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Provisioning Effects on Insulin Hormone and Blood Glucose Concentration in Long-tailed Macaques (*Macaca fascicularis*) in Ngarai Sianok Urban Area, Bukittinggi

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Abstract

Background: *Human provisioning in tourism areas can influence the dietary patterns of long-tailed macaques (Macaca fascicularis) and potentially affect their physiological conditions, including insulin regulation and glucose metabolism. This study aimed to analyze insulin concentrations and blood glucose levels, and to examine the relationship between the two, in a population of M. fascicularis in the Sianok Canyon Tourism Area, Bukittinggi.* **Methodology:** *An observational study with a cross-sectional design was conducted at three locations: Belakang Balok (BB), Bukik Cangang Kayu Ramang (BCKR), and Birugo (BR). A total of 23 individuals were captured and analyzed. Blood glucose levels were measured with a portable glucometer, and insulin concentrations were measured by Enzyme-Linked Immunosorbent Assay (ELISA). Differences in glucose levels and insulin concentrations across locations were analyzed using the Kruskal–Wallis test, while the relationship between the two was analyzed using Spearman's rank correlation.* **Findings:** *There were no significant differences in blood glucose levels ($p = 0.094$) or insulin concentrations ($p = 0.962$) among the study locations. However, glucose levels had a higher mean rank at BB (15.56) than at BCKR (11.88) and BR (8.07). Spearman's correlation analysis revealed a moderate positive relationship between glucose levels and insulin concentrations ($\rho = 0.349$), but it was not statistically significant ($p = 0.102$).* **Contributions:** *The study results indicate variations in glucose levels and insulin concentrations among individuals; however, no significant differences were found between locations, nor was there a significant relationship between the two parameters. Further research with larger sample sizes and more controlled physiological measurements is needed to understand variations in the metabolic profile of M. fascicularis in tourism areas.*

Keywords: *Metabolic hormone; Insulin; Macaca fascicularis; Natural Food; Provisioning*

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INTRODUCTION

Indonesia is a megadiverse country with richness in flora and fauna. Primates are a group characterized by high diversity, with varied species, ecological roles, and adaptive behaviors. According to the International Union for Conservation of Nature (IUCN, 2026), Indonesia is home to 61 primate species. Holzner et al., (2021) Primates are recognized as highly intelligent mammals with complex social capabilities, enabling them to adapt to environmental changes, including those driven by human activity. This adaptability makes primates a crucial subject of study in areas with high human interaction, such as tourist destinations and urban environments.

The long-tailed macaque (*Macaca fascicularis*) is an Asian primate of the family Cercopithecidae that is widely distributed across Indonesia, particularly in Sumatra, Kalimantan, and Java (Bernathirdin et al., 2023). This species exhibits a high capacity to adapt to environmental changes, including adjusting its diet in response to human presence (Bolton, 2015). According to Soimin & Nahlunnisa (2023), *M. fascicularis* lacks specific dietary preferences and can modify its feeding behavior based on proximity to humans. This ability allows individuals to utilize anthropogenic food sources as part of their diet, thereby potentially influencing their physiological condition and body metabolism.

Previous research indicates that provisioning influences the demographics and diet composition of *M. fascicularis* in urban environments. Individuals who frequently receive food from humans exhibit changes in the proportions of natural versus anthropogenic foods they consume (Ilham et al., 2017). Furthermore, according to Ilham et al., (2018), provisioning affects daily activity patterns, with individuals interacting more often with visitors than foraging for natural food. These changes in diet composition and activity patterns are thought to affect energy intake balance, potentially manifesting in physiological parameters related to metabolic regulation, such as blood glucose levels and insulin.

The hormone insulin plays a crucial role in regulating glucose metabolism and maintaining energy balance within the body. Diets high in sugar and fat, commonly found in foods associated with human activity, are known to affect insulin sensitivity and glucose metabolism in primates (Elsakr et al., 2021; Mubiru et al., 2011). Research by Astuti et al., (2009) indicates that a high-soluble-carbohydrate diet can influence metabolic responses in *M. fascicularis*. Furthermore, variations in glucose and insulin levels are also influenced by biological factors such as age, sex, and the individual's physiological condition (Tattersall et al., 1981). Nevertheless, studies specifically evaluating insulin and blood glucose levels in wild *M. fascicularis* populations inhabiting tourism areas with varying provisioning intensities remain very limited.

