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Complementary Feeding Innovation from Soybean and Dragon Fruit Peel Enhances Macro- and Micronutrient Biomarkers in Malnourished Rats

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ABSTRAK

Malnutrisi masih menjadi salah satu masalah kesehatan masyarakat utama yang ditandai dengan defisiensi makronutrien dan mikronutrien. Pemanfaatan pangan fungsional berbasis lokal seperti kedelai (*Glycine max*) *dan kulit buah naga (*Hylocereus polyrhizus*) berpotensi menjadi intervensi gizi alternatif. Penelitian ini bertujuan untuk mengevaluasi pengaruh formulasi Makanan Pendamping ASI (MP-ASI) berbasis kedelai dan kulit buah naga terhadap kadar protein total, albumin, dan zinc pada tikus model malnutrisi. Penelitian eksperimental ini menggunakan* desain *pre–posttest randomized controlled group dengan 15 ekor tikus Sprague Dawley jantan yang dibagi dalam tiga kelompok (KN, KP, dan P). Induksi malnutrisi dilakukan dengan pakan rendah protein (5%) selama 21 hari, dilanjutkan intervensi formula MP-ASI dosis 2,4 g/hari/200 g BB selama 14 hari. Parameter yang diukur meliputi berat badan, kadar protein total, albumin, dan zinc serum sebelum dan sesudah intervensi. Analisis data menggunakan one-way ANOVA,* Tukey's post hoc, *dan* paired t-test. *Hasil penelitian menunjukkan adanya peningkatan yang bermakna pada biomarker status gizi setelah intervensi, ditandai dengan peningkatan kadar protein total dari 1,13 menjadi 6,88 g/dL, albumin dari 1,53 menjadi 4,53 g/dL, dan zinc dari 0,67 menjadi 1,34 mg/dL (seluruhnya p = 0,001). Sebaliknya, kelompok kontrol malnutrisi tidak menunjukkan perbaikan yang bermakna. Kombinasi kedelai dan kulit buah naga dalam formulasi MP-ASI berpotensi meningkatkan kadar protein, albumin, dan zinc pada kondisi malnutrisi, serta dapat menjadi strategi intervensi gizi berbasis pangan lokal yang menjanjikan.*

Kata kunci: *Albumin, Kedelai, Kulit buah naga, Malnutrisi, Protein, Zinc*

ABSTRACT

Malnutrition remains a major public health concern characterized by deficiencies in both macronutrients and micronutrients. The use of locally based functional foods such as soybean (*Glycine max*) *and dragon fruit peel (*Hylocereus polyrhizus*) offers potential as an alternative nutritional intervention. This study aimed to evaluate the effect of soybean and dragon fruit peel-based complementary feeding (MP-ASI) formulation on total protein, albumin, and zinc levels in a malnutrition rat model. This experimental study employed a pre–posttest randomized controlled group design involving 15 male Sprague Dawley rats divided into three groups (KN, KP, and P). Malnutrition was induced using a 5% low-protein diet for 21 days, followed by intervention with the MP-ASI formula at a dose of 2.4 g/day/200 g BW. Parameters measured included weekly body weight, serum total protein, albumin, and zinc levels before and after the intervention. Data were analyzed using one-way ANOVA Tukey's post hoc test, and paired t-test. The results demonstrated marked improvements in nutritional biomarkers following the intervention, with total protein increasing from 1.13 to 6.88 g/dL, albumin from 1.53 to 4.53 g/dL, and zinc from 0.67 to 1.34 g/dL (all p = 0.001). In contrast, no significant improvement was observed in the malnutrition control group. The combination of soybean and dragon fruit peel in MP-ASI formulations has the potential to improve protein, albumin, and zinc levels under malnutrition conditions and may serve as a promising locally based nutritional intervention strategy.*

Keywords: *Albumin, Dragon fruit peel, Malnutrition, Protein, Soybean, Zinc*

I. INTRODUCTION

Malnutrition remains one of the major public health problems worldwide, particularly in developing countries, and is closely associated with increased morbidity and mortality.[1] Inadequate intake of macronutrients and micronutrients over a prolonged period can lead to growth retardation, impaired immunity, and increased susceptibility to infectious diseases. In Indonesia, the prevalence of stunting in 2023 was reported at 21.6%, exceeding the World Health Organization (WHO) target of below 20%. The Indonesian government aims to reduce stunting to 14% and wasting to 7% as part of the Indonesia Emas 2045 initiative. Malnutrition is characterized by metabolic disturbances reflected by reduced serum total protein, hypoalbuminemia, and zinc deficiency, all of which contribute to impaired growth, immune dysfunction, and delayed tissue repair.[3,4]

