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Enhancing metabolic health and exercise performance with zinc-enriched postbiotic supplementation: a nutritional intervention study

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ABSTRACT: In recent years, the focus on improving well-being through natural solutions, such as dietary adjustments to improve the composition and functionality of the microbiota, has gained prominence. This study explored the effects of a zinc-enriched postbiotic of whole-cell yeast strains (*Saccharomyces boulardii* ABB S3, *Kluyveromyces marxianus* ABB S8, and *Saccharomyces cerevisiae* ABB S6) on metabolic health and gastrointestinal well-being in resistance-training individuals. Over a 30-day period, 18 participants who experienced gastrointestinal discomfort and were not using other dietary supplements underwent evaluation. The intervention aimed to assess changes in serum zinc levels, protein metabolism indicators, and gastrointestinal health, using a repeated measures design for comprehensive data analysis. Results showed a significant increase in serum zinc levels and improvements in protein metabolism markers, alongside reduced gastrointestinal discomfort. These findings underline the efficacy of zinc-enriched postbiotic supplementation in enhancing metabolic health and suggest that such targeted nutritional interventions can significantly benefit exercise performance and general well-being. The study's outcomes support the potential of incorporating postbiotics into dietary strategies for health maintenance, offering a promising direction for future research in nutritional science and the management of exercise-induced gastrointestinal symptoms.

KEYWORDS: Dietary supplements, Gastrointestinal microbiome, Metabolic diseases/prevention & control postbiotics, Zinc/metabolism, Exercise performance

INTRODUCTION

The burgeoning interest in the significant role of gastrointestinal microbiota on human health has been capturing the attention of scientists and health-conscious individuals alike. As they seek to enhance well-being through tailored dietary practices, the complex and dynamic network of over 1000 distinct microbial species within the gut emerges as critical in preserving a comprehensive physiological equilibrium [1]. This ecosystem, distinct in each segment of the intestinal tract, is essential not only within the digestive lumen but also beyond it. The escalation of scientific exploration in this field has spurred the development of a spectrum of therapeutic approaches [2, 3]. These aim to modify the composition and function of the gut microbiota, including its bacterial and fungal components (mycobiota), either directly or indirectly, seeking to leverage these alterations for improved clinical outcomes. The strategies include a variety of interventions, ranging from the use of probiotics, prebiotics, and nutraceuticals to the enigmatic faecal microbiota transplantation [4].

Probiotics, which are non-pathogenic and live microorganisms, are recognized by both the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) for their ability to confer health benefits when taken in appropriate amounts. They have gained widespread acceptance in clinical settings worldwide and are available to consumers with or without a prescription, reflecting their established place in health maintenance [5].

On the other hand, postbiotics consist of a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host. To qualify as a postbiotic, an agent must meet stringent criteria: it must be molecularly characterized from its original microbial form, there should be a detailed description of the inactivation process and the matrix used, confirmation of the inactivation, proof of health benefits derived from

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well-designed, high-quality trials, a clear definition of the postbiotic composition, and a safety assessment for the intended use in the intended population [2, 3].

Offering a range of advantages over live probiotics, postbiotics are noted for their ability to adhere to intestinal epithelial cells, their anti-inflammatory and immunomodulatory effects, their capacity to counter pathogens, and their role in maintaining the integrity of the intestinal barrier. Clinically, postbiotics have shown effectiveness in managing a variety of gastrointestinal and systemic conditions, including abdominal bloating, paediatric disorders, diarrhoea, atopic dermatitis, and they are particularly beneficial for the safety of susceptible populations [6, 7].

Economically, postbiotics provide benefits such as an extended shelf life, simplified storage and transportation requirements, and compatibility with various food, pharmaceutical, and cosmetic product matrices. They address the challenges of incorporating live microorganisms into food items by offering superior thermal stability, which adds to their versatility. In industrial settings, postbiotics are favoured over probiotics due to their defined chemical structure, recognized safety profile, ease of handling, stability under different pH levels and temperatures, and wide-ranging antimicrobial properties [8]. When considering the matrix of postbiotics, their resilience to extreme temperatures and high-shear processes stands out. Ensuring the quality of postbiotics across various matrices with different physicochemical characteristics, such as pH, viscosity, and solids content, is essential for their successful application.