One location characterized by high human *M. fascicularis* interaction is the Panorama Ngarai Sianok tourist area in Bukittinggi. In this area, long-tailed macaques frequently interact with visitors and have access to anthropogenic food sources, obtained either through direct feeding or from food waste generated by human activity. These conditions can lead to variations in dietary patterns and physiological states among individuals and across locations. Such intensive interaction also increases the risk of human-wildlife conflict, manifesting as aggressive behavior toward visitors and the encroachment of monkeys into settlements surrounding the tourist area

(Nelfitriza, 2020). A similar phenomenon has been reported at Kuala Selangor Nature Park, Malaysia, where the dependence of *M. fascicularis* on human-provided food is linked to behavioral changes and increased disruption of tourism facilities (Hambali et al., 2012).

The urgency of conserving *M. fascicularis* in tourism areas is increasing due to the high frequency of interactions between humans and wildlife (Woodroffe et al., 2006). Management strategies for tourism areas are essential for minimizing negative impacts on both ecosystems and animal health (Chapman et al., 2005). Effective conservation focuses not only on habitat protection but also on managing human animal interactions to minimize behavioral changes and physiological disturbances (Maréchal et al., 2011). From the perspectives of animal health and One Health, data on physiological parameters, such as blood glucose and insulin levels, can serve as early indicators of metabolic variation in populations inhabiting environments with high levels of human interaction. Such information can support more comprehensive management of *M. fascicularis* populations in tourism areas.

Previous studies have examined the impact of provisioning on the behavior, activity, and diet of *M. fascicularis* (Ilham et al., 2018; Nelfitriza, 2020). However, information on metabolic parameters, specifically insulin concentrations and blood glucose levels, in wild *M. fascicularis* populations within tourism areas remains limited. Furthermore, few studies have compared these parameters across locations with varying levels of human interaction within the same tourism area. Therefore, this study aims to analyze variations in blood glucose levels and insulin hormone concentrations in *M. fascicularis* across three sites within the Ngarai Sianok tourism area and to examine the relationship between these two parameters. The findings are expected to provide baseline information on the metabolic status of *M. fascicularis* in tourism areas, serving as input for managing human-wildlife interactions and conserving populations inhabiting areas influenced by human activity.

METHOD

Research Design and Location

This study employed an observational cross-sectional design to analyze blood glucose levels and insulin concentrations in *Macaca fascicularis* in the Ngarai Sianok tourism area in Bukittinggi, West Sumatra. Data collection was conducted from 16Th June to 26Th June 2025, at three observation sites: Belakang Balok (BB), Bukik Cangang Kayu Ramang (BCKR), and Birugo (BR). A total of 23 *M. fascicularis* individuals were captured and used as research subjects. These three sites were selected based on the characteristics of human-monkey interactions and the availability of anthropogenic food sources.

Capture and Blood Sampling

M. fascicularis individuals were captured using Tomahawk traps. Captured individuals were classified by age category (juvenile or adult) and sex. Prior to blood sampling, individuals were anesthetized using Zoletil. Approximately 500 µL of blood was collected using a sterile syringe, and the sample was subsequently centrifuged at

1,500 rpm for 15 minutes. The resulting sample was transferred to a cryotube and stored at low temperature pending laboratory analysis. All procedures regarding capture, anesthesia, sampling, and animal handling were conducted in accordance with BRIN Animal Experiment Research Ethical Clearance No. 254/KE.02/SK/11/2024.

Measurement of Blood Glucose and Insulin Levels

Blood glucose levels were measured using a GlucoDr-brand glucometer. Measurements were performed using blood from captured individuals; the blood sample was applied to a test strip in accordance with the device's operating instructions. The device's glucose reading was recorded as the measurement result for each individual. Insulin concentration was analyzed using the Enzyme-Linked Immunosorbent Assay (ELISA) method with the FineTest Monkey HS-INS (Highly Sensitive Insulin) AccQuant ELISA Kit (Catalogue No. EMK0153). The analysis was conducted following the procedures recommended by the kit manufacturer. Insulin concentration was determined based on a standard curve generated from absorbance measurements of the samples and standards.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 31. A normality test was first conducted using the *Shapiro–Wilk* test. Subsequently, the relationship between blood glucose levels and insulin concentrations was analyzed using *Spearman's* rank correlation. Differences in blood glucose levels and insulin concentrations across locations were then analyzed using the *Kruskal–Wallis* test. The level of statistical significance was set at $\alpha = 0.05$.

