) of 83.06 - 90.45, that similar than control (93.19). Regarding pasting properties, 477.33 - 683.66 PV, 47.33 - 399 SB and 474 - 1762 tendency to retrogradation that representing a differential advantage considering the looseness consumer preference. In addition, thermal characteristics determined by DSC showed a gelatinization temperature of 78.79 - 86.04 ºC that is similar to polished rice (83.01). In terms of proximate composition, the rice analogues showed 7.65 % of proteins, 0.81 % of dietary fiber and 187.14 J/g of energy value/ 50 g portion. Finally, the analogues (T7+, T9+) are classified as "rich in vitamin D and magnesium", as it provides at least 4.53 μ/100g of vitamin D and 278 mg/100g of Mg. Furthermore, Principal Coordinate Analysis (PCoA) indicated the $T9^{+}$ formulation as the most similar to the control in terms of cooking loss and hardness. With these results, we highlight that the technological qualities of the analogues were improved by the use of extruded flour.

Keywords: Aged 60; Thermoplastic extrusion; Fortification; Pulse flour; Pastification

1 Introduction

Population aging is a global and demographic phenomenon of the 21st century and one of the challenges is the health and well-being promotion of population aged 60 years or over (United Nations, 2023). The world population over 60 years has now reached 1.2 billion people, with a projection of 2.1 billion by 2050 (WHO, 2025). In Brazil, 16.6 % of the population is over 60 years old, and it will reach 29.3 % by 2050 (IBGE, 2024).

Members of *Generation X* (Gen X), who are currently in their mid-40s-to-late 50s (born between around 1965 and 1979), are earlier adopter of new approach to healthy ageing that includes products that will help them thrive in their diverse lifestyles for decades to come. Products addressed to these consumers must consider nutritional, physical, mental and emotional requirements, by seeking to innovate in formulations that properly attend these issues (Mintel, 2024). At this stage of life, important nutrients include vitamin D, vitamin K, calcium, magnesium, phosphorus, proteins, and fatty acids that act in bone and muscle metabolism can protect it, since vitamin and mineral deficiencies throughout life can damage the health of the elderly and lead to some chronic clinical symptoms (Bruins; Dael; Eggersdorfer, 2019).

Vitamin D, a fat-soluble vitamin, is the main regulator of serum calcium and phosphorus homeostasis. It also participates in cell differentiation and proliferation and has effects on the responses of the immune and nervous systems (EFSA, 2016). Vitamin D belongs to the calciferol group, with its two main compounds denominated as vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol) (Figure 1). The differences between the D_2 and D_3 forms do not affect metabolism and both of them present identical responses with the same efficiency (IOM, 2010).

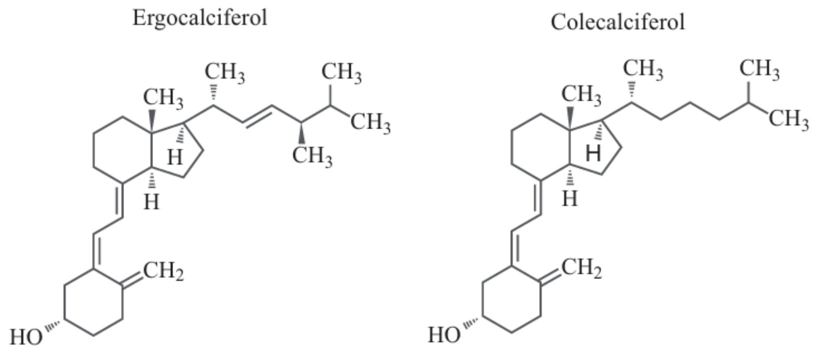


Figure 1. Chemical structures of ergocalciferol (vitamin D_2) and cholecalciferol (vitamin D_3)

Approximately 90 % of vitamin D is produced in the skin through sun exposure and 10 % is obtained through diet, via sources such as UV-exposed mushrooms, eggs, cod liver oil, and high-fat fish. Its production occurs in the skin varying according to age, ethnicity, pigmentation, sun exposure, and use of sunscreen. Elderly people are submitted to elevate risk of vitamin D deficiency due to limited exposure to sunlight (Hoss et al., 2023). Vitamin D deficiency is prevalent worldwide and the absence of food fortification with vitamin D leads to low dietary intake (Glendenning, Inderjeeth, 2016).

Magnesium is primarily involved in the development and maintenance of bones, but it also performs several essential biological functions, such as regulating metabolic and biochemical reactions, participating in protein synthesis, and playing a key role in nerve and muscle function, heart rate, muscle contraction, and bone health (Awuchi et al., 2020; Rosanoff, Shapses, 2016). Inadequate intake of this mineral has been reported in several parts of the world (Carbajal, 2013; Peltonen et al., 2008; Helldán et al., 2012; Amcoff, 2012; Van Rossum et al., 2011; Sette et al.,2011; Olza et al., 2017).

Therefore, food fortification is an efficient and viable option to supplement different people groups with underachieved requirements due to inadequate dietary intake. According to the technical regulation on requirements for food enrichment, RDC No. 714 (July 1, 2022) of the Ministry of Health, the definition of enriched foods is those that contain the addition of one or more nutrients for the purpose of reinforcing their nutritional value or preventing or correcting nutritional deficiencies, and must appear on the label as “Enriched with” or “Fortified with”. In addition, the value of the added nutrient must be considered per 100 mL or 100 grams of the ready-to-eat product (Brazil, 2022).

Rice (*Oryza sativa* (L)) is a cereal with potential for the development of fortified foods since it represents one of the main foods consumed in Brazil and Asia. Approximately 10 million tons are produced in Brazil and 800 million tons worldwide (FAOSTAT, 2023). Some intrinsic characteristics of rice lead it to be widely accepted by most consumers including *gluten-free, hypoallergenic, easily digestible, mildly flavored, small granules, white in color*, and considerable *freeze-thaw stability* if compared to pulse starches (Bemiller, 2009). Rice analogue is an alternative substitute for rice grains due to shaped-like rice, obtained by different ingredient mixtures, presenting similar properties of rice, and delivering health benefits. Fortified rice analogue can provide the daily nutrient, vitamin, and mineral requirements of the senior citizens (Sumardiono et al., 2021).

Extrusion emerges as a technology that can be used in order to formulate fortified foods such as rice analogue. Both cold extrusion and thermoplastic extrusion processes involve passing a mixture of flours, additives and water through a single or twin-screw extruder. Thermoplastic extrusion involves temperatures above 70 °C in contrast to cold extrusion that does not use heating except heat generated during the process itself (Mishra et al., 2012; Chaturvedi; Manickavasagan, 2024). In addition, thermoplastic extrusion is a process that mechanical action of screws is combined with external heat to knead continuously the material, gelatinize starch, denature protein materials and inactivate enzymes, and forming new structures (Clerici; El-Dash, 2008). In this process, changes occur in the structures of the materials, including phase transition, molecular degradation and rearrangement of molecular structures attributed to the effects of heat, shear and pressure generated by the extruder (Ek et al., 2021).

Some legume flours, such as bean flour, can be incorporated into the preparation of analogues to increase fiber content, quantity and quality of proteins, and micronutrients (Sumardiono et al., 2023). Cowpea (*Vigna unguiculata*) is a good option because it is a nutritious legume that provides proteins, fibers, vitamins, and minerals (Moutaleb et al., 2017). In addition, it is also rich in essential amino acids such as lysine, leucine, and tyrosine (Elharadallou et al., 2015). Emulsifiers are also important ingredient in the preparation of analogues that is often added to the flour mixture in order to reduce the loss of mass solids in the water during cooking and increase the uniformity, thickness, and shine of the dough (Nabeshima et al., 2003). Besides, emulsifiers also improve the texture of the final product (Steiger, Müller-Fischer, Cori, and Conde-Petit, 2014). Thus, the present study was carried out aiming a developing of rice analogue enriched with vitamin D and magnesium, using rice flour, cowpea flour, emulsifier and vitamin mineral mix, through extrusion techniques, evaluating the physicochemical properties and nutritional quality.

2 Material and Methods

2.1 Material

Polished white rice was purchased from a local market (Rio de Janeiro, RJ, Brazil). Cowpea (*Vigna unguiculata* (L.) Walp.) was kindly donated by Granfino (Nova Iguaçu, RJ, Brazil). The vitamin-mineral mix formulated with maltodextrin, magnesium sulfate monohydrate, and cholecalciferol was donated by Sattwa Industria, Comercio e Serviço S.A (Colônia, São Paulo, Brazil), and the emulsifier calcium stearoyl-2-lactyllactate (CSL) (GRINDSTED CSL P 2522) was donated by Danisco Brasil Ltda (Cotia, São Paulo, Brazil). The cholecalciferol chromatographic standard used to determine vitamin D was purchased from Merck/Sigma Aldrich (code C9756-5G, Darmstadt, Hesse, Germany).

The strategy adopted in order to carry out the experiments was divided into stages: (i) preparation of the matrix with analogue formulations (9); (ii) selection of the formulations based on the best analogue formation (6); (iii) cooking test of selected formulations; (iv) selection of two best formulations in terms of the cooking test for vitamin mix addition; (v) evaluation of the physical and chemical properties of the formulations (T1, T2, T4, T7, T7+, T8, T9, T7+) and centesimal composition, quantification of vitamin D and microelements of the formulations (T7+, T9+) (Figure 1).

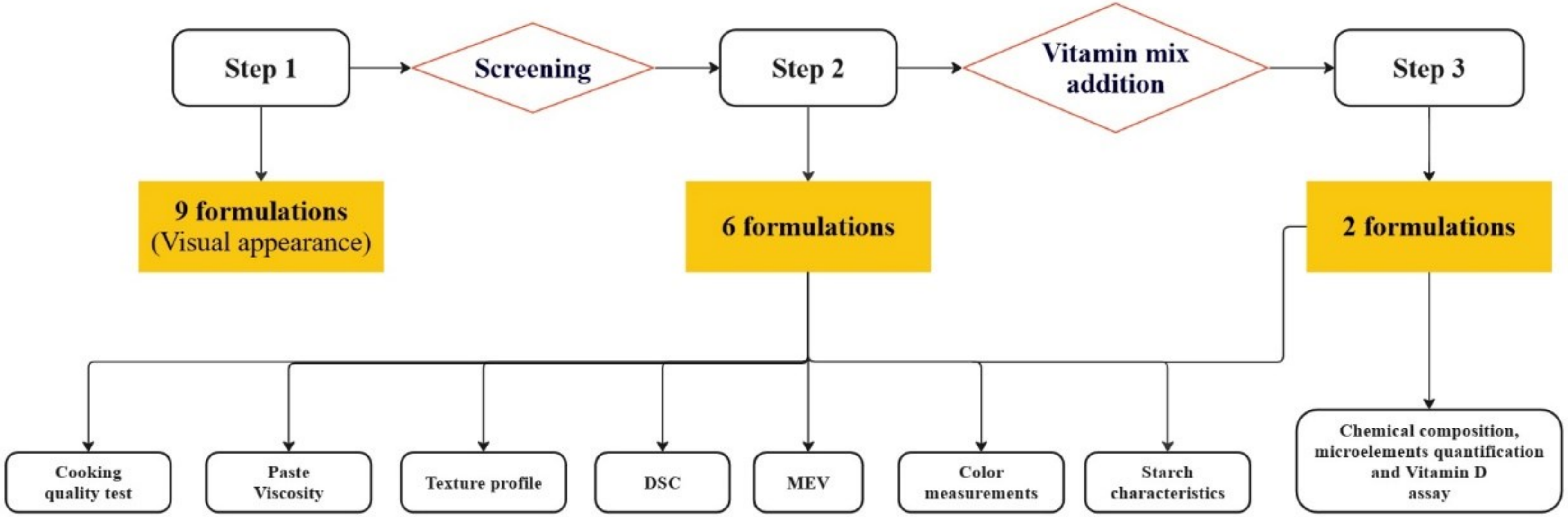
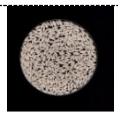
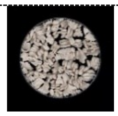
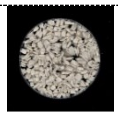
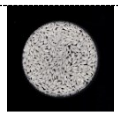


Figure 1. Sequential experiment strategy for screening of formulations.

Table 1. Formulations and visual appearance of the analogues

Sample	RF (%)	ERF (%)	EERF (%)	BF (%)	CSL (%)	Mix (%)	Analogue formation	Dry product
T1	50	50	-	5	0.5	-	Yes	
T2	50	50	-	10	0.5	-	Yes	
T3	50	50	-	5	-	-	No	
T4	50	50	-	10	-	-	Yes	
T5	50	50	-	-	0.5	-	No	
T6	50	50	-	-	1	-	No	
T7	50	-	50	5	0.5	-	Yes	
T8	50	-	50	10	0.5	-	Yes	
T9	50	-	50	-	0.5	-	Yes	
T7^{+}	50	-	50	5	0.5	2	Yes	
T9^{+}	50	-	50	-	0.5	2	Yes	

Where: RF (raw rice flour), ERF (extruded rice flour), EERF (emulsified extruded rice flour), BF (raw bean flour), CSL (calcium stearoyl-2-lactyllactate), MIX (Mg+Vit.D), $^{+}$ mix addition

2.2 Preparation of raw flours

Raw rice flour (RF) was prepared using a Lab Mill 3100 hammer mill (Perten Instruments AB, Huddinge, Sweden) equipped with a 0.8 mm sieve. Raw bean flour (BF) was prepared using a 3600 disc mill (Perten Instruments AB, Huddinge, Sweden) with a 0.6 mm gap between discs. The flours were packaged and stored in a refrigerator 4ºC for further processing.