The postbiotic metabolic formula in question includes *Saccharomyces boulardii* ABB S3, *Saccharomyces cerevisiae* ABB S6, and *Kluyveromyces marxianus* ABB S8 yeast strains. These whole-cell yeasts have been specially developed to maintain their biofunctional properties despite various processing conditions. They are resilient to heat, allowing them to withstand pasteurization, ultra-high temperature (UHT) treatments, infusion, and baking. Their cold resistance makes them suitable for use in frozen desserts like ice cream. Additionally, they are robust enough to endure high-shear processes such as those found in liquid homogenization and adaptable to different moisture levels.

Saccharomyces boulardii ABB S3, a postbiotic derivative of *S. boulardii*, boasts multiple biofunctionalities that support digestive health. It strengthens the intestinal barrier, maintains E-cadherin expression, and shortens the duration of diarrhea. Its anti-inflammatory actions include the suppression of proinflammatory cytokines and modulation of immune responses. By enhancing the production of short-chain fatty acids through its cell wall constituents, it beneficially affects colonocyte function, insulin sensitivity, and reduces intestinal inflammation. *S. boulardii* ABB S3 also promotes a diverse and balanced gut microbiota, offering protection against pathogenic colonization and enhancing overall microbial health. These advantages are integral to promoting intestinal well-being, reducing the length of diarrheal episodes, and preventing pathogen invasion, making *S. boulardii* ABB S3 a valuable asset for digestive health [9, 10].

Kluyveromyces marxianus ABB S8, the postbiotic form of *K. marxianus*, carries several advantageous properties that address various digestive symptoms and deficiencies. It has anti-inflammatory effects, supports gut barrier integrity, modulates the microbiota, and provides protection against Rotavirus and *Clostridioides difficile*. *K. marxianus* ABB S8 also possesses immunomodulatory, antioxidant, and anti-inflammatory properties and interacts with human dendritic cells via its β-glucan components. In conjunction with *Saccharomyces boulardii* ABB S3, it exhibits synergistic effects on immunomodulation and inflammation reduction in gut epithelial and immune cells. This duo minimizes the production of pro-inflammatory cytokines and enhances anti-inflammatory cytokine secretion, thus fostering digestive health [11, 12].

Saccharomyces cerevisiae ABB S6, emerges as a groundbreaking organic source of zinc, offering a refined alternative to the traditional zinc supplements found in the market in the tyndallized form of *S. cerevisiae*. This strain, enriched with zinc, taps into a natural assimilation process during its growth phase, incorporating zinc into its proteins and polysaccharides [13]. This results in a biologically zinc enriched complex that significantly reduces the adverse effects often linked to zinc salts, including toxicity and gastrointestinal issues.

The innovation lies in the yeast's capacity to facilitate a more effective, safe, and harmonious absorption and utilization of zinc, enhancing the efficiency of digestion, absorption, and bioconversion far beyond what is achievable with conventional supplements like zinc sulphate and zinc gluconate. Research highlights the nutritional superiority of zinc-enriched yeast, pointing to its higher bioavailability and the potential to achieve optimal and safe plasma concentrations necessary for bolstering the immune system and offering effective protection against high number of challenges.

Comparative studies in animal models have indicated that zinc yeast can effectively replace high doses of zinc oxide (ZnO) due to its superior bioavailability and reduced excretion rates. This suggests that lower doses of zinc yeast are sufficient to achieve the desired plasma levels without the risk of toxicity. Moreover, studies have

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demonstrated that zinc yeast supplementation leads to an induced anabolic effect on bone calcification in vivo, showcasing its high bioavailability and its impactful clinical effects.

Unlike zinc salts, which presents as a single form with low bioavailability and limited reach to peripheral tissues, zinc yeast embodies a blended form of zinc salts. This distinction ensures higher bioavailability, leading to increased circulating levels of zinc and the absence of toxicity even at lower doses. Such characteristics underscore the transformative potential of utilizing *Saccharomyces cerevisiae* ABB S6 and similar yeast strains as mediums for bioavailable mineral supplementation, marking a significant advance in dietary supplement biotechnology and offering a more effective, safer approach to zinc supplementation.

