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Nutritional Strategies for Enhancing Endurance, Recovery, and Metabolic Efficiency in Athletes in Palu City, Indonesia

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Abstract

Objectives: This study aimed to examine the effectiveness of nutritional strategies in enhancing endurance, recovery, and metabolic efficiency among athletes in Palu City, Indonesia.

Materials and Methods: This study used a quantitative experimental approach with a pretest–posttest design. A total of 40 athletes from various sports disciplines participated in an eight-week structured nutritional intervention program. The intervention consisted of carbohydrate periodization, protein optimization, and hydration strategies. Data were collected using VO_2max testing, blood lactate analysis, and recovery rate measurements. Data were analyzed by comparing pretest and posttest results, with the significance level set at $p < 0.05$.

Results: The results showed significant improvements in endurance after the nutritional intervention, as indicated by increased VO_2max scores. Participants also demonstrated faster recovery rates and improved metabolic efficiency, supported by more favorable blood lactate responses after exercise. These findings indicate that structured nutritional strategies contributed positively to endurance capacity, recovery optimization, and metabolic regulation among athletes.

Conclusions: Structured nutritional strategies are effective in improving endurance, recovery, and metabolic efficiency among athletes in Palu City. The integration of carbohydrate periodization, protein optimization, and hydration planning can support better athletic performance and recovery management. These findings provide practical implications for coaches, athletes, and sports nutritionists in developing evidence-based nutrition programs in regional training contexts.

Keywords: Nutrition, Endurance, Recovery, Metabolic Efficiency, Athletes, Palu.

Introduction

Optimal athletic performance is not determined only by physical training, technical skills, and psychological readiness, but also by appropriate nutritional strategies. Nutrition plays a central role in supporting energy availability, maintaining physiological balance, accelerating recovery, and improving metabolic efficiency during training and competition (Bergeron et al., 2015; Komalasari, 2023). For athletes, especially those involved in endurance-based and intermittent sports, the ability to use energy substrates efficiently is essential for sustaining performance and delaying fatigue (Baiget et al., 2014; Baláš et al., 2012; Bassett, 2000).

Endurance capacity is strongly influenced by carbohydrate availability, glycogen storage, hydration status, and the body's ability to regulate lactate accumulation during exercise (Baláš et al., 2012; Stien et al., 2019; Yang et al., 2025). Inadequate nutritional intake may accelerate fatigue, reduce training quality, prolong recovery time, and increase the risk of performance decline (Baláš et al., 2012; Booth & Orr, 2016; Curtis et al., 2024). Protein intake is also important because it supports muscle repair, adaptation, and recovery after repeated training sessions. Meanwhile, proper hydration helps maintain thermoregulation, cardiovascular function, and exercise tolerance. Therefore, carbohydrate periodization, protein optimization, and hydration management should be considered as integrated components of athlete performance development.

In the Indonesian regional sports context, particularly in Palu City, nutritional planning for athletes is still often based on general eating habits rather than structured, sport-specific nutrition programs. Many athletes may rely on routine dietary patterns without individualized guidance related to training intensity, recovery needs, and metabolic demands. This condition becomes an urgent issue because inadequate nutritional strategies can limit endurance development, delay recovery, and reduce the effectiveness of training adaptations. Regional athletes require practical and evidence-based nutritional interventions that are suitable for their training environment and local conditions.

Previous studies have highlighted the importance of carbohydrate intake in maintaining glycogen stores, protein intake in supporting muscle repair, and hydration in preserving physiological function. However, many studies have examined these components separately, while fewer have investigated them as an integrated nutritional strategy. In addition, research focusing on structured nutrition interventions among regional athlete populations in Indonesia remains limited. This creates a gap between general sports nutrition recommendations and their practical application in local athlete development programs.

The novelty of this study lies in its integrated examination of carbohydrate periodization, protein optimization, and hydration strategies as a structured nutritional intervention to improve endurance, recovery, and metabolic efficiency among athletes in Palu City. This study does not only focus on performance outcomes, but also considers physiological indicators such as VO_2max, blood lactate response, and recovery rate. Therefore, the findings are expected to provide contextual evidence for developing practical sports nutrition programs that support athlete performance and recovery in regional training settings.

Based on this background, this study aims to investigate the effect of structured nutritional strategies on endurance, recovery, and metabolic efficiency among athletes in Palu City, Indonesia.

Materials and Methods

Study Participants

This study employed an experimental method using a one-group pretest–posttest design. This design was used to determine changes in endurance, recovery, and metabolic efficiency before and after the implementation of a structured nutritional intervention.