Malnutrition disrupts protein metabolism by reducing protein synthesis and serum albumin production, leading to impaired nutritional status and metabolic homeostasis. Zinc deficiency commonly accompanies protein-energy malnutrition because of inadequate dietary intake and impaired intestinal absorption, further compromising protein synthesis, immune function, and tissue repair.[4,5] Restoring both macronutrient and micronutrient status is essential during nutritional rehabilitation to support normal growth and physiological recovery.[6]

Nutritional therapy through functional foods rich in protein and bioactive compounds is considered an effective strategy for preventing and managing malnutrition.[7] One important approach is the development of complementary feeding (MP-ASI) formulations to ensure adequate nutrient intake during critical periods of growth. Complementary foods enriched with high-quality protein and essential micronutrients are expected to improve protein and zinc status, as well as overall nutritional outcomes in malnourished children.[8] A locally available food-based approach is particularly relevant in resource-limited settings, where accessibility and affordability of nutritious foods remain major challenges.[9]

Soybean (Glycine max) is a high-quality plant protein source containing nearly all essential amino acids required for protein synthesis and tissue repair. Previous studies have demonstrated that soy protein can improve serum albumin levels and support recovery from protein-energy malnutrition.[10] In addition, soybean isoflavones possess antioxidant properties that may protect hepatocytes from oxidative stress, thereby supporting albumin synthesis in the liver.[11]

Dragon fruit peel (Hylocereus polyrhizus) is an underutilized by-product with high nutritional and functional value. It contains flavonoids, betacyanins, dietary fiber, and minerals, including zinc.[12] Flavonoids and betacyanins exhibit strong antioxidant activity, protecting tissues from oxidative stress and supporting metabolic function.[13] In addition, the zinc and dietary fiber in dragon fruit peel may enhance protein synthesis, immune function, and nutrient absorption, thereby contributing to improved nutritional status under malnourished conditions.[14,15] These properties make dragon fruit peel a promising functional ingredient to complement protein-rich foods in complementary feeding (MP-ASI) formulations.[16]

Although soybean and dragon fruit peel have individually demonstrated beneficial nutritional properties, few studies have evaluated their combined use in complementary feeding (MP-ASI) formulations and its effect on nutritional biomarkers associated with protein-energy malnutrition. Soybean was selected as a source of high-quality protein and essential amino acids, whereas dragon fruit peel provides antioxidants, dietary fiber, and zinc that may complement protein metabolism and nutritional recovery, potentially producing synergistic nutritional benefits.[16,17] Protein-energy malnutrition rat models are widely used because they reproduce key metabolic alterations observed in malnourished children, allowing controlled evaluation of nutritional interventions.[18,19] Therefore, this study aimed to evaluate the effect of soybean and dragon fruit peel-based MP-ASI on serum total protein, albumin, and zinc levels in a malnutrition rat model. We hypothesized that the soybean and dragon fruit peel-based MP-ASI formulation would significantly improve serum total protein, albumin, and zinc levels compared with the malnutrition control group.

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II. METHODS

Research Design and Animal Model

This experimental study employed a pre–posttest randomized controlled group design. The study was conducted at the Laboratory of Nutrition and Food, Universitas Gadjah Mada, from July to September 2025. Male Sprague Dawley rats aged 6–8 weeks with an initial body weight of 100–150 g were used. Sample size was determined using the Resource Equation Method. A total of 15 rats were allocated into three groups, resulting in a resource equation value of E = 12 (15 − 3), which is within the recommended range of 10–20 for animal experiments.[18] Following one week of acclimatization, the rats were randomly allocated into three groups (KN, KP, and P1; n = 5 per group) using a simple randomization method to minimize allocation bias. Malnutrition was induced by administering a 5% low-protein diet ad libitum in solid form. The low-protein diet consisted of casein (10%), corn oil (8%), mineral mix (5%), vitamin mix (1%), carboxymethyl cellulose (CMC, 1%), water (5%), and cornstarch added to complete 100% of the formulation. The diet was administered for 21 consecutive days.[19,20]