2.3 Preparation of extruded flours

Extruded rice flour (ERF) were prepared using RF and emulsified extruded rice flour (EERF) was prepared using RF and 0.5 % emulsifier, which were previously mixed for 15 min using a TE-201/05 homogenizing agitator (Tecnal, São Paulo, Brazil) before submitted to extrusion processing. The flours were processed in an Evolum HT25 twin-screw co-rotating extruder (Clextral Inc., Firminy, France), with a length:diameter ratio of 40:1, equipped with a 6 mm diameter circular die, operating at a rotation speed of 250 rpm and mass flow rate of 5,27 kg/h. The cylinder with ten heating zones was regulated at temperatures of 25, 25, 40, 50, 90, 100, 100, 90, 70 and 70 °C, from the feeding zone to the exit die. The water flow rate (2,3 L/h) was controlled by injecting potable water between the first and second zones of the extruder through a port with an internal diameter of 5.25 mm, using a plunger metering pump Super K PP 6.35 (DKM Clextral Inc., Firminy, France). Finally, the extruded material was dried at 40 °C for 16 h in a food dehydrator (DMS-G. E, Macanuda, Joinville, Brazil), cooled to room temperature, ground in a 3600 disc mill (Perten Instruments AB, Huddinge, Sweden) with a 0.6 mm diameter to reduce it to smaller pieces and then in a Lab Mill 3100 hammer mill (Perten Instruments AB, Huddinge, Sweden) to obtain flours and stored in polyethylene plastic bags for later use.

2.4 Rice analogue preparation

The rice analogues were prepared with a mixture of RF, BF, EERF, emulsifier and vitamin-mineral mix according to Table 1. Each mixture flour was added with 33 % cold water and homogenized continuously for 5 min in a M5A planetary mixer (Guangzhou Panyu Jianye Imp. & Exp. Trading Co. Ltd, Guangzhou, China). The analogues were formatted using a pasta production machine (Pastaia 2, Italvisa, Tatuí-SP, Brazil) coupled with a *risoni* die (Figure S2).

A target concentration of magnesium of 126 mg/kg and vitamin D of 4.5 µg/kg was defined considering a magnesium daily reference value (DRV) of 420 mg and vitamin D of 15 µg (Annex II of IN 75/2020). In order to achieve the desired concentration, 2 % of the vitamin-mineral mix was added to the T7 and T9 formulations. All analogues were dried in an oven (Fabbe-Primar Ind., São Paulo, Brazil) with hot air circulation at 40°C for 16 hours and packaged in metallized plastic packaging and kept refrigerated 4ºC for subsequent analyses.

2.5 Physical properties

2.5.1 Paste viscosity

The paste viscosity profiles were measured with a Rapid Visco Analyser (RVA) series 4 (Newport Scientific Pty. Ltd., Warriewood, Australia, equipped with Thermocline for Windows software) running at 160 rpm and an initial temperature of 25 °C (Carvalho et al., 2010). Three grams of the sample were adjusted to 14 % of water (wet basis) and mixed with 25 mL of distilled water in an RVA aluminum container. The properties evaluated were paste temperature (Tp), peak viscosity (VP), setback, breakdown and final viscosity (VF). The viscosity values were recorded as centipoises (cP). All measurements were carried out in triplicates.

2.5.2 Texture analysis

Texture profile analysis (TPA) of the cooked analogue was conducted to evaluate parameters such as hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience, determined according to the definition provided by Bourne (2002). The texture of the samples was measured using a TA XT Plus Exponent texture analyzer version 6.1.11.0 (Stable Micro Systems, Surrey, UK). Twenty selected cooked rice grains were placed on the objective table symmetrically and compressed with a Probe P025, 75% sample compression and a 5 kg load cell. The pre-test, test and post-test speeds were fixed at 2, 5 and 5 mm/s, respectively and compression time of 5 s between cycles (Xia et al., 2017). Twenty specimens per sample were evaluated. The results comprised the average of the runnings.

2.5.3 Differential scanning calorimetry (DSC)

Thermal properties were performed in duplicate using a DSC Q200 (TA Instruments, New Castle, USA). The onset (To), peak (Tp), and completion (Tc) gelatinization temperatures, as well as the calorimetric enthalpy (ΔH) values were calculated based on the thermograms using Advantage software version 5 (TA Instruments, New Castle, USA). Approximately 2 to 3 mg aliquots of the analogue flour were added with deionized water in a 1:2 ratio (analogue:water) were placed in an aluminum pan. The pans were sealed and stored at room temperature for at least 2 h prior to analysis. An empty pan was used as a reference. The scanning occurred in the range of 5 to 110 °C at a rate of 10°C/min (Bernardo et al., 2018).

2.5.4 Color measurements

Colorimetric measurements of the analogue flours were performed using a portable colorimeter CR-400 (Konica Minolta, Tokyo, Japan) in at least 5 replicates (CIELab*, 1978). The equipment was standardized with a white block (Y = 93.01; x = 0.3139; y = 0.3200) using illuminant D65 and a 2° observer. The color parameters were recorded by measuring the values of lightness (L), yellow intensity (b*) and red intensity (a*). The whiteness index was calculated using the formula (1) (CIELab, 1978).

$$W.I.=100- \sqrt{(100-L)^2+a^2+b^2} \qquad (1)$$

2.6 Morphology characteristics

The microstructure of rice was observed using a Benchtop TM 3000 scanning electron microscope (SEM) (Hitachi, Tokyo, Japan), which operated in an evacuated chamber at 15 kV acceleration. Rice grains were dried in a desiccator with sodium chloride ($CaCO3$) for 15 days and then fixed with double-sided tape on an aluminum stub. Captures were made at 30 and 100X magnification (Vargas-Solórzano et al., 2019).

2.7 Cooking quality test

Cooking quality test was performed according to the 16-50 method (AACC, 1995). The cooking time was determined using aliquots of 10 g of pasta cooked in 140 mL of boiling water. The optimum time was measured by compressing the sample of the cooked product, every 1 min, between two glass plates until the central nucleus disappeared. The percentage of weight increase of the cooked product was determined by the ratio between 10 g of raw rice and its weight after cooking, using the optimum cooking time of each sample. The values were expressed as a percentage (2). The loss of soluble solids in the cooking water was determined by removing 25 mL of the cooking water and placing it in an oven with air circulation at 105 ºC for 16 h. The solids were weighed and the loss of soluble solids (SS %) was calculated (3).

$$AP (\%) = ((PF/PI) \times 100) - 100 \quad (2)$$

$$SS (\%) = (PR (g) \times Vc (mL) / PA (g) \times Va (mL)) \times 100 \quad (3)$$

2.8 Analogue dimension

The dimensions (length and width) of the analogs were measured using a 150 mm digital caliper model 316119 (MTX, Moscow, Russia). The weight of each grain was determined using a Shimadzu analytical balance model AUX 320 (Shimadzu Corporation, Kyoto, Japan).

2.9 Chemical characterization

2.9.1 Chemical composition

The chemical composition of the analogues with addition of the vitamin-mineral mix and the control was performed according to the AOAC methods (2000). Protein content was calculated using method 2001.11 (factor of 6.25) with modification, ash (method 923.03), total dietary fiber (method 991.43), moisture (method 934.01) and carbohydrate content was calculated by the difference. Fat content was determined according to method Am 5-04 (AOCS, 2005).

2.9.2 Starch characteristics

The amylose content of the raw analogue was determined using K-AMYL kit (Megazyme International, Bray, Ireland) following the method 79-13 (AACC, 2000). The resistant starch content was determined using K-RSTAR kit (Megazyme Interrnational, Bray, Ireland) according to methods 2002.02 (AOAC, 2002) and 32-40.01 (AACC, 2000).

2.9.3 Microelements quantification

The quantification of microelements (magnesium, sodium, potassium, calcium phosphorus, manganese, iron, zinc, copper) was performed according to methods 990.10 and 999.08, respectively (AOAC, 2010). For sample digestion, cavity microwave mineralization was used model MARS5 (CEM, Matthews,USA) with maximum power of 1600 W, heating ramp of 20 min up to 180 °C and plateau of 180 °C for 20 min. After digestion, quantification was performed in an inductively coupled plasma optical emission spectrometer (ICP-OES) model Optima 2100DV (Perkin Elmer, Shelton, USA), with a cyclonic nebulization chamber and concentric nebulizer, with sequential optics and dual-view torch visualization.

2.9.4 Vitamin D assay

In order to determine vitamin D contents, formulations $T7^{+}$ and $T9^{+}$ were packaged in metallic plastic bags and stored at room temperature during 0 and 4 months. The analogues were ground in a Lab Mill 3100 hammer mill (Perten Instruments AB, Huddinge, Sweden) equipped with a 0.8 mm sieve to obtain a fine flour.

Then samples were extracted for 15 min with 0.1N HCl and 95 % ethanol at 55°C, and the extract underwent liquid-liquid extraction with hexane. The hexane extract was evaporated in a rotary evaporator and the solid residue dissolved in isopropanol. Vitamin D was separated in UPLC Acquity HClass (Waters, Massachusetts, USA) with a C18 column model Acquity UPCL Beh C18 1.7 µm (Waters, Wexford, Ireland) and gradient elution of methanol and water acidified with formic acid (0.1%). Detection was by triple-quadrupole mass spectrometry with Xevo TQD (Waters, Massachusetts, USA) with electron spray ionization in positive mode (ESI+). Quantification was done using the chromatogram of the mass transition 385-259 m/z. For the purpose of confirm the identity of the presence of vitamin D_3, the transitions 385>367, 385>259, 385>255 and 385>241 were used. Only the peak eluting close to 4.49 min (cholecalciferol peak) was considered and the peak 4.23-4.35 minutes was discarded for quantification.

The Vitamin D_3 standard used was reference C9756-5G (Sigma-Aldrich, St. Louis, USA). The retention time (RT) of Vitamin D_3 was 4.49 min. Three concentration points were injected, in the working range of 100 to 300 ng/mL.

2.10 Statistical Analysis

All results were expressed as mean ± standard deviation (SD). Statistical analysis was performed with one-way ANOVA, followed by Tukey's HSD test ($p < 0.05$) using XLSTAT software version 2023.2.0 (Lumivero, Denver, USA). Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA), and Radar Chart analyses were performed by XLSTAT.

3 Results and discussion

3.1 Pasting properties

The Rapid Visco Analyser (RVA) paste properties are used to measure the viscosity of food products such as pastes, flours, starches, proteins. This technique is essential in the food industry, as it allows the quality of both raw materials and final products to be assessed.

Pasting curves of the rice analogues samples exhibited similar profile (Figure 2), showing a tendency for retrogradation during cooling, while control (polished white rice) was distinguished among all of them. Pasting temperature, peak viscosity, breakdown viscosity, final viscosity, and setback of rice analogues ranged from 57.20 to 68.16 °C, 454.66 to 3352.33 cP, 47.44 to 1073.33 cP, 1018.33 to 7492.66 cP, and 474.00 to 4140.33 cP (Table S1). The addition of different concentrations of BF cause changes in the paste properties, especially in PT, FV and SBV values ($p<0.05$) (Formulation T4). This result was already expected, since the proteins present in the bean interact with the starch changing the properties of the paste (Carvalho et al., 2013).