Zinc, an essential trace element, plays a critical role in numerous biological processes, including as a vital cofactor for DNA and RNA polymerases. These enzymes are fundamental to the mechanisms of DNA transcription and replication. Beyond its involvement with polymerases, zinc influences chromatin structure through histone modification—a process encompassing methylation, acetylation, phosphorylation, and ubiquitination. Such modifications are pivotal in regulating gene expression by controlling the transcription machinery's access to DNA. Given its extensive involvement in processes ranging from enzymatic regulation to gene expression, zinc is crucial for maintaining cellular function and integrity. A deficiency in zinc can lead to significant cellular dysfunction, emphasizing the importance of sufficient zinc intake in the diet. However, excessive zinc intake can also have adverse effects. High levels of zinc can disrupt copper absorption, leading to deficiencies that cause anaemia, neutropenia, and neurological symptoms [14, 15]. Gastrointestinal symptoms such as nausea, vomiting, and epigastric pain, as well as lethargy and fatigue, are common with very high zinc intake [16]. There is also evidence suggesting that extremely high zinc levels can interfere with iron metabolism and affect lipid profiles [17, 16]. Moreover, zinc dysregulation has been linked to cancer, with both deficiency and excess contributing to cancer development and progression in specific contexts [18, 19]. Given these potential risks, it is essential to monitor zinc intake and adhere to recommended dietary levels to avoid toxicity.

In the realm of physical fitness, especially strength training, zinc's significance is underscored by its role in protein synthesis, hormonal balance, and energy production. As a key cofactor in several enzymatic reactions, zinc is integral to muscle repair and growth, making it especially valuable for those engaged in rigorous physical activity [20]. Its role in the production of testosterone, a hormone critical for muscle development and strength, further highlights its importance in the fitness domain. Moreover, zinc is involved in converting food into energy, thereby supporting energy metabolism during exercise [20, 21].

The potential of zinc-enriched food supplements to enhance strength training outcomes is substantial, given its broad biological roles. However, the specific benefits of zinc supplementation for strength training require thorough investigation through well-designed clinical studies. Such research is necessary to confirm the safety, effectiveness, and optimal dosage of zinc supplements, ensuring they can be confidently recommended to enhance physical training regimens.

MATERIAL AND METHODS

Experimental Design

This prospective observational study aimed to evaluate the effectiveness of a Postbiotic Metabolic Blend on protein metabolism and overall physiology over a 30-day period using a repeated measures design. The study also assessed the blend's impact on gastrointestinal comfort, quality of life, and metabolic parameters, alongside evaluating its safety and tolerability.

Study Population and Sampling

Eighteen healthy adult volunteers (aged over 18 years) who engage in strength training at least three times a week and experience gastrointestinal discomfort were recruited in Barcelona. Exclusion criteria included unwillingness to participate, current use of dietary supplements containing zinc, postbiotics, prebiotics, or probiotics, pregnancy, breastfeeding, and recent involvement in other clinical studies. Recruitment took place from June 1st to June 20th, 2023, with the study period lasting four weeks. Participants were evaluated at the beginning and end of the study at facilities near the Echevarne analysis laboratory.

Laboratory Tests

To evaluate the effects of the postbiotic blend, blood samples were collected to measure various metabolic health indicators, including serum albumin, serum and globulin, blood urea nitrogen (BUN), serum urea, total and free testosterone, sex hormone-binding globulin (SHBG), growth hormone (GH), insulin-like growth factor 1 (IGF-1), creatine kinase (CK), and C-reactive protein (CRP). These analyses provided a comprehensive overview of the blend's impact on participants' metabolic parameters, offering insights into its potential benefits for protein metabolism and physiological health. The primary focus was on the "Postbiotic Metabolic Blend," which includes three yeast strains: *Saccharomyces cerevisiae* ABB S6, known for effective zinc fortification; *Saccharomyces boulardii* ABB S3, recognized for its digestive health benefits; and *Kluyveromyces marxianus* ABB S8, known for its synergistic effects on gut health. Each strain contributes unique postbiotic metabolic products, with a high cell count exceeding 1.5 x 10^{10} cells per gram.

Data collection

Data were collected electronically using an electronic Data Collection Notebook (eCRF), where investigators logged data from two visits for each volunteer. This system ensured secure and efficient management of the information gathered throughout the study. The observation period extended over four weeks, with evaluations conducted at the beginning and end of the study.

Main Outcome Variables

- Muscle circumference measurements on day 0 and day 30.
- Anthropometric measures (% of muscle mass, BMI, and % of body fat on day 0 and day 30).
- MSEQ-short scale scores on day 0 and day 30.
- Gastrointestinal symptoms scale on day 0 and day 30.
- Health thermometer of EuroQoL Scale on day 0 and day 30.