Materials and Intervention Dose

This study was a continuation of previous research on MP-ASI formulation, the preparation procedure of which had been published in *ARTERI: Jurnal Ilmu Kesehatan,* Vol. 4, No. 2, February 2023. The dosage was determined based on protein requirements for children aged 3–5 years, namely 25% or 25 g per 100 g of product. The protein content in 100 g of the product was 18.9 g, requiring approximately 20 g of protein. Based on this calculation, the amount of product prepared was 132 g. For administration to experimental animals weighing 200 g, a dose of 2.4 g per rat per day was diluted prior to administration and delivered via oral gavage.[21,22,23]

Parameter Measurement

Blood sampling was performed at the beginning of the intervention (week 4) and at the end of the study (week 8) after a 10-hour fast with ad libitum access to drinking water. Approximately 2 ml of blood was collected from the orbital vein into microtubes, allowed to clot, and centrifuged for 10 minutes at 1620 rpm. The obtained serum was analyzed for total protein using the Biuret method, albumin using the Bromocresol Green (BCG) method, and zinc using atomic absorption spectrophotometry (AAS) or spectrophotometry with a specific reagent.[19]

Data Analysis

Data were analyzed using SPSS software. Differences in biomarker levels between groups were assessed using one-way ANOVA, followed by the Tukey's post hoc test to determine differences among treatment groups. Within-group differences before and after the intervention were analyzed using paired t-tests. A p-value < 0.05 was considered statistically significant.

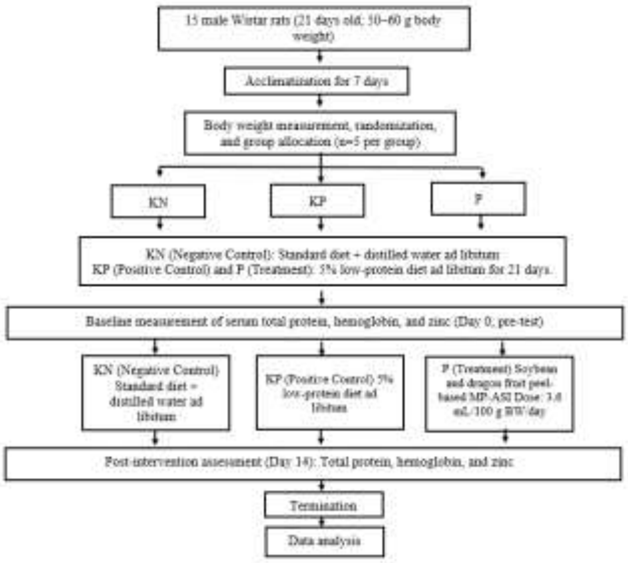

Figure 1. Research Design

Ethical Considerations

This study was approved by the Health Research Ethics Committee (KEPK) of Politeknik Negeri Jember, with approval number: 1008/PL17.4/PG/2025

III. RESULTS AND DISCUSSION

Table 1. Mean Body Weight Before and After Malnutrition Induction

Group	Before Induction (Mean ± SD)	After Induction (Mean ± SD)
KN	97.0 ± 1.58	137.6 ± 2.30
KP	96.6 ± 2.30	120.4 ± 2.41
P	95.2 ± 1.92	121.2 ± 1.92

p	0.345	0.001*

Notes: KN: Negative control group (standard diet) KP: Positive control group (malnutrition control) P: Treatment group receiving soybean and dragon fruit peel-based complementary feeding (MP-ASI)
p: Between-group comparison analyzed using One-Way ANOVA followed by Tukey's post hoc test.

Body weight monitoring confirmed the successful establishment of the malnutrition model after 21 days of feeding with a 5% low-protein diet (Table 1). Baseline body weight did not differ significantly among the three groups (p = 0.345), indicating comparable initial conditions before malnutrition induction. Following the induction period, significant differences in body weight were observed among the groups (p = 0.001). Rats receiving the low-protein diet (KP and P) exhibited markedly lower body weight gain than the normal control group (KN), confirming that protein restriction effectively impaired normal growth. Furthermore, the absence of a significant difference in body weight between the KP and P groups after induction indicated that both groups entered the intervention phase with a comparable degree of malnutrition.