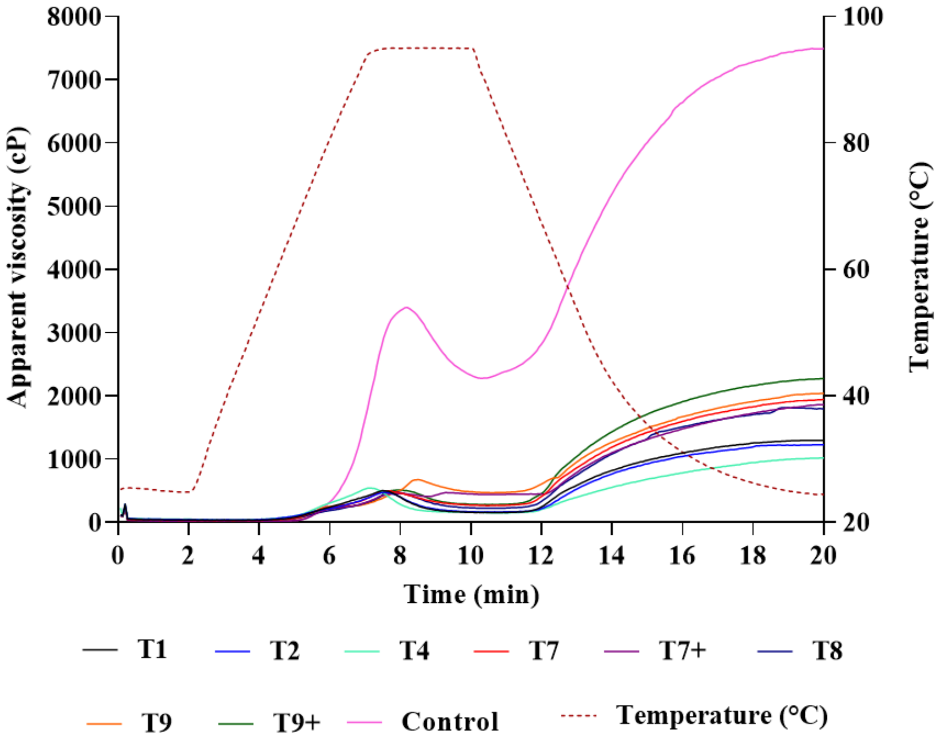


Figure 2. Paste viscosity properties of rice analogues. Where: T1= (50 % RF, 50 % ERF, 5 % BF, 0.5 % CSL); T2= (50 % RF, 50 % ERF, 10 % BF, 0.5 % CSL); T4= (50 % RF, 50 % ERF, 10 % BF); T7= (50 % RF, 50 % EERF, 5 % BF, 0.5 % CSL); $T7^{+}$= (50 %, 50% EERF, 5% BF, 0.5% CSL, 2% Mix), T8= (50% RF, 50% EERF, 10% BF, 0.5 % CSL); T9= (50% RF, 50% EERF, 0.5 % CSL); $T9^{+}$= (50 %, 50% EERF, 0.5% CSL, 2% Mix)

The addition of the vitamin-mineral mix caused a reduction in all pasting properties of formulation T7+ showed the lowest value (454.66 cP) of peak viscosity (PV) and breakdown (BDV) (47.33 cp) ($p< 0.05$). In contrast, the addition of vitamin-mineral mix to formulation T9 (without BF) leads to an increase of parameters related to cooling stage (BDV, SBV and FV) ($p<0.05$).

3.2 Texture profile analysis (TPA)

Texture Profile Analysis (TPA) is a method widely used in food science to measure textural characteristics. The procedure consists of compressing a small sample of food twice with a specific probe, simulating the movement of a bite. From the force-time curve generated, several textural parameters are extracted that present a good correlation with the sensory perception of these attributes.

The texture profile of rice analogues is shown in Figure 3 and Table S2. The hardness of the analogues ranged from 5.71 to 46.48 N, and formulation T7 showed the highest value, 4.5-fold higher than the control ($p<0.05$). The addition of vitamin-mineral mix conducted to a decrease of hardness, gumminess and chewiness regarding formulations 7^+ and 9^+ and comparable to the control values ($p< 0.05$), i. e. as similar as polished rice that is a traditional form of consumption. The palatability of cooked rice is one of the factors that affect its quality. Hardness is the most important evaluation parameter, since high values can interfere with its sensory acceptance, and it is an important human sensory perception (Okabe, 1979; Chaturvedi; Manickavasagan, 2025). Our results agree with Budi et al. (2015) who found similar hardness values (16.77 - 42.74 N) in a rice analogue using yellow corn flour, corn starch, glycerol mono stearate, and water.

Food texture preference changes with age. The aging can lead to physiological changes in the oral digestive system, such as: tooth loss, reduced saliva, decreased flexibility of the tongue and masticatory muscles (Mosca; Chen, 2017). These changes lead to increased swallowing difficulties and the risk of aspiration of food residues (Guo et al., 2025). Thus, soft foods are the most suitable and preferred by elderly consumers due to the physiological conditions of the oral cavity.

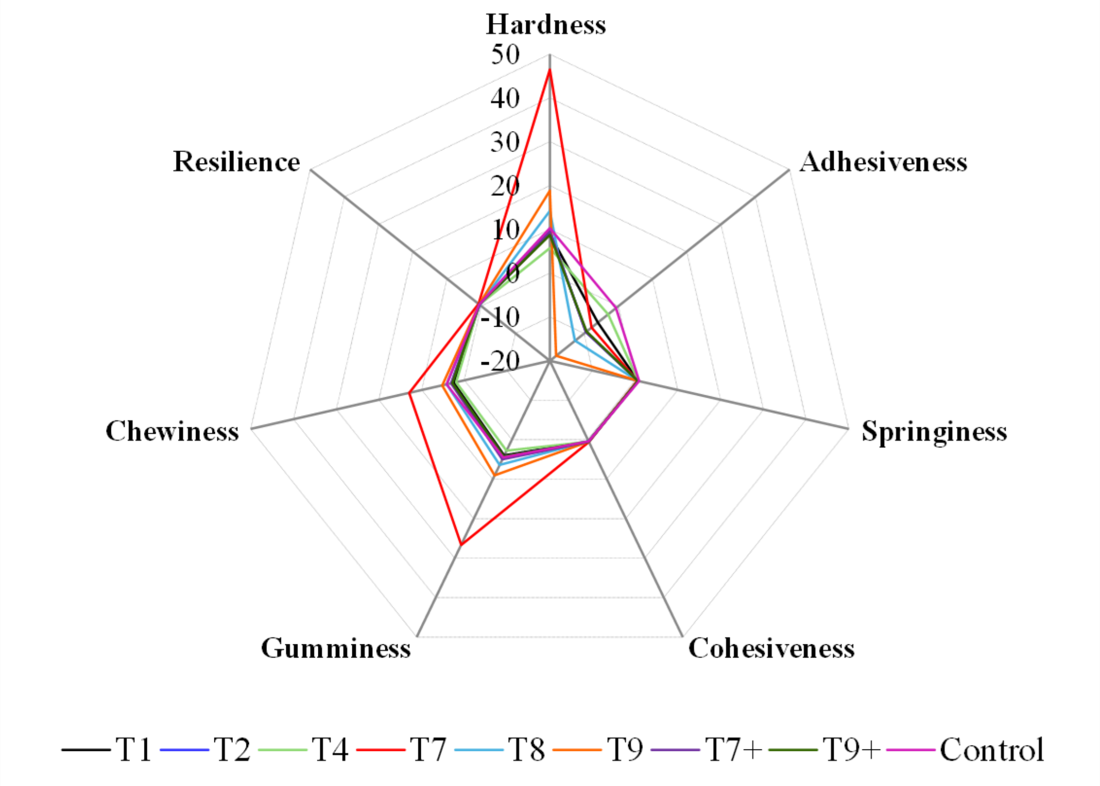


Figure 3. TPA profile of rice analogues. Where: T1= (50 % RF, 50 % ERF, 5 % BF, 0.5 % CSL); T2= (50 % RF, 50 % ERF, 10 % BF, 0.5 % CSL); T4= (50 % RF, 50 % ERF, 10 % BF); T7= (50 % RF, 50 % EERF, 5 % BF, 0.5 % CSL); T7^{+}= (50 %, 50% EERF, 5% BF, 0.5% CSL, 2% Mix), T8= (50% RF, 50% EERF, 10% BF, 0.5 % CSL); T9= (50% RF, 50% EERF, 0.5 % CSL); T9^{+}= (50 %, 50% EERF, 0.5% CSL, 2% Mix)

Based on Table S2, adhesiveness of the analogue ranged from −2.93 to −16.4 g.sec, which was lower than the control (−0.65 g.sec), that is an interesting characteristic in terms of mastication. The adhesiveness refers to the stickiness of rice during decompression or the energy required to pull the compression plunger away from the rice (Kasapis, 2009). Yu et al. (2009) observed that the stickiness of milled rice has a negative correlation with amylose content, which may be attributed to its high value that tends to leach out the gelatinized starch granule and form a coated surface on the rice grain, thus contributing to reduce stickiness (Patindol et al., 2010).

3.3 Thermal properties

DSC is an useful thermal analysis method to study the gelatinization characteristics of starches, and the results are summarized in Table 2. The onset temperatures (To), peak temperatures (Tp) and conclusion temperature (Tc) ranged from 60.75 to 66.2 °C, 68.1 to 73.8 °C and 78.79 to 87.81 °C, respectively, however, statistical difference was not observed concerning T_o and T_p ($p<0.05$).

Particularly in case of $T7^+$ formulation, the vitamin-mineral mix addition conducted to a large increase of enthalpy (2.46 to 5.28 J/g) probably related to V-type amylose complex formation since this mix contain vitamin D that is fat-soluble (Gu et al.,2025). Nevertheless, all analogues presented lower enthalpy (ΔH) than the control as expected, suggesting that less energy was required to disrupt the internal bonds of starch molecules considering that all formulations used at least 50 % of extruded flours. Thermoplastic extrusion can cause a starch degradation, physically modifying the granules, resulting in a reduction in ΔH (Zhao et al., 2022). Wang et al. (2020) also observed this reduction in enthalpy of rice analogue using broken indica rice flour: purple sweet potato powder (90:10). These authors attributed this reduction to the hydrogen bonds between starch molecules that were broken, suggesting that less energy was needed to disrupt the internal bonds of starch molecules.

During extrusion, the use of high pressure and temperature could destroy the original structure present in crystalline and non-crystalline regions of the starch present in the granule, which reduces the number of sites accessible for interaction with water and inhibits the starch swelling capacity, decreasing the enthalpy (Zhang et al., 2023).

Table 2. Thermal properties and colour characteristics of rice analogues

Samples	DSC parameters				Color measurements			
	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	L*	a*	b	W.I.
T1	62.31±0.98^{a}	70.17±0.89^{a}	84.73±1.87^{a}	2.34±0.21^{bc}	89.67±0.20^{e}	0.00±0.00^{e}	9.14±0.22^{d}	86.21±0.28^{e}
T2	62.34±1.06^{a}	69.94±0.40^{a}	82.95±2.36^{ab}	1.47±0.49^{c}	87.28±0.13^{g}	0.52±0.04^{b}	10.75±0.08^{b}	83.34±0.12^{h}
T4	66.2±4.75^{a}	73.8±3.90^{a}	86.04±2.15^{a}	1.79±0.66^{c}	88.30±0.04^{f}	0.58±0.01^{a}	9.96±0.15^{c}	84.62±0.12^{g}
T7	63.83±0.35^{a}	70.35±0.39^{a}	78.79±0.00^{b}	2.46±0.24^{bc}	89.54±0.09^{e}	-0.23±0.02^{h}	10.11±0.08^{c}	85.44±0.11^{f}
$T7^{+}$	65.48±1.01^{a}	72.28±0.95^{a}	87.81±1.07^{a}	5.28±0.03^{b}	90.76±0.25^{d}	0.26±0.03^{c}	7.18±0.20^{e}	88.29±0.32^{d}
T8	65.61±0.67^{a}	72.04±0.34^{a}	83.21±0.15^{ab}	2.79±0.14^{bc}	87.44±0.12^{g}	0.15±0.04^{d}	11.36±0.12^{a}	83.06±0.16^{h}
T9	65.07±2.88^{a}	71.92±2.04^{a}	82.91±0.43^{ab}	3.90±1.52^{bc}	92.52±0.17^{b}	-0.26±0.11^{h}	5.92±0.14^{f}	90.45±0.22^{b}
$T9^{+}$	60.75±0.62^{a}	68.49±0.19^{a}	83.21±0.71^{ab}	3.91±1.94^{bc}	91.98±0.11^{c}	-0.17±0.01^{g}	6.20±0.80^{f}	89.86±0.14^{c}
Control	61.22±0.29^{a}	68.1±0.25^{a}	83.01±0.57^{ab}	8.92±0.15^{a}	95.58±0.05^{a}	-0.06±0.02^{f}	5.18±0.07^{g}	93.19±0.09^{a}

Note: Values are mean (n=3) ± standard deviation. Data with same letters in the same column did not differ significantly by Tukey test ($p < 0.05$). Where: T_0= Temperature onset, T_p = Peak temperature, T_c= Conclusion temperature, ΔH= Enthalpy and W.I.= Whiteness index, T1= (50 % RF, 50 % ERF, 5 % BF, 0.5 % CSL); T2= (50 % RF, 50 % ERF, 10 % BF, 0.5 % CSL); T4= (50 % RF, 50 % ERF, 10 % BF); T7= (50 % RF, 50 % EERF, 5 % BF, 0.5 % CSL); $T7^{+}$= (50 %, 50% EERF, 5% BF, 0.5% CSL, 2% Mix), T8= (50% RF, 50% EERF, 10% BF, 0.5 % CSL); T9= (50% RF, 50% EERF, 0.5 % CSL); $T9^{+}$= (50 %, 50% EERF, 0.5% CSL, 2% Mix).