The Muscle-Strengthening Exercise Questionnaire (MSEQ) is a tool designed to assess various aspects of muscle-strengthening exercise (MSE) participation, including frequency, duration, intensity, types of exercises, and muscle groups targeted [22].

Statistical Analysis

The statistical analysis was comprehensive, covering both descriptive and inferential statistics. Descriptive statistics summarized categorical variables by frequencies and proportions, and quantitative variables were described using central tendency (mean, median, mode) and dispersion measures (standard deviation, minimum, maximum values). To assess the effectiveness of the "Postbiotic Metabolic Blend," repeated measures t-tests were used for normally distributed data, and the Wilcoxon test was applied for non-normally distributed data. McNemar's test was employed for repeated nominal variables. Group comparisons for numerical variables were conducted using one-way ANOVA or the Mann-Whitney U test, and Pearson's Chi-square test was used for nominal variable comparisons. Effect sizes were calculated for all inferential tests to quantify the magnitude of observed differences, using measures such as odds ratios (O.R.), Cohen's d, correlation coefficient (r), or eta squared (η^2), depending on the test applied. A significance level of 0.05 was established for all tests to determine statistical significance. All analyses were performed using SPSS for Windows version 26 and R version 4.2.3.

RESULTS

The study sample comprised 18 participants, with a distribution of 72.2% male (n=13) and 27.8% female (n=5). The average age of the participants was 35.8 ± 5.5 years, with heights and weights recorded at an average of 170.0 ± 5.3 cm and 71.0 ± 11.9 kg, respectively (See table 1). The body fat percentage across the group was 29.8% ± 7.8%, while the average body mass index (BMI) was 24.4 ± 3.1. Within the BMI categorization, 66.7% of participants were classified as normal weight, 27.8% as overweight, and 5.6% fell into the obesity category, with none classified as underweight or in the severe obesity categories. Further analysis of body composition revealed an average skeletal muscle percentage of 32.3% ± 5.1 and a visceral fat rating of 9.4 ± 5.0. The basal metabolic rate (BMR) averaged at 1530.9 ± 206.1 kcal/day, and daily water intake was reported at 2.2 ± 0.6 litres. Circumference measurements indicated an average biceps muscle circumference of 34.2 ± 4.9 cm, chest circumference of 98.1 ± 8.3 cm, waist circumference of 80.7 ± 10.3 cm, hips circumference of 97.9 ± 7.0 cm, thigh circumference of 53.8 ± 3.7 cm, and calf circumference of 37.9 ± 3.7 cm.

Regarding gastrointestinal symptoms, participants reported bloating (3.6 ± 3.3), nausea (0.6 ± 0.8), vomiting (0.4 ± 0.5), heartburn (1.9 ± 2.2), reflux (1.3 ± 1.9), stomach-ache (1.7 ± 2.3), heavy digestion (2.9 ± 2.2), gas/flatulence (3.9 ± 2.8), and burps (3.5 ± 2.3) on a scale where higher numbers indicate more frequent or severe symptoms (See Graph 1). These symptoms at Day 30 were bloating (3.34 ± 3.26), nausea (0.71 ± 1.9), vomiting (0.2

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± 0.54), heartburn (2.08 ± 2.62), reflux (1.73 ± 2.59), stomach-ache (1.64 ± 2.29), heavy digestion (2.12 ± 2.27), gas/flatulence (2.86 ± 2.18), and burps (2.38 ± 2.03). The gastrointestinal rhythm, measured in times per week, showed that 61.5% of participants had a rhythm of three times per week, followed by 23.1% at two times per week, and 15.4% at one time per week. The Bristol Stool Scale, used to classify the form of human faeces into seven categories, showed that 33.3% of participants had Type 3 (like a sausage but with cracks on its surface) and Type 4 (like a sausage or snake, smooth and soft) stools, which are generally considered indicative of normal stool. Types 1 and 2, which indicate constipation, and Type 5, which suggests a lack of fibre, were reported by 11.1% of participants each. No participants reported Types 6 or 7, which are indicative of increasing degrees of diarrhoea.

To assess gastrointestinal rhythm, the Wilcoxon signed-rank test was utilized to analyse changes pre- and post-intervention. Initially, the average rhythm was 4.44 times per week (SD = 1.85), which increased to 7.33 times per week (SD = 3.06) following the intervention. This change represents a statistically significant increase in the gastrointestinal rhythm frequency, as evidenced by a Wilcoxon Z-value of -3.46 and a p-value of 0.0005, indicating that the intervention had a meaningful impact on the participants' gastrointestinal rhythm.