A total of 40 athletes aged 16–22 years from various sports clubs in Palu City, Indonesia, participated in this study. Participants were selected using purposive sampling based on their active involvement in regular training programs and their ability to complete the full intervention period.

The inclusion criteria were athletes aged 16–22 years, actively training at least three times per week, registered in sports clubs in Palu City, and declared medically fit to participate in training and testing procedures. Athletes who had injuries, metabolic disorders, cardiovascular problems, or incomplete participation during the intervention period were excluded from the study.

Before data collection, all participants received information about the study objectives, procedures, and potential risks. Participation was voluntary, and informed consent was obtained from participants or parents/guardians for athletes under 18 years of age.

Study Organization

The intervention was conducted over eight weeks. During this period, participants followed a structured nutritional program designed to support endurance performance, recovery, and metabolic efficiency. The program consisted of three main components: carbohydrate periodization, protein optimization, and hydration strategies.

Carbohydrate periodization was applied by adjusting carbohydrate intake according to training intensity and training schedule. Higher carbohydrate intake was recommended on high-intensity or high-volume training days, while moderate intake was applied on low-intensity or recovery days. This strategy aimed to support glycogen availability and sustain energy during training.

Protein optimization was provided by recommending daily protein intake within the range of 1.6–2.2 g/kg body weight/day. This intake was distributed across daily meals to support muscle repair, adaptation, and recovery after training sessions.

Hydration strategies were implemented by monitoring fluid intake before, during, and after exercise. Participants were encouraged to maintain adequate hydration status, especially during training sessions, to support thermoregulation, cardiovascular function, and recovery.

Pretest measurements were conducted before the intervention to assess baseline endurance, blood lactate response, and recovery rate. After the eight-week nutritional intervention, posttest measurements were conducted using the same procedures and instruments.

Research Instruments

Endurance was measured using the VO_2max test through the Beep Test. This test was used to estimate aerobic capacity and evaluate changes in endurance performance before and after the intervention.

Metabolic efficiency was assessed using a blood lactate analyzer. Blood lactate levels were measured to describe the body's metabolic response to exercise and to evaluate changes in lactate accumulation following the nutritional intervention.

Recovery was measured using the heart rate recovery test. Heart rate was recorded after exercise to determine how quickly participants' heart rate returned toward resting levels. Faster heart rate recovery was interpreted as better recovery capacity.

Statistical Analysis

Data were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean and standard deviation, were used to describe VO_2max, blood lactate, and recovery rate values before and after the intervention.

The normality of the data distribution was examined before inferential analysis. A paired sample t-test was used to compare pretest and posttest results for endurance, blood lactate response, and recovery rate. The significance level was set at $p < 0.05$.

Results

The results of this study showed significant improvements in all measured variables after the eight-week structured nutritional intervention. The intervention, which consisted of carbohydrate periodization, protein optimization, and hydration strategies, positively influenced endurance capacity, metabolic efficiency, and recovery response among athletes in Palu City.

Table 1. Pretest and Posttest Results of Endurance, Blood Lactate, and Recovery Rate

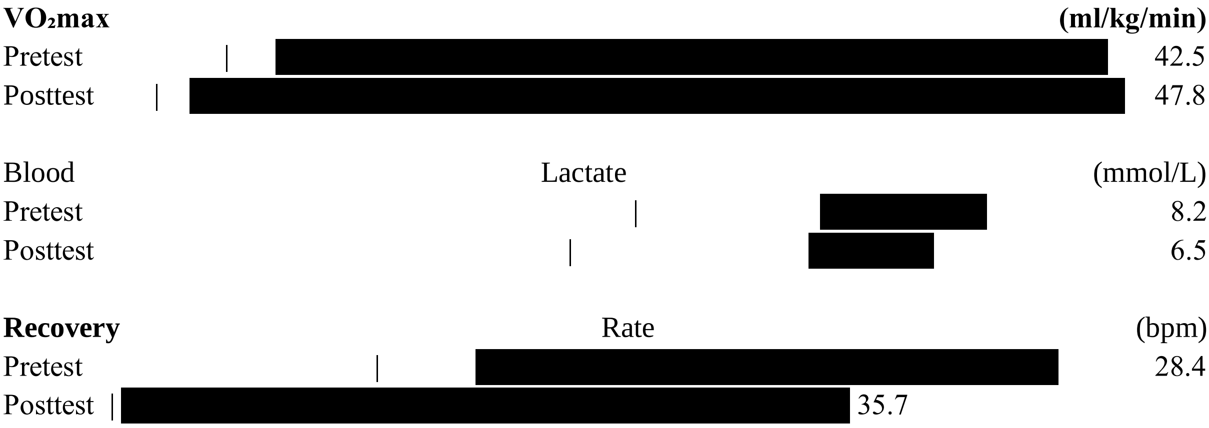
Variable	Pretest Mean	Posttest Mean	Mean Difference	Percentage Change	p-value
VO_2max (ml/kg/min)	42.5	47.8	+5.3	+12.47%	0.001
Blood lactate (mmol/L)	8.2	6.5	-1.7	-20.73%	0.003
Recovery rate (bpm)	28.4	35.7	+7.3	+25.70%	0.002