RESULT AND DISCUSSION

Characteristics of the Research Sample

A total of 23 *M. fascicularis* individuals were successfully analyzed, comprising 12 males and 11 females. By age category, the sample comprised 11 juveniles and 12 adults. The distribution of individuals across the respective locations is shown in Table 1. Blood glucose levels across the observation sites in this study exhibited inter-individual variation, although this was not statistically significant. Physiologically, blood glucose is a highly dynamic metabolic parameter influenced by the balance between energy intake, tissue utilization, and hormonal regulation—particularly by insulin. Insulin plays a crucial role in enhancing cellular glucose uptake and maintaining stable circulating glucose levels (Guyton & Hall, 2021). Furthermore, disruptions or variations in insulin sensitivity can lead to fluctuations in glucose levels, even in the absence of extreme environmental differences (Petersen & Shulman, 2018). The statistical finding of no significant difference between locations ($p > 0.05$) can be explained by the concept of physiological homeostasis.

Mammalian endocrine systems maintain internal stability through negative feedback mechanisms; consequently, glucose and insulin levels tend to remain within specific physiological ranges despite individual variation. The nonparametric Kruskal–Wallis test was employed to compare medians across groups when data were not normally distributed; the results are interpreted as indicating that a p-value greater than

0.05 provides insufficient evidence to conclude that differences exist between groups (Conover, 1999; Hall & Hall, 2020).

Table 1. Individual characteristics based on observation location

Location	N	Male	Female	Juvenille	Adult
BB	8	5	3	4	4
BCKR	8	4	4	2	6
BR	7	3	4	5	2
Total	**23**	**12**	**11**	**11**	**12**

Notes: BB (Belakang Balok); BCKR (Bukit Cangang Kayu Ramang); BR (Birugo)

Higher intra-group variability compared to inter-site variability likely reflects individual heterogeneity, particularly within primate social systems. Among primates, differences in social status, access to food resources, and foraging behaviors can influence the physiological conditions of individuals within a population. Furthermore, interactions with anthropogenic environments can affect individual energy consumption patterns and metabolic responses (Strier, 2021). The observed variation highlights individual differences rather than ecological differences between sites.

The study sites (BB, BCKR, and BR) were selected to represent varying intensities of provisioning; BCKR exhibits high provisioning levels due to tourism activities, whereas BB and BR reflect indirect provisioning via anthropogenic food sources such as waste. Provisioning—the provision of food by humans—is known to alter natural primate consumption patterns, primarily by increasing energy intake from sources rich in simple carbohydrates. Theoretically, this condition can trigger elevated blood glucose levels and insulin responses as part of the metabolic regulation of excess energy (Fuentes, 2012; Sha & Hanya, 2013). However, the absence of significant differences between sites suggests that the variations in provisioning intensity were unlikely to be sufficiently pronounced or sustained to induce detectable physiological changes.

The lack of significant inter-site differences indicates that the populations maintain metabolic stability despite exposure to varying environmental conditions, thanks to homeostatic mechanisms. Under non-extreme environmental conditions, primates can preserve metabolic stability despite fluctuations in energy intake; consequently, changes in dietary patterns do not always result in discernible changes in metabolic biomarkers. Additionally, similarities in human-wildlife interaction patterns across sites may lead to relatively homogeneous nutritional conditions, rendering inter-group differences statistically undetectable (Strier, 2021).

Although not statistically significant, the higher mean glucose levels observed at sites with potentially more intensive provisioning suggest a trend wherein ecological factors influence individual metabolic status. This pattern aligns with the hypothesis that increased access to anthropogenic foods can influence energy regulation in primates. The failure to achieve statistical significance in this study is likely attributable to the limited sample size (n= 23) and high inter-individual physiological variation, which is commonly observed in studies of wild primates (Strier, 2021).