Lastly, the overall quality of life, as measured on a scale with higher scores indicating better quality, was reported at 85.8 ± 10.9, suggesting a generally positive perception of well-being among the study participants. The paired t-test analysis for serum zinc levels, from Days 0 to 30 (See Graph 2), revealed an increase in the mean levels from 75.94 ug/dL to 82.33 ug/dL, with a mean difference of 6.39 ug/dL. The standard deviations were 12.98 initially and 12.77 finally. This analysis yielded a t-value of 2.24 with 17 degrees of freedom, leading to a statistically significant increase with a two-tailed p-value of 0.04 and a one-tailed p-value of 0.019. The 95% confidence intervals for the mean difference stretched from 0.38 to 12.4 ug/dL. A correlation coefficient of 0.56 (p-value 0.02) indicated a moderate positive correlation between initial and final measurements, and the effect size, represented by Hedges' g, was 0.51, suggesting a moderate effect over the study period.

The study observed an increase in serum albumin levels from a basal mean of 44.22 g/L to a final mean of 45.44 g/L over 30 days, with a mean difference of 1.22 g/L. The standard deviations for the initial and final measurements were 2.07 and 2.85, respectively. Statistical analysis yielded a t-value of 2.54 with 17 degrees of freedom, leading to a two-tailed p-value of 0.02, indicating the increase was statistically significant. The 95% confidence intervals for the mean difference ranged from 0.21 to 2.24 g/L. A strong positive correlation (correlation coefficient of 0.7, p-value < 0.001) was observed between initial and final levels, and the effect size (Hedges' g) was calculated to be 0.57, suggesting a moderate effect of the treatment over the period.

In our sample of 18 participants, zinc supplementation via a postbiotic resulted in an increase in MSEQ scores for holistic exercises from an average of 0.8177 to 1.2778. The intervention showed a strong positive correlation (r = .973, p < .001), with a significant mean difference of -0.46013 (t = -2.429, df = 17, p = .027). The effect size was substantial with a Cohen's d of 0.80364 and a Hedges' g of 0.84141, indicating an impact of the supplementation on the quantity of holistic exercises.

Table 1. Sample Characteristics

Variable	Category	n	%	Mean ± SD
Gender	Female	5	27.8%	
	Male	13	72.2%	
	Total	18	100.0%	
Age		18		35.8 ± 5.5
Height		18		170.0 ± 5.3
Weight		18		71.0 ± 11.9
Body Fat Percentage		18		29.8 ± 7.8
Body Mass Index (BMI)		18		24.4 ± 3.1
Body Mass Index (BMI) - 4 categories	Underweight	0	0.0%	
	Normal weight	12	66.7%	
	Overweight	5	27.8%	
	Obesity	1	5.6%	
	Total	18	100.0%	
Bowel movements/week		18		4.44 ± 1.85
Bristol scale	Type 1	2	11.1%	
	Type 2	2	11.1%	

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	Type 3	6	33.3%	
	Type 4	6	33.3%	
	Type 5	2	11.1%	
	Total	18	100.0%	
Quality of life		18		85.8 ± 10.9

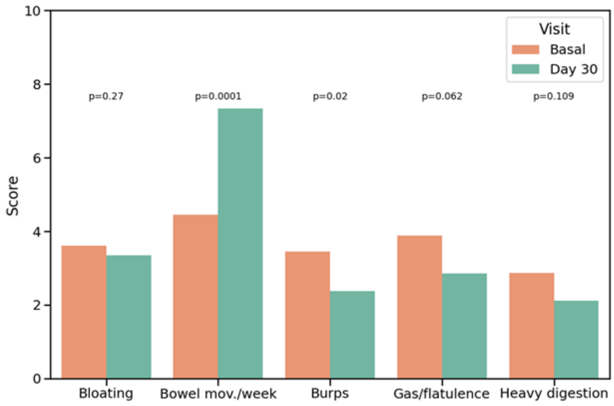

Figure 1. presents a comparative analysis of gastrointestinal symptoms. including bloating. bowel movements. burps. gas. and digestion severity. across multiple visits. Scores range from 0 (no symptoms) to 10 (severe symptoms). highlighting changes between the initial and follow-up visits. Among the significant changes observed. "Bowel movements per week" stands out with a remarkable improvement (p=0.0001).