The reduced body weight gain observed in the malnourished groups reflects the physiological consequences of prolonged protein deficiency. Dietary protein provides essential amino acids required for protein synthesis, tissue accretion, and the production of enzymes and hormones involved in normal growth. When protein intake is insufficient, anabolic processes are suppressed, resulting in impaired muscle development, reduced tissue growth, and lower body weight gain.[24,25]

The comparable body weights between the KP and P groups after the induction period are particularly important because they indicate that both groups had a similar nutritional status before the intervention. This finding minimizes baseline bias and strengthens the interpretation that subsequent improvements observed in the treatment group were attributable to the soybean and dragon fruit peel-based complementary feeding (MP-ASI) rather than differences in the severity of malnutrition

The present findings are consistent with previous studies demonstrating that low-protein diets effectively induce protein-energy malnutrition in experimental animals. Wei et al. (2021) reported that protein restriction in weaning rats significantly reduced body weight gain and altered metabolic profiles associated with malnutrition. Similarly, Xu et al. (2024) found that prolonged protein deficiency impaired hepatic protein synthesis and delayed somatic growth. Collectively, these findings confirm that the 5% low-protein diet successfully established a reproducible malnutrition model suitable for evaluating the nutritional efficacy of the soybean and dragon fruit peel-based MP-ASI formulation.

A. Total Protein

Table 2. Changes in Serum Total Protein Levels Before and After Intervention Among Experimental Groups

Group	Pretest Mean ± SD	Posttest Mean ± SD	Δ Mean ± SD	p^b
KN	8.18 ± 0.08	8.15 ± 0.08	-0.03 ± 0.00	0.641
KP	1.26 ± 0.05	1.18 ± 0.08	-0.08 ± 0.03	0.214
P	1.13 ± 0.07	6.88 ± 0.16	5.75 ± 0.09	0.001*
p^a	0.001*	0.001*		

Notes: p^a: Between-group comparison analyzed using One-Way ANOVA followed by Tukey's post hoc test.
p^b: Within-group comparison between pretest and posttest values analyzed using paired t-test.

Serum total protein levels differed significantly among the experimental groups before and after the intervention (p < 0.001) (Table 2). Following the intervention, total protein concentrations remained stable in the normal control group and persistently low in the malnutrition control group, indicating that spontaneous recovery of protein nutritional status did not occur under continued protein-deficient conditions. In contrast, rats receiving the soybean and dragon fruit peel-based complementary feeding (MP-ASI) exhibited a marked improvement in serum total protein, demonstrating the effectiveness of the dietary intervention in restoring protein nutritional status. Although total protein levels in the treatment group remained slightly lower than those of the normal control group, the substantial improvement observed after intervention

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indicates meaningful nutritional recovery toward physiological levels.

The marked improvement in serum total protein observed in the treatment group indicates that the soybean and dragon fruit peel-based MP-ASI effectively restored protein metabolism following malnutrition. Dietary proteins are initially hydrolyzed by gastric pepsin and pancreatic proteases into peptides and amino acids, which are subsequently absorbed through intestinal enterocytes and transported via the portal circulation to the liver.[15,28] These absorbed amino acids serve as essential substrates for the synthesis of plasma proteins, structural proteins, enzymes, and other functional proteins required for tissue repair and metabolic recovery. Adequate protein intake during nutritional rehabilitation plays a central role in restoring serum total protein concentrations and overall nutritional status.[16,26]

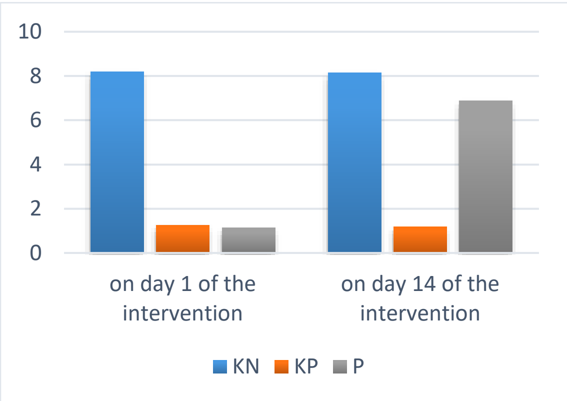

Figure 2. Comparison of Mean Serum Total Protein Levels

Soybean was selected as the primary protein source because it contains high-quality plant protein with a well-balanced essential amino acid profile, making it highly suitable for supporting protein synthesis during nutritional rehabilitation.[13] Although raw soybean naturally contains anti-nutritional compounds such as phytates and trypsin inhibitors, these compounds are substantially reduced through soaking, heating, and flour-processing methods commonly used in complementary food preparation. Consequently, protein digestibility and amino acid bioavailability are markedly improved, allowing more efficient utilization of dietary protein for tissue regeneration and plasma protein synthesis.[25] In addition, soybean is rich in bioactive compounds, particularly isoflavones, which possess antioxidant and anti-inflammatory properties that may protect hepatocytes from oxidative damage and further support hepatic protein synthesis during recovery.[16,27]