3.4 Color measurement

The color of food products has a significant impact on purchase intention and consumer acceptance. The color measurements of the analogues are presented in Table 2. The L value ranged from 87.28 to 92.52 and was observed that all measurements presented significant statistical difference ($p<0.05$). It was observed that the L value decreased in the samples with 10 % bean flour addition (T2, T4, T8), which can be attributed to the composition of the flour due to the colored pigments presented in the grain pericarp (Pintel et al., 2024). In contrast, the combined effect of low BF content on formulation and the addition of the vitamin-mineral mix (T7, $T7^{+}$, T9 and $T9^{+}$) led to the L values similar to the control (95.58). In fact, the W.I. of these fortified samples are closer to the control value (88.29 and 89.86).

3.5 Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) images (Figure 5) showed that all rice analogues had irregular, rough and porous surfaces. The rough and porous surface may be due to heterogeneous mixing during processing, in addition to the shear at the die exit and drying conditions after extrusion process. As observed by SEM micrographs, the surfaces are not compact as indicated by a yellow oval and a red arrow. This suggests that the process may not provide sufficient cohesion and structure to form a smooth and compact grain. In fact, Liu et al. (2022) suggests that prolonged mixing may improve the appearance of the analogues.

Cracks and irregular pores were observed in the longitudinal section of all the analogues, which may be due to drying conditions and retrogradation during cooling.

A more compact analogue improves the texture and prevents the loss of solid components during cooking. The cracks were suggested to be channels for water penetration during cooking (Ogawa et al., 2003). No differences were observed in the rice analogues with the addition of vitamin mixture.

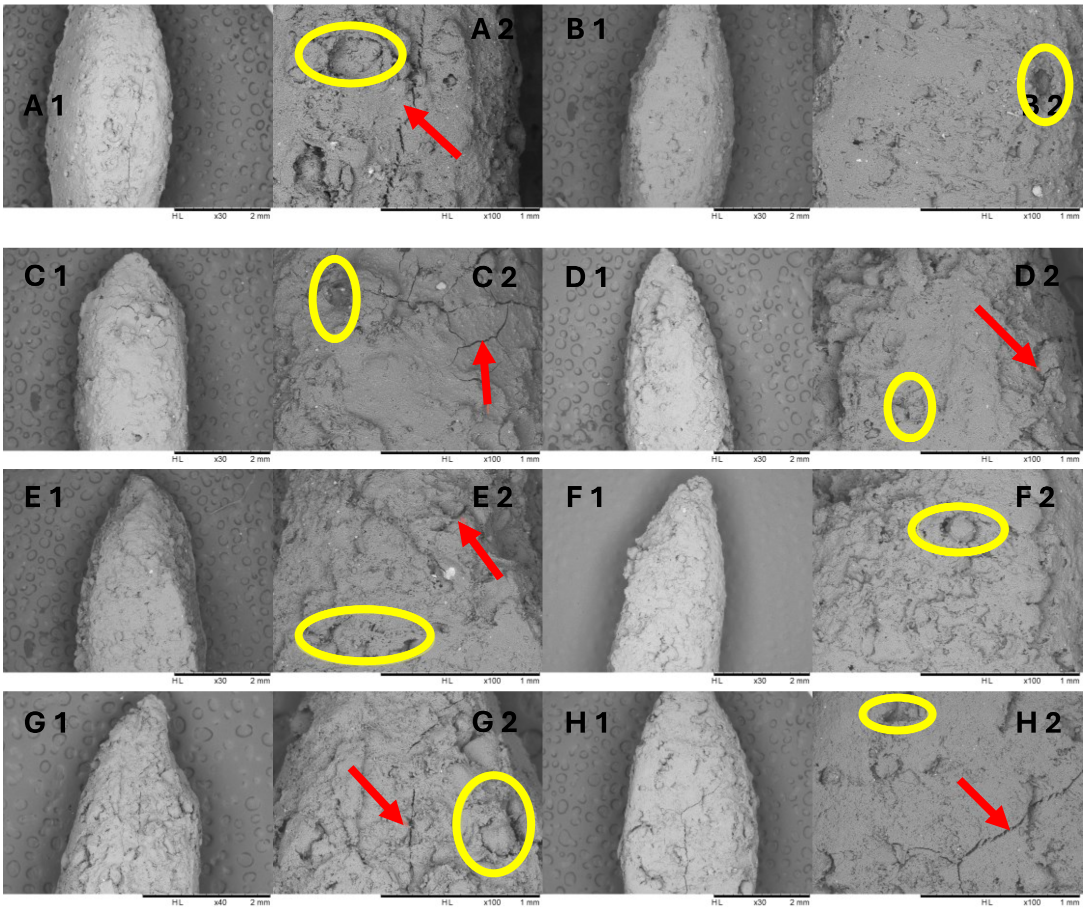


Figure 5. Scanning electron microscopy (SEM) images of rice analogues (A) T1, (B) T2, (C) T4, (D) T7, (E) T8, (F) T9, (G) T7+, (H) T9+. A1–H1 are whole grain longitudinal section images at 30× magnification; A2–F2 are whole grain longitudinal section images at 100× magnification. Yellow shape (rough and irregular surface), red arrow (cracks).

3.6 Analogue dimension

The dimensions of the rice analogues are shown in Table 3. The length and width of the analogues ranged between 7.29 to 7.91 mm and 2.48 to 2.83 mm, respectively. It was observed that there was no significant difference in length and width among the analogues, except for $T9^{+}$ in case of length. The dimensions obtained by analogues were larger than control (6.69 × 2.02 mm, L/W), notably in case of width in which values reaching up to 73 % higher than the control.

Cruz and Khush (2000) reported that rice with length of 6.61 to 7.50 mm can be considered as *long rice* and more than 7.50 as *very long grain*. Thus, the rice analogues T2 and T4 are classified as long grain category and the analogues (T1, T7, T7+, T8, T9 and T9+) are very long grain category. The larger size of the rice analogue is responsible for the variation in grain weight compared to the control (16.90 mg/grain) and the weight ranged from 14.89 to 30.48 mg/g.

3.7 Cooking characteristics

Cooking characteristics are important parameters for the quality of the rice analogue. The optimum cooking time, loss of soluble solids and water uptake ratio of the analogues are presented in Table 3. It was observed that the analogue did not disintegrate and maintained its shape after cooking (Figure S1). The cooking time of the analogues varied between 6 (T7) and 12 min (T4). All samples showed a shorter cooking time when compared to the control (14 minutes), this means a reduction up to 14 % in time, this is a convenient quality to simplify the elderly's routine. The reduced optimum cooking time is related to the 50% increase in extruded flour. The extrusion process causes starch breakdown, which is important for reducing cooking time (De Arcangelis et al., 2020; He et al., 2018). Our findings were consistent with the RVA results, in which formulations using extruded flours presented a decrease on pasting parameters compared to the control (polished rice) (Figure 2).

After cooking, all samples tended to increase their water uptake ratio between 59.41 (T7) and 152.67% (T2), but the water uptake of the control (167%) was higher if compared to the analogues. Weight increase is an important parameter to evaluate the yield of rice analogue. In this study, all samples tended to increase their water absorption rate between 59.41 (T7) and 152.67% (T2), but the water absorption of the control (167%) was higher compared to analogues. Weight increase in rice occurs due to high water retention capacity during cooking (Sutrismo et al., 2024). Kraithong; Rawdkuen, (2021) reported that better water absorption can contribute to softer texture of rice pasta.

Soluble solids indicate the content of solid components found in the cooking water. The soluble solids loss values of the analogues ranged from 5.08 (T9) to 15.95% (T7+). The solids loss of the analogue was, in general, greater than that of the control. In fact, the presence of dietary fiber may be increasing solids losses. Similar results of increased solids loss with the addition of dietary fiber were observed in the analogue rice prepared with defatted soy flour (Asael; Nassef, 2022).

3.8 Starch characteristics

Amylose content substantially influences both the cooking quality and sensorial characteristics of rice whereas resistant starch has impact on carbohydrate metabolism in human health and disease. The amylose content and the resistant starch are presented in Table 3. The amylose content ranged from 19.08 to 24.87 %, which was comparable to the control 26 %. Amylose content is categorized as low (15–22 %), intermediate (23–26 %), high (27–30 %) and very high (> 30 %) and thus, the rice analogues can be classified as intermediate amylose content that tends to be softer and stickier (IRRI, 2006). Furthermore, as much as amylose content is higher, the grater retrogradation tendency that leads to an increase of resistant starch (Ashwar et al., 2016). Regarding resistant starch, analogues showed values ranging from 0.47 to 1.56 % below than the control (3.89 %), as expected. (Qiang et al.,2025). Resistant starch is an important functional ingredient in food that is not digested in the small intestine, which provides it with several health benefits. It can be used to improve the nutritional quality of foods and is considered a form of dietary fiber due to reducing the glycemic index of foods and increasing satiety after meals, making it an ally in promoting a more balanced and healthy diet.

Table 3. Grain dimensions, cooking quality and starch characteristics of rice analogues

Samples	Lenght (mm)	Width (mm)	Weight (mg/grain)	Cooking time (min)	Cooking loss (%)	Water uptake ratio (%)	Amylose (%)	Resistant Starch (%)
T1	7.63±0.27[abc]	2.76±0.25[ab]	30.48±0.00[a]	09.00±0.00[c]	5.54 ± 0.38[b]	125.21±11.55[bcd]	22.31±1.19[bc]	0.63±0.03[e]
T2	7.29±0.26[b]	2.54±0.13[bc]	20.14±0.00[bc]	08.00±0.00[cd]	8.13 ± 2.02[b]	152.67 ±12.59[ab]	21.99±0.41[bc]	1.29±0.08[c]
T4	7.48±0.28[bc]	2.83±0.23[a]	29.64±0.00[a]	12.00±0.00[b]	9.33 ± 4.34[ab]	137.93±0.23[abc]	24.13±0.18[ab]	1.01±0.01[d]
T7	7.57±0.25[abc]	2.48±0.15[c]	14.89±0.00[c]	06.00±0.15[d]	5.44 ± 3.94[b]	59.41±1.02[f]	22.54±0.10[bc]	1.56±0.00[b]
$T7^+$	7.86±0.01[a]	2.75±0.16[ab]	29.79±0.00[a]	09.00±0.04[c]	15.95 ± 1.98[a]	103.72±16.78[cd]	19.08±0.32[c]	0.59±0.04[e]
T8	7.74±0.16[ab]	2.49±0.16[c]	17.93±0.00[c]	07.00±0.09[d]	6.15 ± 1.77[b]	101.5±10.59[de]	24.87±0.36[ab]	0.50±0.07[e]
T9	7.73±0.24[ab]	2.62±0.23[abc]	24.02±0.01[b]	06.30±0.02[e]	5.08 ± 0.69[b]	67.74±4.64[ef]	23.76±2.22[ab]	0.89±0.04[d]
$T9^+$	7.91±0.12[a]	2.73±0.18[abc]	29.79±0.00[a]	06.30±0.00[e]	11.41 ± 1.90[ab]	96.94±6.88[de]	21.78±0.05[bc]	0.46±0.03[e]
Control	6.69±0.38[c]	2.02±0.10[d]	16.90±0.00[c]	14.00±0.02[a]	5.31 ± 0.66[b]	167.37±3.82[a]	26.55±0.35[a]	3.89±0.00[a]

Note: Values are mean (n=3) ± standard deviation. Data with same letters in the same column did not differ significantly by Tukey test ($p<0.05$). Where: T1= (50 % RF, 50 % ERF, 5 % BF, 0.5 % CSL); T2= (50 % RF, 50 % ERF, 10 % BF, 0.5 % CSL); T4= (50 % RF, 50 % ERF, 10 % BF); T7= (50 % RF, 50 % EERF, 5 % BF, 0.5 % CSL); $T7^+$= (50 %, 50 % EERF, 5 % BF, 0.5% CSL, 2% Mix), T8= (50 % RF, 50 % EERF, 10 % BF, 0.5 % CSL); T9= (50 % RF, 50% EERF, 0.5 % CSL); $T9^+$= (50 %, 50% EERF, 0.5% CSL, 2 % Mix).

3.9 Chemical characterization

3.9.1 Chemical composition

The chemical composition of the analogues is presented in Table 4. These formulations produced rice analogs with a macronutrient composition providing 8.03 g and 7.66 g of protein; lipids 0.69 g and 0.79 g; and carbohydrates 86.13 g and 84.13 g, together with an ash value of 1.68 g and 1.76 g. This proportion can be considered ideal to achieve a desirable balance of nutrients in the rice analog, providing protein and fat, in addition to offering a substantial amount of carbohydrates. In general, it is observed that the addition of beans did not contribute to an increase in macronutrients.

Moisture is one of the important parameters that affect the shelf life of the rice analogue. Moisture content should be well controlled through processing, such as drying, to ensure a longer shelf life of the rice analogue. Reducing moisture content is effective in preventing fungal growth and insect proliferation (Los et al., 2018). Moisture content was low in both formulations, ranging from 2.67 to 4.47 %.

The ash content in formulations $T7^{+}$ (1.68) and $T9^{+}$ (1.76) was higher than that found in the control (0.31). Higher ash values indicate that the rice was successfully enriched and are related to the content of microelements (Table 4) found in the samples.