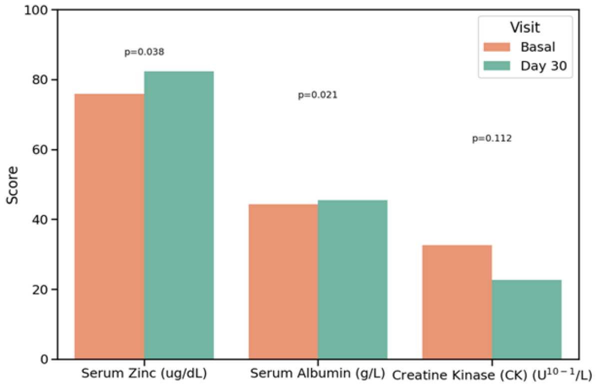

Figure 2. This analysis highlights changes in biochemical markers. including Serum Albumin. Creatine Kinase (CK). and Serum Zinc. across two visits. Notably. Serum Albumin and Serum Zinc showed statistically significant changes (p=0.021 and p=0.038. respectively). suggesting meaningful alterations in these markers over the study period.

DISCUSSION

The present investigation provides robust evidence supporting the beneficial role of the "Postbiotic Metabolic Blend," incorporating *Saccharomyces boulardii* ABB S3, *Saccharomyces cerevisiae* ABB S6, and *Kluyveromyces marxianus* ABB S8, in enhancing gastrointestinal health and systemic metabolic parameters. Notably, the formulation's impact on serum zinc and albumin levels signifies its potential in fortifying mineral balance and protein synthesis, key factors in overall physiological maintenance [3]. This is particularly advantageous for individuals engaged in strength training. The increase in serum zinc levels from 75.94 μg/dL to 82.33 μg/dL and in albumin levels reflects an improvement in metabolic function and the body's ability to synthesize proteins, essential for muscle repair and immune response.

Postbiotic Metabolic Blend Improves Biochemical Indicators, the analysis comparing serum albumin and creatine kinase (CK) levels between Day 0 and Day 30 (Figure 2) shows that serum albumin levels increased following supplementation, whereas creatine kinase levels were not significantly modified.

On the one hand, serum albumin concentration is taken as a control value as it represents the total protein content of an individual, as well as indicating liver and kidney function. Albumin also contributes to the transport of vital nutrients and hormones required by the body. In fact, serum albumin level has been widely used as a marker of protein nutritional status. Thus, the postbiotic intervention seems to improve this function in the body.

On the other hand, creatine kinase (CK) is a key enzyme in muscle contraction, released into the bloodstream by these organs when there is muscle degeneration or disease. Intense exercise can cause micro-tears in muscle fibres, causing these cells to break down and release creatine kinase into the blood. Specifically, creatine kinase is responsible for the phosphorylation of ADP to ATP during muscle contraction. Thus, a decrease in the amount of creatine kinase (CK) detected due to the Postbiotic Metabolic Blend indicates favourable results, since high levels of this enzyme could indicate skeletal muscle, heart, or brain damage.

The intake of the Postbiotic Metabolic Blend improves biochemical markers of healthy metabolism such as albumin and creatine kinase. Furthermore, the noticeable improvement in gastrointestinal rhythm post-intervention, as evidenced by the Wilcoxon signed-rank test, underscores the blend's efficacy in promoting digestive regularity. Postbiotics not only enhance the bioavailability of zinc but also can reduce gastrointestinal symptoms such as reflux, bloating, and heavy digestion, as observed in previous studies.

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Our study highlights encouraging indications of the potential benefits of postbiotic supplementation, despite facing certain limitations that necessitate a balanced interpretation of the findings. The enhancements in zinc status, a crucial trace element known to influence a myriad of biological processes, emerged as a promising outcome. However, it is important to recognize that such improvements do not immediately lead to observable changes in muscle mass or metabolic shifts. These physiological transformations are complex, developing over time through a combination of nutritional and physical stimuli, and might extend beyond our study's 30-day observation period.

Acknowledging the study's constraints provides a framework for future research. The primary limitation was the sample size; with only 18 participants, the generalizability of our results may be restricted. Furthermore, our study design—a prospective observational study with repeated measures—cannot offer the same level of evidence as a randomized controlled trial (RCT) due to the inherent absence of randomization and control groups, which are essential for mitigating confounding variables and bias. Additionally, the duration of our study, while adequate for detecting changes in serum zinc levels, might not allow enough time for more complex physiological outcomes to emerge, such as significant improvements in muscle mass or broader metabolic health impacts. Future investigations, therefore, should aim for larger sample sizes, include control groups, extend observation periods, and employ randomized designs to substantiate and build upon our preliminary findings.

