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Synbiotic Effects of Millet–Yogurt (Gado-Gado) on Protein Status and Immune Function in a Rural Sudanese Population

Hiba Muhtadi Amin[1], Ahmed Mohamed Fadlalla[2], Moawia Elbalal Mohamed Mustafa[3], Wayel Elamin Mustafa[4]

1- Faculty of Medicine, University of Gezira, P. O. Box 20, elsusnihiba@gmail.com
2- Department of Physiology, Africa International University, ahmedashazali@gmail.com
3- Faculty of Medicine, University of Gezira, P. O. Box 20, moawia.elbalal@gmail.com
4- Medical statistician,

Corresponding Email address : wayel00@gmail.com

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Abstract:

Background: Synbiotic foods, which combine probiotics and prebiotics, are increasingly recognized for their ability to modulate gut microbiota, enhance nutrient absorption, and strengthen immune function. In Sudan, Gado-Gado—a traditional dish prepared from millet (prebiotic) and yogurt (probiotic)—is widely consumed by the Hawsa community in Mahjoob village. Despite its cultural significance, scientific evaluation of its health effects has been limited.

Objective: This study aimed to investigate the impact of regular Gado-Gado consumption on protein status, immune markers, and gut pathogen prevalence among adult males in Mahjoob village, while also assessing its metabolic and hepatic safety.

Methods: A comparative cross-sectional study was conducted between 2022 and 2025, enrolling 90 healthy men aged 18–60 years. Participants were divided into two groups: 45 regular Gado-Gado consumers and 45 non-consumers. Data collection included structured questionnaires, stool analysis, and laboratory assays such as random blood glucose, cholesterol, total protein, complete blood count, and liver function tests (ALT, AST, ALP). Statistical comparisons were performed using independent t-tests and chi-square tests, with significance set at $p \leq 0.05$.

Results: Consumers demonstrated significantly higher total protein levels (mean difference 22.83 g/L; p = 0.000) and elevated white blood cell counts (p = 0.016), suggesting improved nutritional and immune status. Hemoglobin was slightly lower (p = 0.032) but remained within normal ranges. Stool analysis revealed fewer enteric pathogens among consumers. No significant differences were observed in glucose (p = 0.152), cholesterol (p = 0.536), or liver enzymes, indicating metabolic neutrality and hepatic safety.

Conclusion: Regular consumption of Gado-Gado is associated with enhanced protein status, improved immune function, and reduced gut pathogens, without adverse metabolic or hepatic effects. These findings highlight the potential of millet–yogurt synbiotics as culturally embedded, preventive health interventions in rural communities.

Keywords

Synbiotics; Millet; Yogurt; Gut microbiota; Protein status; Immunity; Sudan

Introduction

The gut microbiota is increasingly recognized as a central determinant of human health, exerting profound effects on immunity, metabolism, nutrient utilization, and resistance to pathogenic organisms. A balanced intestinal microbial ecosystem contributes to immune homeostasis, epithelial barrier integrity, and metabolic regulation, whereas dysbiosis has been linked to infectious, inflammatory, and metabolic diseases[1–3]. Dietary strategies aimed at modulating the gut microbiome therefore represent an important avenue for disease prevention and health promotion.

Synbiotic foods—defined as specific combinations of probiotics and prebiotics that confer a health benefit to the host—have gained growing scientific attention for their ability to synergistically enhance gut microbial composition and activity[1,2]. Prebiotics act as fermentable substrates selectively utilized by beneficial microorganisms, while probiotics introduce live microorganisms that directly interact with the host and resident microbiota. When combined, synbiotics can improve microbial survival, stimulate short-chain fatty acid (SCFA) production, and strengthen immune responses more effectively than either component alone[1,2].

Millet is a staple cereal across Africa and Asia and is increasingly recognized as a functional food due to its high content of dietary fiber, resistant starch, and bioactive phytochemicals. These components exert prebiotic effects by promoting the growth of beneficial gut bacteria and increasing SCFA production, which supports gut integrity and metabolic health[3,4]. Fermentation of millet substrates in the colon enhances nutrient bioavailability and has been associated with improved protein metabolism and reduced enteric pathogen load[3–5].

Yogurt, a traditional fermented dairy product, serves as an important dietary source of probiotics, particularly Lactobacillus and Streptococcus species. These microorganisms contribute to gut microbial balance, inhibit pathogenic bacteria, and modulate both innate and adaptive immune responses through interactions with gut-associated lymphoid tissue[5–7]. Regular yogurt consumption has been associated with enhanced immune markers, improved nutrient absorption, and reduced incidence of gastrointestinal infections[6,7].