Dragon fruit peel may complement the nutritional effects of soybean through mechanisms beyond protein provision. Although it contributes relatively little dietary protein, it is rich in flavonoids, betacyanins, dietary fiber, and essential minerals that support nutritional rehabilitation. Its antioxidant compounds help reduce oxidative stress, a condition commonly associated with protein-energy malnutrition that may impair protein metabolism and cellular repair. Furthermore, the dietary fiber present in dragon fruit peel promotes gastrointestinal health by improving intestinal integrity and creating a favorable environment for nutrient absorption, thereby enhancing the utilization of dietary protein supplied by soybean. These complementary effects may explain the substantial improvement in serum total protein observed in the treatment group.[17,28]

The present findings are consistent with previous studies demonstrating the beneficial effects of soybean supplementation on protein nutritional status. Hu et al. (2023) reported that soybean proteins and bioactive peptides enhanced protein metabolism, reduced inflammatory responses, and promoted nutritional recovery in experimental models of malnutrition. Similarly, Hasna and Maryanto (2020) found that soybean supplementation significantly improved serum protein-related biomarkers in protein-energy malnutrition. Although studies investigating the combined use of soybean and dragon fruit peel remain limited, the present study suggests that combining a high-quality protein source with antioxidant-rich plant materials may provide complementary nutritional benefits, resulting in greater improvement in protein nutritional status than would be expected from protein supplementation alone.

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B. Albumin

Table 3. Changes in Serum Albumin Levels Before and After Intervention Among Experimental Groups

Group	Pretest Mean ± SD	Posttest Mean ± SD	Δ Mean ± SD	*pb*
KN	5.19 ± 0.13	5.15 ± 0.13	-0.04 ± 0.00	0.624
KP	1.53 ± 0.11	1.50 ± 0.10	-0.03 ± 0.01	0.671
P	1.53 ± 0.09	4.53 ± 0.07	3.00 ± 0.02	0.001*
p^a	0.001*	0.001*		

Notes: p^a: Between-group comparison analyzed using One-Way ANOVA followed by Tukey's post hoc test. p^b: Within-group comparison between pretest and posttest values analyzed using paired t-test.

Serum albumin analysis demonstrated a significant response to nutritional intervention (Table 3). Albumin concentrations remained within the normal physiological range in the normal control group and showed little change in the malnutrition control group throughout the study, indicating persistent impairment of visceral protein status in the absence of nutritional rehabilitation. In contrast, rats receiving soybean and dragon fruit peel-based complementary feeding (MP-ASI) exhibited a marked recovery in serum albumin concentration, demonstrating substantial restoration of hepatic protein synthetic function following the intervention. Although albumin levels remained slightly lower than those of the normal control group, the improvement indicates effective reversal of hypoalbuminemia induced by protein-energy malnutrition.

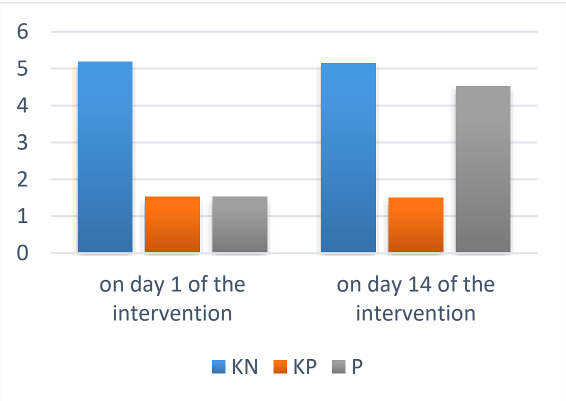

Figure 3. Comparison of Mean Serum Albumin Levels

Albumin is the most abundant plasma protein synthesized exclusively by hepatocytes and is widely recognized as a sensitive indicator of visceral protein status. Unlike total protein, which reflects overall protein metabolism, serum albumin more specifically represents hepatic protein synthetic capacity and the body's ability to maintain protein homeostasis during nutritional rehabilitation. The marked increase in serum albumin observed following administration of soybean and dragon fruit peel-based MP-ASI therefore suggests substantial recovery of liver protein synthesis after prolonged protein deficiency.[14]