The $T7^{+}$ analogue has the highest protein content (8.03 g/100g) but does not show statistical difference ($p<0.05$). The addition of bean flour to the analogues was associated with a higher protein content (Handayani et al., 2024).

The analogue with the highest lipid content (0.79 %) is $T9^{+}$ that does not contain beans. Handayani et al. (2024) reported a lipid content between 2.02 and 3.13 % in rice analogues using cowpea flour addition. In addition, these authors using also skimmed milk powder in formulations that can be contributed to high values found. In general, the analogues ($T7^{+}$ and $T9^{+}$) contained more significant amounts than the control, which is due to the supplementation of bean flour and emulsifier.

The highest carbohydrate content (86.13 g) was observed by $T7^{+}$ sample that was formulated using BF. In the work of Handayani et al. (2024), the analogues with beans varied between 81.03 and 84.06. The carbohydrate content found in the 2 formulations is higher than that of the control rice 82.92. This difference in carbohydrate may have been influenced by the addition of the vitamin mix that is composed of maltodextrin (glucose polymers).

A higher fiber content was observed in the T7$^+$ (0.81 %) and T9$^+$ (1.20 %) analogues compared to the control 0.57 %. Fiber plays an important role in improving overall gut health, therefore, a higher fiber content in the analogue is nutritionally favorable. According to Kanetro et al. (2017), the cowpea analogue has a lower glycemic index than conventional rice.

Table 4. Chemical composition, vitamin D quantification and microelement profile of rice analogues

	T7$^+$	T9$^+$	Control
Moisture (g/100g)	2.67±0.28^b	4.46±0.38^b	8.05±0.75^a
Ash (g/100g)	1.67±0.02^a	1.75±0.03^a	0.30±0.01^b
Protein (g/100g)	8.03±0.21^a	7.65±0.13^a	7.65±0.13^a
Lipid (g/100g)	0.68±0.13^a	0.79±0.28^a	0.51±0.04^a
Carbohydrates (g/100g)	86.13±0.35^a	84.13±0.52^{ab}	82.92±0.95^b
Fiber dietary (g/100g)	0.81±0.02^b	1.20±0.01^a	0.57±0.01^c
Vitamin D (µg/100g) (0 months)	4.53±0.54^b	8.52±1.20^a	0.00±0.00^c
Vitamin D (µg/100g) (4 months)	4.48±0.29^b	8.67±0.07^a	0.00±0.00^c
Mg (mg/100g)	286.8.05±7.57^a	278.25±1.25^b	4.30±0.10^c
Na (mg/kg)	11.84±0.07^a	11.12±0.94^{ab}	8.39±0.96^b
K (mg/kg)	396.17±6.51^b	662.03±6.12^a	325.42±1.56^c
Ca (mg/kg)	323.96±2.79^a	316.63±0.06^b	8.20±0.15^c
P (mg/kg)	543.21±0.26^b	635.88±15.51^a	400.98±4.22^c
Mn (mg/kg)	5.96±0.02^b	6.06±0.16^b	6.62±0.02^a
Fe (mg/kg)	4.18±0.24^b	4.88±0.00^b	0.00±0.00^c
Zn (mg/kg)	9.43±0.19^b	10.55±0.32^a	6.57±0.04^c
Cu (mg/kg)	5.82±0.21^a	6.13±0.96^a	1.40±0.02^b

Note: Values are mean (n=3) ± standard deviation. Data with same letters in the same lines did not differ significantly by Tukey test ($p<0.05$). Where: T7+= (50 %, 50% EERF, 5 % BF, 0.5% CSL, 2 % Mix), T9+= (50 %, 50 % EERF, 0.5 % CSL, 2 % Mix).

3.9.2 Vitamin D quantification

Determining Vitamin D levels in foods is essential for assessing dietary vitamin D intake and correlating vitamin D intake with overall health. Vitamin D deficiency in elderly patients is common and a risk of various diseases including osteoporosis, sarcopenia, cardiovascular disease, cancer and even mortality (Tanaka et al., 2024). The vitamin D quantification is presented in (Table 4)

At zero time, the vitamin D content found in formulations $T7^+$ and $T9^+$ was 4.54 and 8.52 µg/100g, respectively. After 4 months kept at room temperature, the results found were 4.48 and 8.67 µg/100g for $T7^+$ and $T9^+$ formulations, respectively. These findings showed that there is non- statistical difference during storage at room temperature ($p<0.05$). According to the Brazilian Food Composition Table (TBCA, 2023), raw polished white rice naturally does not contain vitamin D. The values found in the analogues are in accordance with the labeling “rich”, which corresponds at least 30 % of the RDA, i. e. provides at least 4.5 µg/100g of vitamin D per day for both formulations (Annex II of IN 75/2020) (ANVISA, 2020).

3.9.3 Microelements

Minerals are micronutrients that play important roles in various systems of the human body, energy metabolism and immune system, such as: (i) bones and teeth health, (ii) helps to relax and contract the muscles, (iii) nerve functioning, (iv) blood clotting and blood pressure regulation, (v) good balance in body fluids, (vi) hormone components among others (Gharibzahedi; Jafari, 2017). The sodium, potassium, magnesium, calcium, manganese, iron, zinc, copper, and phosphorus contents of rice analogues are presented in (Table 4).

The magnesium found in $T7^+$ formulation was 286.80 mg/100g and in $T9^+$ formulation was 278.25 mg/100g. According to the Brazilian Food Composition Table, polished white rice showed 29.5 mg of magnesium (TBCA, 2023). The values found in the analogues are in agreement with the labeling “rich”, which corresponds at least 30 % of the VDR, i.e. provides at least 126 mg/100g of magnesium per day considering both fortified formulations (Annex II of IN 75/2020) (ANVISA, 2020).

It was observed that the original rice contained 8.20 mg of calcium, while the rice analogues presented high calcium values (323 and 316 mg/kg) probably due to the use of emulsifier (calcium stearoyl-2-lactyl lactate).

Iron (4.18 and 4.88 mg/kg) and zinc (9.43 and 10.55 mg/kg) values are higher than those found in the control. Iron and zinc are considered trace elements and have specific functions in the human body. Foods containing these trace elements can help reduce the incidence of iron deficiency anemia and strengthen the immune system (Awuchi et al., 2020).

4 Pairwise correlation coefficient (r) and Principal component analysis (PCA)

Regarding to explore the relationship between pasting properties, thermal and texture profile, cooking quality, grain dimensions, amylose and resistant starch contents of rice analogues, a correlation matrix was calculated (Figure 6 A). The correlogram indicates a strong positive relationship between resistant starch with peak viscosity (r= 0.92), final viscosity (r= 0.89), setback (r= 0.83), breakdown (r= 0.89), springiness (r= 0.72), enthalpy (r= 0.71) and amylose content (r= 0.61).

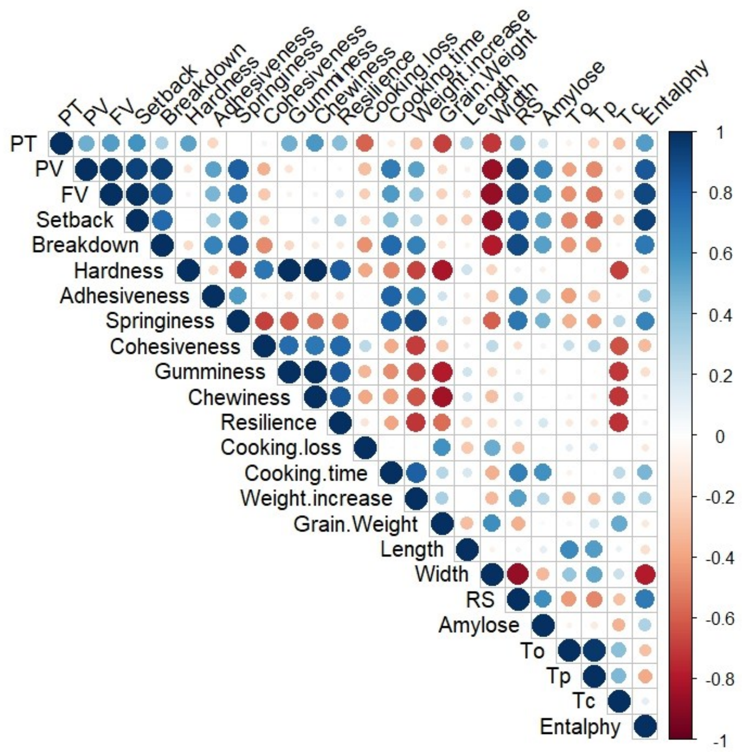
Amylose can easily form double helices after cooking and show a high level of retrogradation (He et al., 2018). The positive correlation with the amylose content and RS can be explained due to amylose content is a strong predictor of RS (Chen et al., 2017). RS has a strong impact on enthalpy and peak melting temperature, since higher levels of RS present high degree of crystallinity and more stabilization of double helical structures (Shi; Gao, 2011).

A strong negative correlation was found between width, all parameters of pasting properties (PT: r= -0.70; PV: r= -0.85; BDV: r= -0.86, SBV: r= -0.85; FV: r= -0.78) and enthalpy (r= -0.78). It was also observed a negative correlation between grain weight and hardness (r= -0.81), gumminess (r= -0.78) and chewiness (r= -0.83). Regarding the hardness and dimensions of the grains, our results are contrary to the found in the literature (Mohapatra; Bali, 2011). These authors attribute a strong positive correlation between hardness, surface area (r= 0.91) and volume (r= 0.93) of the rice due to the compressive force required to break the rice grain in terms of their higher surface area and volume.

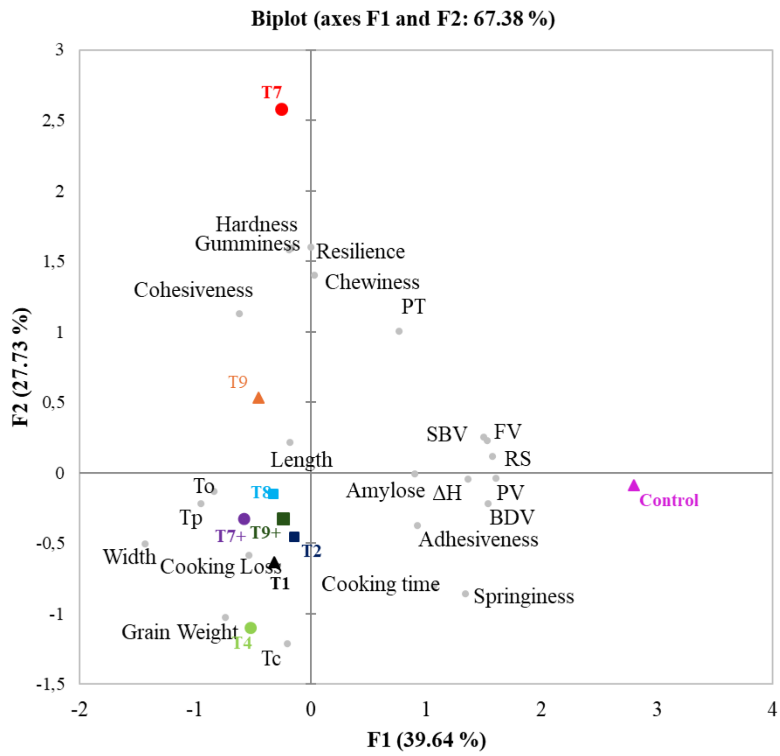
Biplot PCA was applied to evaluate the relationship among the 22 variables related rice analogues characteristics (Figure 6B). The parameters of the close vectors are positive and correlated. PCA1 and PC2 explained 67.38 % of the total variance among four quality characteristics of rice analogues (physical, texture profile, cooking properties and starch). PCA analysis evidenced the differences between the rice analogues and the control (polished rice). Dim 1 is described by hardness, gumminess, resilience, chewiness, pasting temperature, length, setback, final viscosity and resistant starch. The other variables described by Dim 2 are amylose, thermal profile, cooking loss, cooking time, springiness, adhesiveness, pasting viscosity, breakdown grain weight and width. A hierarchical cluster analysis (HCA) of the principal components of PCA was used to better categorize similar parameters of rice analogues in groups. HCA formed three sample groups according to their similarities: Cluster 1 ($T9^+$, control); Cluster 2 ($T7^+$, T4, T1 and T2) and Cluster 3 (T8, T7, T9).

Our results showed that different formulation of rice analogues, had positive effects on physical properties and starch characteristics. $T9^+$ formulation presented similar characteristics in terms of cooking loss and hardness, important parameters for the sensory acceptance of an elderly consumer. Therefore, it can be concluded that the formulations, specialty $T9^+$, has the potential to be used as a rice analogue with adequate nutritional, technological and texture characteristics in order to be a useful alternative for the food industry.