The VO_2max score increased from 42.5 ml/kg/min in the pretest to 47.8 ml/kg/min in the posttest, with a mean improvement of 5.3 ml/kg/min or 12.47%. This increase indicates that the nutritional intervention contributed to better aerobic capacity and endurance performance.

Blood lactate levels decreased from 8.2 mmol/L to 6.5 mmol/L, with a reduction of 1.7 mmol/L or 20.73%. This finding suggests improved metabolic efficiency, as athletes produced or accumulated less lactate after the intervention. Lower lactate accumulation may indicate better carbohydrate utilization, delayed fatigue, and improved exercise tolerance.

The recovery rate also improved from 28.4 bpm to 35.7 bpm, showing an increase of 7.3 bpm or 25.70%. This result indicates better physiological recovery after exercise, suggesting that the nutritional program supported cardiovascular recovery and post-exercise adaptation.

Figure 1. Comparison of Pretest and Posttest Scores



Overall, the findings demonstrated that the structured nutritional intervention significantly improved endurance, metabolic efficiency, and recovery among athletes. The significant increase in VO_2max ($p = 0.001$) indicates enhanced aerobic capacity after the intervention. The significant reduction in blood lactate levels ($p = 0.003$) reflects improved metabolic regulation and a lower fatigue response during exercise. In addition, the significant improvement in recovery rate ($p = 0.002$) shows that athletes experienced faster physiological recovery after training.

These results suggest that the combination of carbohydrate periodization, protein optimization, and hydration strategies can support better endurance performance, reduce metabolic stress, and enhance recovery capacity in regional athletes.

Discussion

The findings of this study demonstrate that structured nutritional strategies significantly improved endurance, recovery, and metabolic efficiency among athletes in Palu City. The increase in VO_2max after the eight-week intervention indicates that appropriate nutritional planning can support aerobic capacity and help athletes sustain physical performance during training. This improvement may be related to better carbohydrate availability, which supports glycogen storage and provides energy for prolonged exercise.

The decrease in blood lactate levels suggests improved metabolic efficiency and better lactate regulation during physical activity. Lower lactate accumulation after the intervention may indicate that athletes were able to use energy substrates more efficiently, delay fatigue, and maintain exercise intensity with less metabolic stress. This adaptation can be explained by the combination of carbohydrate periodization, adequate protein intake, and proper hydration, which collectively support energy metabolism and physiological balance.

The improvement in recovery rate also shows that the nutritional intervention had a positive effect on post-exercise recovery. Protein optimization may support muscle repair and adaptation after training, while hydration strategies help maintain cardiovascular function, thermoregulation, and fluid balance. Faster recovery is important for athletes because it allows them to maintain training quality, reduce excessive fatigue, and prepare more effectively for subsequent training sessions.

These findings reinforce the importance of integrating structured nutrition programs into athlete development. Nutrition should not be viewed only as daily food intake, but as a performance-supporting strategy that must be adjusted to training intensity, recovery needs, and individual athlete characteristics. In the context of Palu City, this study is particularly relevant because many regional athletes may still rely on general dietary habits without systematic nutritional guidance.

Therefore, coaches, athletes, and sports practitioners are encouraged to apply evidence-based nutritional planning, including carbohydrate periodization, protein optimization, and hydration monitoring, as part of regular training programs. However, this study was limited by its one-group design and relatively short intervention period. Future research should involve a control group, longer intervention duration, larger sample size, and sport-specific analysis to strengthen the evidence regarding nutritional strategies for athlete performance and recovery.

Conclusion

Structured nutritional strategies involving carbohydrate periodization, protein optimization, and hydration management significantly improved endurance, recovery, and metabolic efficiency among athletes in Palu City. These findings indicate that evidence-based nutrition programs can be an effective approach to supporting athletic performance and recovery in regional training contexts.

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