Restoration of serum albumin is closely associated with improved availability of amino acids following correction of protein deficiency. During malnutrition, hepatic albumin synthesis is markedly reduced because limited amino acids are preferentially utilized to maintain essential metabolic functions rather than plasma protein production. Following nutritional rehabilitation, improved protein availability allows hepatocytes to resume albumin synthesis, resulting in recovery of visceral protein status. The present findings therefore indicate that the intervention not only increased dietary protein intake but also restored hepatic metabolic function required for albumin production.[16,27]

The improvement in albumin synthesis may also be supported by the functional properties of both intervention ingredients. Soybean contains isoflavones with antioxidant and anti-inflammatory activities that may protect hepatocytes against oxidative injury, thereby preserving their capacity to synthesize plasma proteins. Meanwhile, dragon fruit peel provides flavonoids and betacyanins that reduce oxidative stress, as well as dietary fiber that supports intestinal health and nutrient utilization. Rather than acting as a direct protein source, dragon fruit peel likely enhanced the efficiency of nutritional rehabilitation by creating a more favorable metabolic environment for hepatic protein synthesis.[27,29]

The present findings are in agreement with the work of van den Berg et al. (2022), who emphasized that soy protein possesses high digestibility and a balanced essential amino acid profile capable of supporting protein synthesis after appropriate processing. Likewise, Sui et al. (2021) reported that advances in soy protein processing substantially improve protein

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functionality and bioavailability, thereby enhancing its nutritional value. These findings support the marked increase in serum albumin observed in the present study, suggesting that the processed soybean-based MP-ASI provided sufficient amino acids for hepatic albumin synthesis. Furthermore, the addition of dragon fruit peel may have complemented this effect through its antioxidant compounds, which help preserve hepatocellular function during nutritional rehabilitation.

Although serum albumin did not completely return to the level observed in healthy animals, the substantial improvement indicates meaningful recovery of hepatic protein synthetic function during the intervention period. Beyond serving as an indicator of visceral protein status, albumin is the principal transport protein for circulating zinc and plays an essential role in maintaining plasma oncotic pressure, nutrient transport, and overall metabolic homeostasis.[32] Therefore, restoration of albumin concentrations may have enhanced zinc transport and bioavailability, thereby contributing to the improvement in serum zinc observed following nutritional rehabilitation. These findings suggest that the intervention restored not only protein availability but also hepatic functional capacity, supporting the recovery of both protein metabolism and micronutrient homeostasis.

C. Zinc

Table 4. Changes in Serum Zinc Levels Before and After Intervention Among Experimental Groups

Group	Pretest Mean ± SD	Posttest Mean ± SD	Δ Mean ± SD	p^b
KN	1.55 ± 0.12	1.32 ± 0.04	-0.23 ± 0.08	0.083
KP	0.65 ± 0.03	0.57 ± 0.05	-0.08 ± 0.02	0.109
P	0.67 ± 0.06	1.34 ± 0.06	0.67 ± 0.01	0.001*
p^a	0.001*	0.001*		

Notes: p^a: Between-group comparison analyzed using One-Way ANOVA followed by Tukey's post hoc test. p^b: Within-group comparison between pretest and posttest values analyzed using paired t-test.

Serum zinc concentrations were significantly influenced by the dietary intervention (Table 4). Zinc status remained relatively unchanged in both the normal control and malnutrition control groups throughout the study, indicating that spontaneous recovery of micronutrient status did not occur following protein restriction. In contrast, rats receiving soybean and dragon fruit peel-based complementary feeding (MP-ASI) exhibited a marked increase in serum zinc concentration, approaching the physiological range observed in the normal control group. These findings indicate that the intervention effectively restored zinc homeostasis during nutritional rehabilitation.