(A)


PT
PV
FV
Setback
Breakdown
Hardness
Adhesiveness
Springiness
Cohesiveness
Gumminess
Chewiness
Resilience
Cooking.loss
Cooking.time
Weight.increase
Grain.Weight
Length
Width
RS
Amylose
To
Tp
Tc
Entalphy
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

(B)


Biplot (axes F1 and F2: 67.38 %)
F2 (27.73 %)
F1 (39.64 %)
T7
Hardness
Gumminess
Resilience
Chewiness
PT
Cohesiveness
T9
SBV
FV
RS
Length
Amylose
ΔH
PV
BDV
Control
To
T8
Tp
T7+
T9+
T2
Adhesiveness
Width
Cooking Loss
T1
Cooking time
Springiness
Grain Weight
T4
Tc
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
-1
0
1
2
3
4

(C)

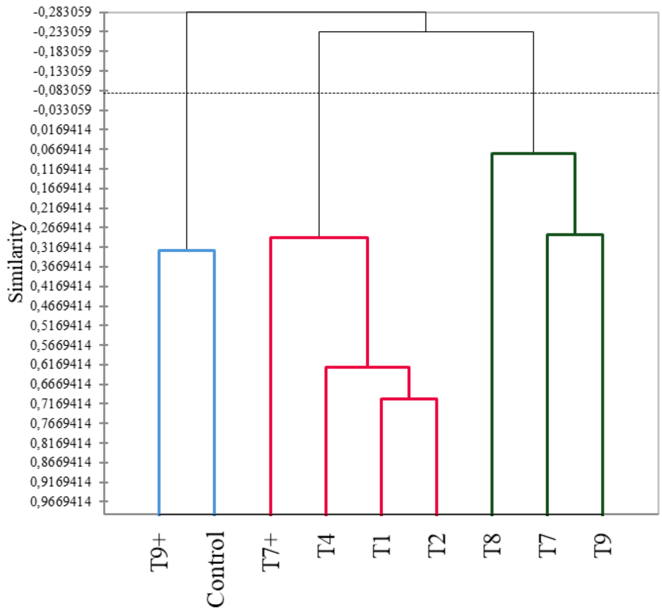


Figure 6. Pairwise correlation coefficient (*r*) for pasting, thermal, texture, grain dimension and starch properties (A), Biplot from principal component analysis (PCA) (B) and Hierarchical Cluster Analysis (HCA) by the principal components of PCA (C). Where: PT= Pasting Temperature, PV= Peak Viscosity, FV= Final Viscosity; BDV= Breakdown Viscosity, SBV= Setback Viscosity, T_o= Onset Temperature; T_p= Peak Temperature, T_c= Conclusion Temperature, TS= Total Starch and RS= Resistant Starch.

5 Conclusion

This study demonstrated that rice analogue can be used as a strategy in order to promote the vitamin D and magnesium fortification. The results revealed that the paste properties, DSC, and SEM were affected by the addition of BF at different concentrations (5 e 10%). The analogue presented a low WI (83,06) with the increase of cowpea flour (10%). The texture of the analogue was comparable to control, especially in samples 7^+ and $9^{+.}$ in terms of the hardness, gumminess, and chewiness. In addition, the grains showed a cooking time 14% shorter than the control, which could save energy for cooking. In this study, it was possible to provide rice analogues ($T7^+$, $T9^+$) with 4.54 and

8.52 µg/100g of vitamin D and with 286.81 and 278.25 mg/100g of magnesium. These results show that the analogues can be classified as "Vitamin D enriched" and "Magnesium enriched" labelings. The Principal Coordinate Analysis - PCoA indicated that $T9^+$ formulation presented similar characteristics in terms of cooking loss and hardness, important parameters for the sensory acceptance of an elderly consumer. Therefore, it can be concluded that the formulations, specialty $T9^+$, has the potential to be used as a rice analogue with adequate nutritional. Further studies on product biodigestibility and bioavailability, shelf life and consumer acceptability are needed in order to implemented it on an industrial scale.

Author statement

The authors declare that the submitted manuscript has not been published elsewhere and it is not under consideration for publication elsewhere.

Declaration of competing interest

The authors attest that there are no interests of competing with the objective, interpretation, and presentation of the results.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

Not applicable

Code availability

Not applicable

6 References

AACC. Approved Methods of the AACC Association of Cereal Chemists, St. 2000.

Abhinav Mishra, Hari Niwas Mishra, Pavuluri Srinivasa Rao, Preparation of rice analogues using extrusion technology, International Journal of Food Science and Technology, Volume 47, Issue 9, September 2012, Pages 1789–1797, https://doi.org/10.1111/j.1365-2621.2012.03035.x

Aboubakar, Y.N. Njintang, J. Scher, C.M.F. Mbofung, Physicochemical, thermal properties and microstructure of six varieties of taro (Colocasia esculenta L. Schott) flours and starches, Journal of Food Engineering, Volume 86, Issue 2, 2008, Pages 294-305, ISSN 0260-8774, https://doi.org/10.1016/j.jfoodeng.2007.10.006.

Agência Española de Seguridad Alimentaria y Nutrición (AESAN). Evaluación Nutricional de la Dieta Española II. Micronutrientes. Sobre Datos de la Encuesta Nacional de Ingesta Dietética (ENIDE); Agencia Española de Seguridad Alimentaria y Nutrición (AESAN): Madrid, Spain, 2011. (In Spanish)

Aji Sutrisno, Andi Nur Fajri Suloi, Erni Sofia Murtini, Nur Alim Bahmid, The effect of corn starch and transglutaminase on quality improvement of soybean-based analog rice, Future Foods, Volume 10, 2024, 100407, ISSN 2666-8335, https://doi.org/10.1016/j.fufo.2024.100407.

Ambouroue Avaro, M. R., Tong, L., & Yoshida, T. A Simple and Low-Cost Method to Classify Amylose Content of Rice Using a Standard Color Chart. Plant Production Science, 2009, 12(1), 97–99. https://doi.org/10.1626/pps.12.97

Amcoff, E. (2012). Riksmaten-vuxna 2010-11: Livsmedels-och näringsintag bland vuxna i Sverige. Livsmedelsverket.

American Association of Cereal Chemists. Approved methods committee. Approved methods of the American association of cereal chemists. American Association of Cereal Chemists, 2000.

ANVISA. Agência Nacional de Vigilância Sanitária. Resolução da diretoria colegiada-RDC Nº 15, de 15 de março de 2012

Asael, A. et al. Preparation of Novel Analog Rice Produced from Different Carbohydrates Resources and Defatted Soy flour. International Journal of Family Studies, Food Science and Nutrition Health, 2022. v. 3, n. 1, p. 177-201..

Awuchi, CG; Igwe, VS; Amagwula, IO; Echeta, CK. Health benefits of micronutrients (vitamins and minerals) and their associated deficiency diseases: A systematic review. International Journal of Food Sciences, 2020, 3(1), 1-32.

Bemiller, JN.; Whistler, RL. Starch: chemistry and technology. Academic Press, 2009.

Bernardo, CO, Ascheri, J L R; Chávez, D W H; Carvalho, CWP. Ultrasound Assisted Extraction of Yam (Dioscorea bulbífera) Starch: Effect on Morphology and Functional Properties, 2018, https://doi.org/10.1002/star.201700185

Bilal Ahmad Ashwar, Adil Gani, Idrees Ahmed Wani, Asima Shah, Farooq Ahmad Masoodi, Dharmesh Chandra Saxena, Production of resistant starch from rice by dual autoclaving-retrogradation treatment: Invitro digestibility, thermal and structural characterization, Food Hydrocolloids, Volume 56, 2016, Pages 108-117, ISSN 0268-005X, https://doi.org/10.1016/j.foodhyd.2015.12.004.

Bourne, M. Food texture and viscosity: concept and measurement. Elsevier, 2002.

Brasil. Ministério da Saúde. Agência Nacional de Vigilância Sanitária (ANVISA). Resolução da Diretoria Colegiada - RDC nº 714, de 1º de julho de 2022. Dispõe sobre os requisitos sanitários para enriquecimento e restauração de alimentos.

Bruins, Maaike J., Van Dael, Peter, & Eggersdorfer, Manfred. The role of nutrients in reducing the risk for noncommunicable diseases during aging. Nutrients, 2019, v. 11, n. 1, p. 85.

Budi, FS; Hariyadi, P; Budijanto, S; Dahrul Syah, D. Effect of extrusion temperature and moisture content of corn flour on crystallinity and hardness of rice analogues. *AIP Conf. Proc.* 29 December 2015; 1699 (1): 030001. https://doi.org/10.1063/1.4938286

Buchman, A. (Ed.). *Clinical nutrition in gastrointestinal disease*. SLACK incorporated, 2006.

Ascheri, JLR; CWP; John R. Capillary, M. rheometry of maize and wheat effect of sugar and temperature Localización: Alimentaria: *Revista de tecnología e higiene de los alimentos,* ISSN 0300-5755, Nº 356, 2004, págs. 109-118

Carbajal Azcona, Á. Ingestas recomendadas de energía y nutrientes. In Nutrición y Dietética; (revisited 2013); García-Arias, M.T., García-Fernández, M.C., Eds.; Secretariado de Publicaciones y Medios Audiovisuales, Universidad de León: León, Spain, 2003; pp. 1–26. Available online: https://www.ucm.es/data/cont/docs/458-2013-07-24-CARBAJAL-IR-2003-ISBN-84-9773-023–2-rev2013.pdf

Carvalho, AV; Bassinello, PZ; Mattietto, RDA; Rios, ADO; de Lima, ACP; Koakuzu, SN; Carvalho, RN. Physicochemical, technological and sensory characteristics of a rice (O ryza sativa L.) and bean (P haseolus vulgaris L.) soup prepared by extrusion. *International journal of food science & technology*, 2013, 48(10), 2057-2063.

Carvalho, CWP; Takeiti, CY; Onwulata, CI; Pordesimo, LO. Relative effect of particle size on the physical properties of corn meal extrudates: Effect of particle size on the extrusion of corn meal. J. Food Eng. 2010, 98 (1), 103– 109, DOI: 10.1016/j.jfoodeng.2009.12.015

Chen M-H; Bergman, CJ; McClung, AM; Everette, JD; Tabien, RE. Resistant starch: Variation among high amylose rice varieties and its relationship with apparent amylose content, pasting properties and cooking methods, *Food Chemistry*, Volume 234, 2017, Pages 180-189, ISSN 0308-8146, https://doi.org/10.1016/j.foodchem.2017.04.170.

Clerici, MTPS; EL-DASH, AA. Características tecnológicas de farinhas de arroz pré gelatinizadas obtidas por extrusão termoplástica. *Ciência e Agrotecnologia*, 32(5), 1543 1550, 2008. doi: 10.1590/S1413-70542008000500028.

Commission International de l'Eclairage (CIE). (1978). Recommendations on uniform color spaces, color difference equations, psychometric color terms. Supplement No. 2 to CIE Publication No. 15, Colorimetry, Paris, France: Bureau Central de la CIE.

Cruz, N. Dela; Khush, GS. Rice grain quality evaluation procedures. Aromatic rices, v. 3, p. 15-28, 2000.

De Arcangelis, E; Cuomo, F; Trivisonno, MC; Marconi, E; Messia, MC. Gelatinization and Pasta Making Conditions for Buckwheat Gluten-Free Pasta. J. Cereal Sci. 2020; 95, 103073.

E. Rojo-Gutiérrez, R. Sánchez-Vega, G.I. Olivas, N. Gutiérrez-Méndez, R. Baeza-Jiménez, C. Rios-Velasco, D.R. Sepúlveda, Manufacture of magnesium-fortified Chihuahua cheese, Journal of Dairy Science, Volume 105, Issue 6, 2022, Pages 4915-4924, ISSN 0022-0302, https://doi.org/10.3168/jds.2021-21631.

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). (2016). Dietary reference values for vitamin D. EFSA journal, 14(10), e04547.

Ek, Pichmony; Gu, BJ; Saunders, ST; Huber, K; Ganjyal, GM. Exploration of physicochemical properties and molecular interactions between cellulose and high-amylose cornstarch during extrusion processing, *Current Research in Food Science*, Volume 4, 2021, Pages 588-597, ISSN 2665-9271, https://doi.org/10.1016/j.crfs.2021.07.001.

Elharadallou, S. B; Khalid, II; Gobouri, AA; Abdel-Hafez, SH. Amino acid composition of cowpea (Vigna ungiculata L. Walp) flour and its protein isolates. *Food and Nutrition Sciences*, 2015, 6(9), 790-797.

Budi, FS; Hariyadi, P; Budijanto, S; Dahrul Syah, D. Effect of extrusion temperature and moisture content of corn flour on crystallinity and hardness of rice analogues. *AIP Conf. Proc.* 29 December 2015; 1699 (1): 030001. https://doi.org/10.1063/1.4938286

Food and Agriculture Organization of the United Nations (FAO).
FAOSTAT. 2023. Production Indices. FAOSTAT Food and Agriculture Organization.
Annex 4 - Micronutrient fortification of food: technology and quality control. FAO Technical consultation on food fortification: Technology and Quality Control. Rome, Italy. 1995.

Gharibzahedi SMT; Jafari SM. The importance of minerals in human nutrition: Bioavailability, food fortification, processing effects and nanoencapsulation, *Trends in Food Science & Technology,* Volume 62, 2017, Pages 19-132, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2017.02.017.