Variation in Blood Glucose and Insulin Hormone Levels Across Locations

Based on blood glucose measurements of *M. fascicularis* at the three observation sites, variations in the distribution of values were observed at each location; these were subsequently visualized using boxplots (Figure 1). Based on the analysis, the distribution of blood glucose levels across the three study sites (BB, BCKR, and BR) showed inter-group variation (Figure 1). The BB group had a higher median than the BCKR and BR groups, with one data point falling outside the main distribution. The BCKR group displayed a wider data range, reflecting relatively high inter-individual variation. Meanwhile, the BR group tended to show a lower median and a narrower distribution. The *Kruskal–Wallis* test indicated that these differences were not statistically significant (H= 4.561; df= 2; p= 0.102); thus, there was no significant difference in glucose levels between the sites. Nevertheless, the mean glucose levels showed a trend—BB (15.56), followed by BCKR (11.88) and BR (8.07)—suggesting a pattern of variation across sites, although this was not statistically significant. Based on measurements of insulin hormone concentrations in *M. fascicularis* at the BB, BCKR, and BR sites, variations in the distribution of values across the sites were observed (Figure 2).

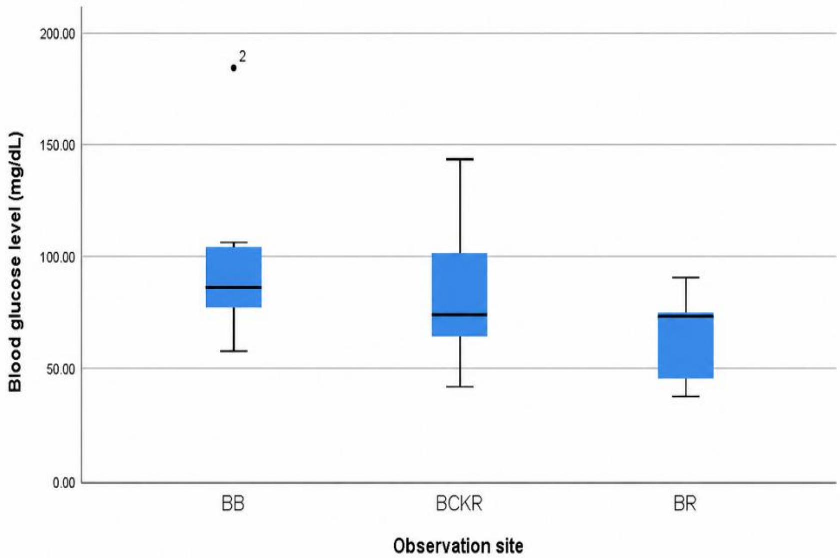

Figure 1. Distribution of blood glucose levels in *M. fascicularis* at three observation sites.

The distribution of insulin concentrations across the three study sites (BB, BCKR, and BR) reveals considerable variation within each group. Median insulin levels at BB and BCKR fall within a relatively similar range, whereas BR tends to exhibit a lower median. The data spread across all three sites appears wide—particularly for BCKR and BR—indicating heterogeneity in values among individuals within the groups. Overall, the boxplots show no striking differences between the sites. *Kruskal–Wallis* test results confirm that the differences are not statistically significant (H= 0.077; df= 2; p= 0.962); thus, there is no meaningful difference in insulin levels between the study sites. Consequently, the observed variation in data distribution reflects intra-group variation rather than differences between the sites.