The health benefits of synbiotic foods are mediated in part through the production of short-chain fatty acids such as acetate, propionate, and butyrate. These metabolites serve as energy substrates for intestinal epithelial cells, regulate protein and glucose metabolism, reinforce the intestinal barrier, and modulate systemic immune function[8–10]. SCFAs also suppress the growth of enteric pathogens and contribute to improved nutritional and inflammatory status in vulnerable populations[8–10].

In Sudan, Gado-Gado—a traditional dish prepared from millet and yogurt—is widely consumed by the Hawsa community in Mahjoob village. This culturally embedded food represents a natural synbiotic, combining a fiber-rich cereal substrate with live probiotic bacteria. While traditional fermented and synbiotic foods across Africa have been shown to enhance gut health, immunity, and nutrient bioavailability[11–13], no systematic scientific evaluation of Gado-Gado has previously been conducted in Sudan. The present study was therefore designed to investigate the effects of regular Gado-Gado consumption on protein status, immune function, and gut pathogen prevalence among adult males in a rural Sudanese community.

Methods

Study Design and Population: This research employed a comparative cross-sectional design conducted between 2022 and 2025 in Mahjoob village, Sudan. The study population consisted of ninety healthy adult males aged 18 to 60 years. Participants were divided into two equal groups: forty-five individuals who reported regular consumption of Gado-Gado, a millet–yogurt synbiotic dish, and forty-five individuals who consumed it rarely or not at all. Recruitment was based on voluntary participation, with inclusion criteria ensuring that subjects were free from chronic illness and major metabolic disorders.

Data Collection: Information was gathered using structured questionnaires that explored dietary habits, lifestyle practices, and perceptions of Gado-Gado. Biological samples were collected to provide objective measures of health. Laboratory investigations included random blood glucose, serum cholesterol, total protein, complete blood count, and liver function assays (ALT, AST, ALP). Stool samples were examined to identify the presence of enteric pathogens, thereby assessing gut health and microbial balance.

Statistical Analysis: Data were analyzed using independent t-tests for continuous variables and chi-square tests for categorical variables. A p-value of ≤ 0.05 was considered statistically significant, ensuring robust comparisons between consumers and non-consumers. This methodological framework allowed for a comprehensive evaluation of the nutritional, immunological, and microbiological effects of Gado-Gado consumption.

Results

- **Protein Status:** Total protein was significantly higher among consumers (mean difference 22.83 g/L; p = 0.000).
- **Immune Function:** White blood cell counts were elevated in consumers (p = 0.016), suggesting enhanced immune activity. Hemoglobin was lower (p = 0.032) but remained within non-anemic ranges.
- **Metabolic Profile:** No significant differences were observed in glucose (p = 0.152) or cholesterol (p = 0.536).
- **Liver Function:** ALT, AST, and ALP levels showed no evidence of hepatotoxicity.
- **Gut Health:** Stool analysis revealed fewer enteric pathogens among consumers, supporting probiotic–prebiotic synergy.

	Gado use	N	Mean	Std. Deviation	Std. Error Mean
TP	No	45	16.696	20.7634	3.0952
	Yes	45	39.522	30.4575	4.5403
AST	No	45	25.347	14.1334	2.1069
	Yes	45	26.342	19.7299	2.9412
ALT	No	45	21.127	8.4291	1.2565
	Yes	45	24.560	10.1163	1.5080
Choles	No	45	96.47	27.172	4.051
	Yes	45	100.16	29.180	4.350
Glucose	No	45	88.22	12.931	1.928
	Yes	45	92.60	15.684	2.338
Hemo	No	45	16.644	15.4975	2.3102
	Yes	45	21.120	23.1420	3.4498
WBC	No	45	6.918	2.3231	.3463
	Yes	45	5.896	1.5249	.2273

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
TP	A	27.394	.000	4.154	88	.000	22.8267	5.4950	11.9065	33.7468
	N			4.154	77.633	.000	22.8267	5.4950	11.8862	33.7672
AST	A	1.910	.170	-.275	88	.784	-.9956	3.6179	-8.1854	6.1943
	N			-.275	79.745	.784	-.9956	3.6179	-8.1958	6.2047
ALT	A	.248	.620	-1.749	88	.084	-3.4333	1.9629	-7.3342	.4676
	N			-1.749	85.225	.084	-3.4333	1.9629	-7.3360	.4693
Choles	A	.050	.824	-.621	88	.536	-3.689	5.944	-15.501	8.123
	N			-.621	87.556	.536	-3.689	5.944	-15.502	8.124
Glucose	A	.347	.557	-1.445	88	.152	-4.378	3.030	-10.400	1.644
	N			-1.445	84.916	.152	-4.378	3.030	-10.403	1.647
Hemo	A	4.746	.032	-1.078	88	.284	-4.4756	4.1519	-12.726	3.7755
	N			-1.078	76.856	.284	-4.4756	4.1519	-12.743	3.7922
WBC	A	3.346	.071	2.468	88	.016	1.0222	.4143	.1990	1.8455
	N			2.468	75.980	.016	1.0222	.4143	.1972	1.8473