Glendenning, P; Inderjeeth, C A. Controversy and consensus regarding vitamin D: Recent methodological changes and the risks and benefits of vitamin D supplementation. *Critical reviews in clinical laboratory sciences*, 53(1), 2016, 13-28.

Handayani, NA; Sumardiono, S; Purbasari, A; Fatikah, AF; Alhakim IM. Physicochemical Properties of Sago- and Corn Flour-Based Rice Analogues Fortified with Black-Eyed Bean Flour and Skimmed Milk Powder. *Food Technol Biotechnol*. 2024;62(4):501-511 https://doi.org/10.17113/ftb.62.04.24.8357

He, M; Qiu, C; Liao, Z; Sui, Z; Corke, H. Impact of Cooking Conditions on the Properties of Rice: Combined Temperature and Cooking Time. *Int. J. Biol. Macromol*. 2018; 117, 87–94.

Helldán, A; Raulio, S; Kosola, M; Tapanainen, H; Ovaskainen, ML; Virtanen, S. Finravinto 2012—Tutkimus; The National FINDIET 2012 Survey; THL Raportti 16/2013; Juvenes Print: Tampere, Finland, 2013; p. 217. (In Finnish)

Instituto Brasileiro de Geografia e Estatística. Projeção da população: Brasil e unidades da federação: Revisão 2024. IBGE. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html

IOM (Institute of Medicine). 2010. Dietary reference intakes for calcium and Vitamin D. Food and nutrition board. Washington, DC: National Academies Press [03/2025]. Disponível http://www.nap.edu/openbook.php?record_id=13050

Mosca, AC; Chen, J. Food-saliva interactions: Mechanisms and implications. *Trends in Food Science & Technology*, v. 66, p. 125-134, 2017

Mintel. Global Food and Drink Trends https://www.mintel.com/press-centre/mintel-announces-global-food-and-drink-trends-for-2024/Acessado em 15/04/2025

IRRI, International rice research institute, 2006 http://www.knowledgebank.irri.org/ricebreedingcourse/Grain_quality.htm

Jia Guo, Min Zhang, Tiantian Tang, Benu Adhikari, Chunli Li, Novel technologies to produce nutritious texture-modified foods for elderly: Advances, challenges and applications, *Food Bioscience*, Volume 67, 2025, 106362, ISSN 2212-4292, https://doi.org/10.1016/j.fbio.2025.106362.

Jung, K- J; Lee, H; Lee, SH; Kim, JC. Retrogradation of heat- gelatinized rice grain in sealed packaging: Investigation of moisture relocation. *Food Science and Technology*, 2016, 37, 97–102. https://doi. org/10.1590/1678- 457x.07816

Laleg, K; Cassan, D; Barron, C; Prabhasankar, P; Micard, V. Structural, culinary, nutritional and anti-nutritional properties of high protein, gluten free, 100% legume pasta *PLoS One,* 11 (9) (2016), Article e0160721, 10.1371/journal.pone.0160721

Kanetro, B; Pujimulyani, D; Luwihana, S; Sahrah, A. Character istics of low glycemic index artificial rice from oyek with addition of various legumes. J Fak Tekn Pert UGM. 2017; 37(3):256–62. https://doi.org/10.22146/agritech.31538

Hoss, KE; Salla, M; Khaled, S; Krayem, M; Hassan, H; Khatib, SE. Update on vitamin D deficiency and its impact on human health major challenges & technical approaches of food fortification, *Journal of Agriculture and Food Research,* Volume 12, 2023, 100616, ISSN 2666-1543, https://doi.org/10.1016/j.jafr.2023.100616.

Kasapis, S. Developing Minced Fish Products of Improved Eating Quality: An Interplay of Instrumental and Sensory Texture. International *Journal of Food Properties,* 12(1), 11–26.2009, https://doi.org/10.1080/10942910802252171

Khairunnisa, K; Budijanto, S; Sitanggang, AB; Formulation of high protein rice analogue made of cassava, maize starch, and soybean. In: Proceedings of the 24th Tri-University International Joint Seminar and Symposium, Mie University Japan, 23–27 2017

Kraithong, S; Rawdkuen, S. Quality attributes and cooking properties of commercial Thai rice noodles. PeerJ. 2021 Apr 6;9: e11113. doi: 10.7717/peerj.11113. PMID: 33868813; PMCID: PMC8034366

Liu, CY; Amani, R; Sulaiman, S; Mahmood, K; Ariffin, F; Mohammadi Nafchi, A. Formulation and characterization of physicochemical, functional, morphological, and antioxidant properties of cassava-based rice analogue. *Food Science & Nutrition*, 2022, 10, 1626–1637. https://doi.org/10.1002/fsn3.2785

Liu, R; Geng, Z; Li, T; Zhang, M; Zhang, C; Ma, T; Wang, L. Effects of different extrusion temperatures on the physicochemical properties, edible quality and digestive attributes of multigrain reconstituted rice. *Food & Function*, 2024. *15*(11), 6000-6014.

Los, A; Ziuzina, D; Bourke, P. Current and Future Technologies for Microbiological Decontamination of Cereal Grains. *Journal of Food Science*, 2018, 83: 1484-1493. https://doi.org/10.1111/1750-3841.14181

Luo, M; Gong, W; Zhang, S; Xie, L; Shi, Y; Wu, D; Shu, X. Discrepancies in resistant starch and starch physicochemical properties between rice mutants similar in high amylose content. *Frontiers in Plant Science* Volume 14 – 2023 DOI=10.3389/fpls.2023.1267281

Gu, M; Luo, H; Zhang Z; Fayin Ye, Guohua Zhao, Efficient preparation of starch-lipid complexes: *A review, International Journal of Biological Macromolecules,* Volume 302, 2025, 140544, ISSN 0141-8130, https://doi.org/10.1016/j.ijbiomac.2025.140544.

Mintel. Global Food and Drink Trends https://www.mintel.com/press-centre/mintel-announces-global-food-and-drink-trends-for-2024/Acessado em 15/04/2025

Mohapatra, D; Bal, S. Physical properties of Indica rice in relation to some novel mechanical properties indicating grain characteristics, 2012.

Moutaleb, OH; Amadou, I; Amza, T; Zhang, M. Physico-functional and sensory properties of cowpea flour based recipes (akara) and enriched with sweet potato. *J Nutr Health Food Eng*, 2017, 7(4), 00243.

Nabeshima, E; Hashimoto, J; M., El-Dash, AA. Efeito da adição de emulsificantes em massas alimentícias sem glúten produzidas com extrusora termoplástica. *Boletim Do Centro De Pesquisa De Processamento De Alimentos*, 2003, 21(2). https://doi.org/10.5380/cep.v21i2.1161

Ogawa, Y; Glenn, GM; Orts, WJ; Wood, DF. Histological structures of cooked rice grain. *Journal of Agricultural and Food Chemistry*, 2003, 51(24), 7019–7023. https://doi.org/10.1021/jf034 758o

Okabe, M. Texture measurement of cooked rice and its relationship to the eating quality. *Journal of Texture Studies*, *10*(2), 131-152, 1979.

Oliveira, MEAS; Carvalho, CWP; Nascimento, MS; Hertwig, AMV; Mellinger-Silva, C; Takeiti, CY. (2019). Extrusion of λ-carrageenan gum: Physical properties and in vitro bifidogenic effect. *Journal of Food Processing and Preservation*, 43(8), 1–13. https://doi.org/10.1111/jfpp.14027

Olza, J; Aranceta-Bartrina, J; González-Gross, M; Ortega, RM; Serra-Majem, L; Varela-Moreiras, G; Gil, Á. Reported Dietary Intake, Disparity between the Reported Consumption and the Level Needed for Adequacy and Food Sources of Calcium, Phosphorus, Magnesium and Vitamin D in the Spanish Population: Findings from the ANIBES Study †. *Nutrients*, 2017, 9(2), 168. https://doi.org/10.3390/nu9020168

Pinel, P; Barron, C; Cassan, D; Robert, M; Bourlieu-Lacanal, C; Micard, V; Culinary properties, nutritional quality, and in vitro starch digestibility of innovative gluten-free and climate smart cowpea-based pasta, *LWT*, Volume 211, 2024, 116917, ISSN 0023-6438, https://doi.org/10.1016/j.lwt.2024.116917.

Patindol, J; Gu, X; Wang, Y-J. Chemometric analysis of cooked rice texture in relation to starch fine structure and leaching characteristics. *Starch/Stärke*, 2010, 62: 188-197. https://doi.org/10.1002/star.200900181

Peltonen, M.; Harald, K.; Männistö, S.; Saarikoski, L.; Peltomäki, P.; Lund, L.; Sundvall, J.; Juolevi, A.; Laatikainen, T.; Aldén-Nieminen, H.; et al. The National FINRISK 2007 Study; B34/2008; National Public Health Institute: Helsinki, Finland, 2008.

Xia, Q; Tao, H; Huang, P; Wang, L; Mei, J; Li, Y. Minerals in vitro bioaccessibility and changes in textural and structural characteristics of uncooked pre-germinated brown rice influenced by ultra-high pressure, *Food Control*, Volume 71, 2017, Pages 336-345, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2016.07.018.

Rosanoff, A; Dai, Q; Shapses, SA. Essential nutrient interactions: does low or suboptimal magnesium status interact with vitamin D and/or calcium status? *Advances in nutrition*, 2016, 7(1), 25-43.

Qiang, R; Zhu, G; Diao, B; Ding, M; Song, J; Ruan, X; Saleem, S; Ali, A; Song, D; Wu, X; Chen, X. Identifying key attributes contributing to resistant starch levels in rice: A comparison of raw and cooked forms, *Journal of Food Composition and Analysis*, Volume 140, 2025, 107280, ISSN 0889-1575, https://doi.org/10.1016/j.jfca.2025.107280.

Saha, S; Jha, S; Tiwari, A; Jayapalan, S., Roy, A. Considerations for improvising fortified extruded rice products. *Journal of Food Science*, 2021.*86*(4), 1180-1200.

Sahu, C; Patel, S; Tripathi, A. Effect of extrusion parameters on physical and functional quality of soy protein enriched maize based extruded snack. *Applied Food Research*, 2, n. 1, p. 100072, 2022.

Sette, S.; Le Donne, C.; Piccinelli, R.; Arcella, D.; Turrini, A.; Leclercq, C. The third Italian National Food Consumption Survey, INRAN-SCAI 2005-06—Part 1: Nutrient intakes in Italy. *Nut. Metab*. Cardiovasc. Dis. 2011, 21, 922–932.

Shi, MM; Gao, QY. Physicochemical properties, structure and in vitro digestion of resistant starch from waxy rice starch. *Carbohydrate Polymers*, *84*(3), 1151-1157, 2011.

Chaturvedi, S; Manickavasagan, A. Rice analogues: Processing methods and product quality, Trends in *Food Science & Technology*, Volume 148, 2024, 104493, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2024.104493.

Steiger, G; Müller-Fischer, N; Cori, H; Conde-Petit, B. Fortification of rice: Technologies and nutrients. *Annals of the New York Academy of Sciences*, 1324(1), 2014. https://doi.org/10.1111/nyas.12418

Sumardiono, S; Budiyono, B; Kusumayanti, H; Silvia, N; Luthfiani, VF; Cahyono, H. Production and Physicochemical Characterization of Analog Rice Obtained from Sago Flour, Mung Bean Flour, and Corn Flour Using Hot Extrusion Technology. *Foods*, 10(12), 3023, 2021. https://doi.org/10.3390/foods10123023

Tabela Brasileira de Composição de Alimentos (TBCA). Universidade de São Paulo (USP). Food Research Center (FoRC). Versão 7.2. São Paulo, 2023. [Acesso em: 2025]. Disponível em: http://www.fcf.usp.br/tbca.

United Nations. (2023). World population ageing 2023: Challenges and opportunities of population ageing in the least developed countries. United Nations, Department of Economic and Social Affairs, Population Division. Disponível em https://desapublications.un.org/publications/world-population-ageing-2023-challenges-and-opportunities-population-ageing-least

Van Rossum, C.T.M.; Fransen, H.P.; Verkaik-Kloosterman, J.; Buurma-Rethans, E.J.M.; Ocké, M.C. Dutch National Food Consumption Survey 2007–2010: Diet of Children and Adults Aged 7 to 69 Years; RIVM Report Number: 350050006/2011; *National Institute for Public Health and the Environment*: Amsterdam, The Netherlands, 2011; p. 143.

Vargas-Solórzano, JW; Ascheri, JLR; Carvalho, CWP; Takeiti, CY; Galdeano, M. Impact of the Pretreatment of Grains on the Interparticle Porosity of Feed Material and the Torque Supplied During the Extrusion of Brown Rice. *Food Bioprocess Technol* 13, 88–100 (2020). https://doi.org/10.1007/s11947-019-02379-8

Wang, J; Li, M; Wang, C; Dai, Y; Sun, Y; Li, X; Liang, J. Effect of extrusion processing and addition of purple sweet potatoes on the structural properties and in vitro digestibility of extruded rice. *Food & Functio*, 2021, 12(2), 739-746.