The trial's findings also underscore the feasibility and effectiveness of employing postbiotics as a therapeutic agent, with distinct advantages over probiotics, especially in terms of stability, safety, and predictable responses. The integration of postbiotics into dietary regimes offers a promising avenue for enhancing not only digestive health but also contributing to a broader spectrum of physiological benefits, including immunomodulatory effects and maintenance of the gut epithelial barrier.

Economically, the application of postbiotics offers a pragmatic and cost-effective solution to the challenges of incorporating live microorganisms into various product matrices, ensuring quality and stability across diverse environmental conditions. The strains used in this study, recognized for their safety by authoritative bodies, have proven their resilience and bio functional integrity through rigorous processing, making them highly suitable for industrial applications.

Overall, our study's outcomes reinforce the notion that strategic modulation of the gut microbiota through postbiotic supplementation can be a valuable component of health optimization strategies. It opens new doors for further research into the complex interplay between diet, microbiota, and health outcomes, heralding a new era of microbiota-targeted therapies. As we continue to unravel the intricate dynamics of the gut ecosystem, the deliberate manipulation of its constituents could become a cornerstone of preventive medicine and personalized nutrition.

The promising results from our prospective observational study advocate for larger scale, randomized controlled trials to validate these findings and potentially extend the application of postbiotics in clinical practice. The profound implications of this research resonate with the broader scientific quest to harness the gut microbiota's potential, marking a significant stride in the journey towards a more profound understanding and utilization of microbial allies in our pursuit of optimal health.

The study notably found an enhancement in MSEQ scores for holistic exercises, attributed to the supplementation with three postbiotics, including one enriched with zinc. This enhancement was the unique significant result among the variables measured by the MSEQ. This outcome highlights the critical role of targeted nutritional supplementation in enhancing the satisfaction and perceived quality of holistic health practices among participants. The positive impact of zinc, delivered through a postbiotic mechanism, emphasizes the potential of such interventions to support well-being in a natural and non-invasive manner [7]. Despite the absence of other significant findings in the MSEQ assessment, this result alone underscores the importance of microbiome-modulating solutions such as postbiotics and micronutrients like zinc in holistic exercise routines, suggesting that even subtle dietary adjustments can have meaningful effects on individuals' health perceptions and satisfaction. This insight contributes to the broader conversation on integrating nutritional strategies into holistic health frameworks, advocating for further exploration into how specific supplements can optimize the holistic health experience.

CONCLUSION

Our study demonstrated a notable increase in serum zinc levels following supplementation with the "Postbiotic Metabolic Blend," indicating the blend's potential to enhance metabolic health and support physiological well-being, particularly for those engaged in strength training. This significant result, alongside improvements in

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gastrointestinal rhythm and a marked increase in the quantity of holistic exercises as measured by MSEQ scores, highlights the comprehensive impact of zinc delivered through postbiotics. Although the findings offer promising insights, it is important to approach them with caution due to limitations such as a modest sample size, the lack of a randomized controlled trial design, and a brief observation period. These factors gently remind us that our conclusions are preliminary and underscore the need for further studies with larger samples and more comprehensive designs to fully elucidate the effects of postbiotic supplementation. Nonetheless, the observed benefits reinforce the value of integrating specific nutritional strategies into holistic health practices. This study advocates for further exploration into how postbiotics can optimize health outcomes, suggesting a promising direction for future research in nutritional science and the management of exercise-induced gastrointestinal symptoms. Future studies should aim to confirm these findings and fully explore the potential of postbiotics in improving metabolic and gastrointestinal health.

DECLARATIONS

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Authors' contributions

All authors contributed equally to this work.

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Competing interests

Authors declare that this study was funded by AB Biotek Human Nutrition & Health. The first four authors: Jordi Cuñé, Maria Tintoré, Laia Martí, and Carlos de Lecea are employees of AB Biotek Human Nutrition & Health. (www.abbiotekhealth.com). Beyond this, there are no additional competing interests to disclose. Agustí Martí, the fifth author, is affiliated with Greenhouse Data Science S.L., Barcelona, Spain (ghdatascience.com). "The authors declare that. apart from the aforementioned. they have no competing interests".

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