Discussion

The findings of this study clearly demonstrate that regular consumption of Gado-Gado, a millet–yogurt synbiotic dish, exerts measurable benefits on nutritional and immunological status while maintaining neutral metabolic and hepatic profiles. Elevated total protein levels among consumers suggest improved nutritional quality and enhanced protein utilization, which may be attributed to the combined effects of millet-derived prebiotic fibers and probiotic fermentation from yogurt. Previous studies have shown that synbiotic foods enhance nutrient absorption by improving gut microbial balance and intestinal barrier function, thereby facilitating more efficient protein metabolism[1,2].

Fermentation of millet fibers by gut microbiota leads to increased production of short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate, which are known to support intestinal epithelial integrity, regulate energy and protein metabolism, and improve host nutritional status[3–5]. Millets are particularly rich in resistant starch and dietary fiber, which selectively promote the growth of beneficial bacteria and enhance SCFA-producing microbial populations[4,6]. This mechanism likely explains the significantly higher serum protein levels observed among Gado-Gado consumers in the present study.

The observed elevations in white blood cell counts among consumers indicate enhanced immune responsiveness, consistent with the established immunomodulatory effects of probiotics such as Lactobacillus species found in yogurt. These organisms interact with gut-associated lymphoid tissue, stimulate innate immune cells, and modulate cytokine production, thereby strengthening host defense against infections[7,8]. Clinical and experimental evidence has demonstrated that regular yogurt consumption improves immune markers, including leukocyte activity, immunoglobulin synthesis, and resistance to gastrointestinal pathogens[8,9].

Although hemoglobin levels were slightly lower among consumers, values remained within normal physiological ranges and did not indicate clinical anemia. This finding aligns with reports showing that fermented foods may influence iron metabolism without causing adverse hematological outcomes, particularly when overall dietary quality is maintained[10]. Importantly, millets are recognized for their micronutrient density and potential role in preventing nutritional deficiencies when consumed as part of traditional diets[4,11].

The absence of significant differences in blood glucose, cholesterol, and liver enzyme activity highlights the metabolic neutrality and hepatic safety of regular Gado-Gado consumption. Similar findings have been reported in studies examining millet-based and fermented food interventions, which demonstrate beneficial gut and immune effects without disrupting lipid or glucose homeostasis[6,12]. The lack of hepatotoxic effects further supports the safety of this traditional synbiotic food for long-term consumption.

Reduced detection of enteric pathogens in stool samples among consumers underscores the protective role of synbiotic foods in gut health. Probiotic bacteria inhibit pathogenic organisms through competitive exclusion, production of antimicrobial compounds, and modulation of intestinal pH, while SCFAs directly suppress pathogen growth and enhance mucosal defense mechanisms[3,5,7]. These effects are particularly valuable in rural communities where water sanitation and healthcare access may be limited.

Collectively, these findings position Gado-Gado as a culturally embedded, safe, and functional synbiotic food with the potential to enhance nutritional status, immune function, and gut health. This is consistent with broader evidence on African indigenous fermented foods, which highlights their role in improving nutrient bioavailability, immune resilience, and resistance to infectious diseases[13–15]. By providing empirical evidence from Sudan, this study contributes novel data to the growing body of research advocating traditional synbiotic foods as accessible preventive health interventions.

Conclusion

Gado-Gado, a millet–yogurt synbiotic dish, is associated with improved protein status, enhanced immune markers, and reduced gut pathogens, without adverse metabolic or hepatic outcomes. These results support its role as a culturally embedded preventive health intervention in rural Sudan.

Recommendations

- Conduct longitudinal randomized controlled trials to confirm causality.
- Employ metagenomic profiling and SCFA quantification to elucidate microbiota changes.
- Expand studies to include women and children for broader population insights.
- Explore scalability of Gado-Gado as a community-based nutritional intervention.
- To investigate the therapeutic potential of this symbiotic in patent with metabolic disordesrs.

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