Zhang G; Xuan, Y; Lyu, F; Ding, Y. Microstructural, physicochemical properties and starch digestibility of brown rice flour treated with extrusion and heat moisture, *International Journal of Biological Macromolecules*, Volume 242, Part 1, 2023, 124594, ISSN 0141-8130, https://doi.org/10.1016/j.ijbiomac.2023.124594.

Zhao, S; Jiao, A; Yang, Y; Liu, Q; Wu, W; Jin, Z. Modification of physicochemical properties and degradation of barley flour upon enzymatic extrusion. *Food Bioscience,* 2022, 45, 101243.

Conclusão geral

O envelhecimento populacional é um fenômeno crescente e exige estratégias integradas para garantir a nutrição e o bem-estar dos idosos. Este grupo, que tende a se tornar o principal consumidor até 2050 quando atingirá 28 % da população total, demanda produtos que considerem suas necessidades dietéticas específicas. A fortificação de alimentos é uma solução eficaz para suprir deficiências nutricionais comuns nessa fase da vida, marcadas por desafios como sarcopenia e disfagia. O análogo de arroz, por sua semelhança com o arroz tradicional e possibilidade de enriquecimento com nutrientes, destaca-se como uma alternativa viável para promover a saúde e qualidade de vida dessa população. Os resultados desse estudo mostraram que a adição de farinha de feijão-caupi (BF) em diferentes concentrações influenciou as propriedades de pasta, assim como as análises térmicas (DSC) e morfológicas (SEM). Com o aumento da proporção de BF, houve uma redução no grau de brancura dos análogos de arroz. Quanto à textura, especialmente as formulações 7^+ e 9^+ que foram elaboradas a partir de misturas com farinha de arroz cru (RF) e farinha emulsificada e extrudada de arroz cru (EERF) (1:1), apresentaram desempenho com valores de dureza, gomosidade e mastigabilidade semelhantes aos do arroz branco polido (controle). Também é importante salientar que o análogo de arroz produzido apresenta boa qualidade tecnológica em termos de textura e de viscosidade e, por isso, pode ser uma opção de alimentação para pessoas com disfagia nível 7, segundo a classificação do painel *Iniciativa Internacional de Padronização da Dieta Disfágica* (IDDSI). Os grãos também se destacaram pela boa qualidade de cozimento, com uma redução considerável no tempo de cocção (35 e 53 % menores que o controle), o que representa uma vantagem para o consumidor final e apelo mercadológico. As amostras fortificadas ($T7^+$ e $T9^+$) apresentaram teores de vitamina D entre 4,54 e 8,52 μg/100g e de conteúdo em magnésio entre 278,25 e 286,81 mg/100g, o que permite classificá-las como alimentos "*ricos*" nesses nutrientes de acordo com nossa legislação. A obtenção desse novo produto fortificado destinado a população com mais de 60 anos pode contribuir com os objetivos da década do envelhecimento saudável (2021-2030), declarada pela Assembleia Geral das Nações Unidas (ONU) em 2021, ofertando um produto não-pastoso e de consumo amplo e tradicional em nosso país, sem mudanças consideráveis dos hábitos alimentares.

Supplementary Material

Table S1. Physical properties of rice analogues

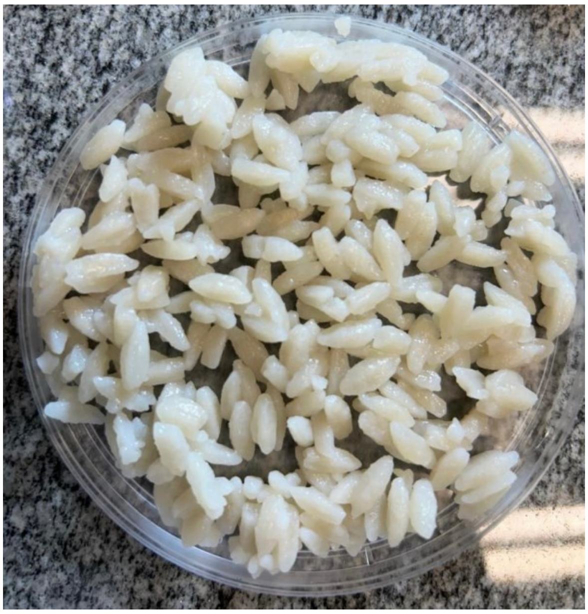
Samples	**RVA Parameters**				
	Pasting Temperature (°C)	**Peak viscosity (cP)**	**Breakdown viscosity (cP)**	**Final viscosity (cP)**	**Setback (cP)**
T1	63.33±1.45^{abc}	502.00±0.05^{cd}	350.00±10.14^{c}	1297.00±13.45^{e}	795.00±8.71^{d}
T2	60.56±7.33^{abc}	477.33±0.34^{cd}	317.66±6.65^{c}	1225.33±3.51^{e}	748.00±3.60^{d}
T4	57.20±0.45^{c}	544.33±0.77^{c}	399.00±18.33^{b}	1018.33±38.94^{f}	474.00±24.06^{e}
T7	66.95±0.49^{ab}	498.66±0.53^{cd}	233.66±20.10^{de}	1943.66±179.11^{cd}	1445.00±129^{c}
T7+	62.50±0.62^{abc}	454.66±0.50^{d}	47.33±16.16^{f}	1862.00±75.44^{cd}	1407.33±74.27^{c}
T8	65.81±1.47^{ab}	488.66±0.05^{cd}	267.66±10.59^{d}	1795.33±36.50^{d}	1306.66±31.32^{c}
T9	66.90±2.34^{ab}	683.66±0.28^{b}	216.66±7.50^{e}	2039.66±29.20^{c}	1356.00±24.00^{c}
T9+	59.83±0.57^{c}	512.33±0.05^{cd}	234.00±3.60^{de}	2274.66±36.17^{b}	1762.33±40.20^{b}
Control	68.16±0.46^{a}	3352.33±0.02^{a}	1073.33±24.50^{a}	7492.66±27.46^{a}	4140.33±31.87^{a}

Each value is the Mean ± Standard deviation of three replicates. For the same column, data with same letters do not differ significantly from each other whereas at the probability level of Tukey test ($p < 0.05$).

Table S2. Texture parameters (TPA) of analogues of rice

Sample	Texture parameters						
	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
T1	8.82±0.57^{d}	-6.01±3.22^{abc}	0.62±0.22^{ab}	0.45±0.03^{c}	3.98±0.42^{de}	2.50±1.03^{bc}	0.51±0.05^{cd}
T2	9.64±0.55^{d}	-9.48±3.20^{bc}	0.72±0.16^{ab}	0.44±0.02^{c}	4.28±0.43^{de}	3.03±0.61^{bc}	0.49±0.04^{d}
T4	5.71±0.09^{e}	-2.93±1.07^{ab}	0.73±0.13^{ab}	0.49±0.00^{bc}	2.78±0.04^{e}	1.88±0.36^{c}	0.55±0.03^{bcd}
T7	46.48±1.09^{a}	-7.79±3.02^{abc}	0.48±0.07^{b}	0.57±0.02^{a}	26.65±0.92^{a}	12.94±2.38^{a}	0.79±0.04^{a}
T7^{+}	9.51±0.79^{d}	-9.49±1.57^{bcd}	0.63±0.08^{ab}	0.52±0.02^{ab}	4.99±0.55^{d}	3.09±0.34^{bc}	0.58±0.06^{bcd}
T8	14.23±1.27^{c}	-12.66±3.98^{cd}	0.63±0.14^{ab}	0.45±0.03^{c}	6.41±0.88^{c}	4.11±1.15^{bc}	0.54±0.04^{bcd}
T9	18.8±0.78^{b}	-16.4±6.03^{d}	0.54±0.11^{b}	0.47±0.02^{bc}	8.80±0.65^{b}	4.75±1.13^{b}	0.63±0.06^{bc}
T9^{+}	8.72±0.56^{d}	-9.25±2.17^{bcd}	0.64±0.18^{ab}	0.48±0.02^{bc}	4.21±0.43^{de}	2.79±1.08^{bc}	0.65±0.10^{b}
Control	10.26±0.08^{d}	-0.65±0.27^{a}	0.91±0.11^{a}	0.44±0.03^{c}	4.51±0.31^{d}	4.12±0.65^{bc}	0.60±0.03^{bcd}

Each value is the Mean ± Standard deviation of three replicates. For the same column, data with same letters do not differ significantly from each other whereas at the probability level of Tukey test ($p < 0.05$).



Credits: Costa, E.S. L. (2025)

Figure S1. Cooked rice analogue

Credits: Alves, T.T. (2025)

Figure S2. Risoni die

FÁCIL DE MASTIGAR

Ferramenta de Testagem do IDDSI

Produto ou alimento testado			
Se aquecido, método(s) de aquecimento			
Temperatura quando testado em:	°C / ao servir	°C / 15 minutos depois de servir	°C / 30 minutos depois de servir

Instruções

- Testes obrigatórios para o Nível 7 Fácil de mastigar incluem **teste de separação com garfo/colher e teste de pressão com garfo/colher** OU, se esses não estiverem disponíveis, teste do dedo.
- O alimento deve passar ou atender aos critérios de todas as linhas marcadas com *.

Testes	Atende aos critérios em		
	Ao servir	15 min. depois de servir	30 min. depois de servir
Obrigatório: separação de garfo/colher e teste de pressão (necessário garfo de metal ou colher de chá)			
* Deve ser capaz de quebrar os alimentos facilmente com o lado de um garfo ou colher	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
* Ao amassar uma amostra de 15 mm x 15 mm com um garfo ou colher de chá, com pressão suficiente para que a unha do polegar fique branca, a comida desmancha, pode ser esmagada e não retornará à forma original	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
Alternativa se garfo ou colher não estiver disponível: teste do dedo			
* Deve ser capaz de quebrar os alimentos facilmente com os dedos	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
* Ao amassar uma amostra de 15 mm x 15 mm usando o polegar, com pressão suficiente para que a unha do polegar fique branca, o alimento pode ser esmagado e não retornará à forma original	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
* A comida fica úmida	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
Opcional: teste com pauzinhos ou hashi			
Pauzinhos ou Hashis podem perfurar alimentos fáceis de mastigar	☐Sim ☐Não	☐Sim ☐Não	☐Sim ☐Não
CONCLUSÃO GERAL – a amostra atende aos critérios para:			
Nível 7 Fácil de Mastigar?	**☐Sim ☐Não**	**☐Sim ☐Não**	**☐Sim ☐Não**

Notas: *A habilidade de morder é necessária para esta textura. As habilidades de mastigação e motricidade oral são necessárias para essa textura.
*Consulte também a descrição dos métodos do teste em português https://iddsi.org/IDDSI/media/images/Translations/Portuguese%20(Brazil)%20v2/Definicoes-Detalhadas-dos-Niveis-per-pair-review_-Sep_2021.pdf

Versão: AuditToolL7EasyToChew26Jun2020

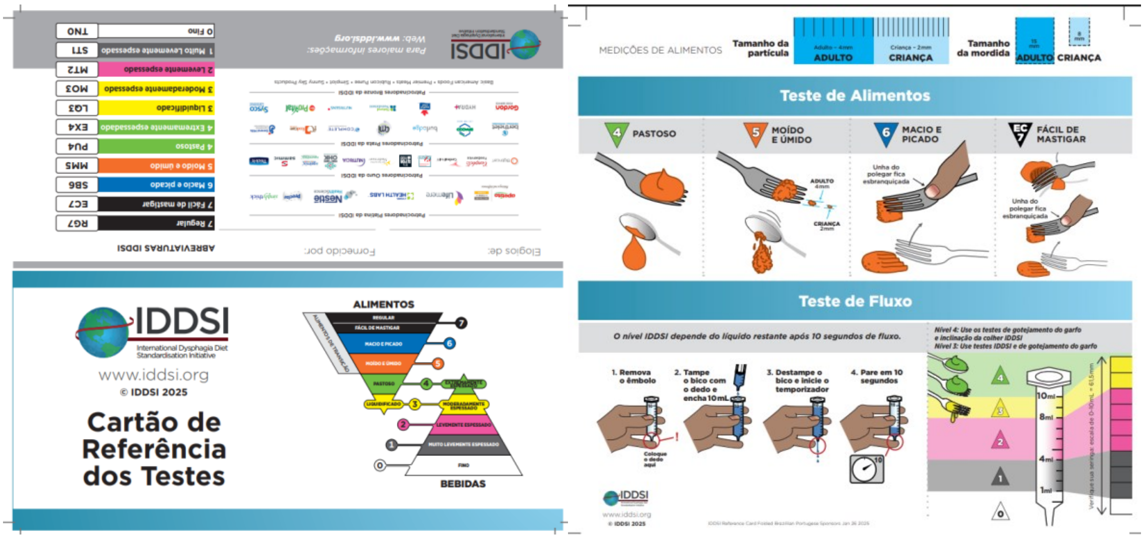


Figure S3. IDDSI diagrams and testings