Zinc is an essential trace element involved in numerous biological processes, including protein synthesis, cellular proliferation, immune regulation, antioxidant defense, and tissue repair. Protein-energy malnutrition is frequently accompanied by zinc deficiency because inadequate dietary intake, impaired intestinal absorption, and altered protein metabolism reduce zinc availability. Restoration of serum zinc represents an important indicator of successful nutritional rehabilitation beyond recovery of macronutrient status.[30,31]

The improvement in serum zinc observed in the treatment group is likely attributable to several complementary mechanisms. First, recovery of protein nutritional status may have enhanced zinc absorption and retention because adequate dietary protein facilitates intestinal zinc uptake and improves whole-body zinc metabolism. Second, restoration of serum albumin may have increased the transport capacity for circulating zinc, as approximately 60% of plasma zinc is bound to albumin. The concurrent improvement in total protein and albumin provides a physiological explanation for the marked increase in serum zinc following nutritional rehabilitation.

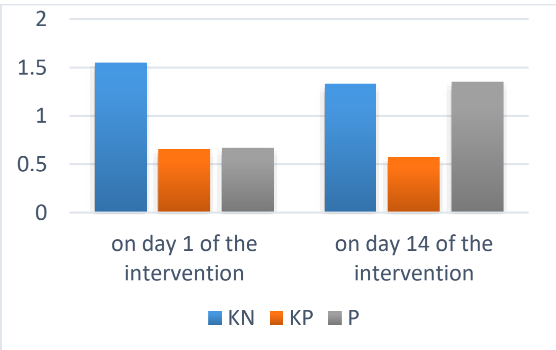

Figure 4. Comparison of Mean Serum Zinc Levels

The intervention ingredients may also have contributed directly to zinc recovery. Soybean naturally contains zinc together with high-quality protein that supports mineral utilization during tissue repair. In addition, dragon fruit peel provides minerals, flavonoids, betacyanins, and dietary fiber that may improve micronutrient bioavailability by maintaining intestinal integrity and reducing oxidative stress. Antioxidant compounds may preserve intestinal epithelial function and cellular metabolism, thereby facilitating more efficient zinc absorption and utilization during nutritional rehabilitation. These complementary nutritional and functional properties likely contributed to the restoration of serum zinc observed in the present study.[13,17]

The present findings are supported by the studies of Zhu et al. (2021) and Coverdale et al. (2022). Zhu et al. demonstrated that peptides derived from soy protein possess a strong zinc-binding capacity and improve zinc stability during gastrointestinal digestion, thereby enhancing zinc bioavailability. Meanwhile, Coverdale et al. reported that albumin is the principal transporter of circulating zinc and plays a critical role in regulating zinc distribution and cellular uptake. These findings are consistent with the present study, in which improvements in serum albumin were accompanied by increased serum zinc concentrations following administration of soybean and dragon fruit peel-based MP-ASI. In addition, the antioxidant constituents of dragon fruit peel may further support zinc utilization by reducing oxidative stress and maintaining intestinal epithelial integrity during nutritional rehabilitation.

The restoration of serum zinc observed in the present study has important physiological implications because zinc functions as a cofactor for numerous enzymes involved in protein synthesis, antioxidant defense, and cellular growth. Therefore, recovery of zinc status may further support the improvement of protein metabolism and tissue repair, creating a positive cycle of nutritional rehabilitation. Collectively, the concurrent improvement in serum total protein, albumin, and zinc demonstrates that soybean and dragon fruit peel-based MP-ASI effectively enhanced both macronutrient and micronutrient status, supporting its potential as a locally available functional complementary food for the management of protein-energy malnutrition.

This study has several limitations. Although the sample size was determined using the Resource Equation Method, a larger sample would improve the generalizability of the findings. In addition, this study was conducted in a Sprague Dawley rat model; therefore, further clinical studies are required to confirm the effectiveness of soybean and dragon fruit peel-based complementary feeding in human infants.

IV. CONCLUSION AND RECOMMENDATIONS

The soybean and dragon fruit peel-based complementary feeding (MP-ASI) formulation significantly improved serum total protein, albumin, and zinc concentrations in a malnutrition rat model, indicating its potential to restore both macronutrient and micronutrient status during nutritional rehabilitation. These findings provide preliminary evidence that combining a high-quality protein source with antioxidant-rich plant ingredients may offer complementary nutritional benefits for improving nutritional biomarkers. Practically, this formulation may serve as a promising locally sourced functional complementary food to support nutritional rehabilitation in resource-limited settings. Future studies should focus on validating these findings through larger animal studies and well-designed clinical trials in infants, while further investigating growth outcomes, nutrient bioavailability, safety, and long-term nutritional effects.

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