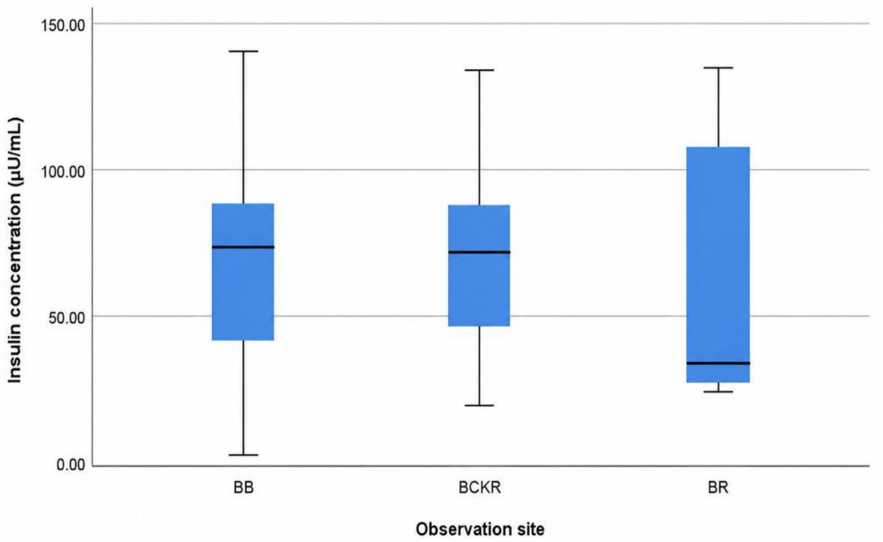

Figure 2. Distribution of insulin hormone levels in *M. fascicularis* across three observation sites.

Variations in glucose and insulin levels among individuals within a population can be explained by differences in physiological responses regarding fundamental metabolic regulation. The glucose-insulin system operates via a negative feedback mechanism that is highly sensitive to changes in energy intake and tissue demands. However, insulin sensitivity varies between individuals due to differences in insulin receptor expression, glucose uptake capacity, and basal metabolic states, resulting in variations in glucose levels even when individuals exist in relatively similar environments (Hall & Hall, 2020; Petersen & Shulman, 2018). Beyond intrinsic metabolic factors, physiological variation is also significantly influenced by psychophysiological stress. Activation of the hypothalamic-pituitary-adrenal (HPA) axis during stress increases glucocorticoid secretion, which, in turn, raises blood glucose levels by stimulating gluconeogenesis and inhibiting peripheral glucose uptake. While this response is adaptive in the short term, it can lead to fluctuations in glucose and insulin levels among individuals experiencing varying degrees of stress (van Herk et al., 2024).

In non-human primates, including *M. fascicularis*, social and ecological factors play a major role in shaping individual physiological variation. Differences in social dominance status can influence access to food resources, levels of competition, and exposure to chronic social stress. Individuals of lower social status tend to experience greater physiological stress, which can affect glucose metabolism and insulin regulation. Furthermore, primates living in environments involving human interaction may undergo dietary changes that affect their metabolic responses. Overall, the high degree of individual physiological variation in glucose and insulin levels can be understood as the result of complex interactions among endocrine factors, stressors, and socio-ecological dynamics. The combination of these factors results in heterogeneity in metabolic responses even among individuals within the same population and location; consequently, intra-group variation often outweighs differences between locations (Petersen & Shulman, 2018; Strier, 2021).

Relationship between Blood Glucose Levels and Insulin Hormone Concentrations

Based on measurements of blood glucose levels and insulin concentrations, the relationship between the two parameters was analyzed using the *Spearman* correlation test. The analysis yielded a correlation coefficient of 0.349 with a significance value (p-value) of 0.102 ($p > 0.05$). This indicates a trend toward a positive relationship of weak to moderate strength, yet the result is not statistically significant. Consequently, there is insufficient evidence to establish a significant relationship between blood glucose levels and insulin hormone concentrations in the studied population.

The physiological relationship between blood glucose levels and insulin concentrations in *M. fascicularis* is underpinned by regulatory mechanisms of energy homeostasis. Under normal conditions, an increase in blood glucose levels stimulates insulin secretion by pancreatic β-cells via negative feedback, thereby enhancing glucose uptake by peripheral tissues and lowering circulating glucose levels (Guyton, 2021). While this relationship is generally positive in the context of an acute response, the endocrine system tightly regulates it within a narrow physiological range (Kahn et al., 2014; Petersen & Shulman, 2018; Rorsman & Ashcroft, 2018).

The lack of a significant relationship may also be attributed to methodological factors and field conditions, such as variations in sampling times, differences in individual physiological status at the time of blood collection, and short-term hormonal fluctuations. In the context of population physiology, a weak yet positive correlation often reflects an underlying biological relationship that is obscured by high inter-individual variability (Bland & Altman, 1995; Schober & Schwarte, 2018).

Furthermore, in non-human primates, factors such as feeding behavior, differential access to food sources, and the influence of anthropogenic environments can confound the simple linear relationship between glucose and insulin levels (Fuentes, 2011; Strier, 2021). Thus, the results of this study are best interpreted as an indication of multifactorial metabolic regulation, in which the relationship between glucose and insulin is determined not by a single, simple linear mechanism but by complex interactions among physiological, ecological, and behavioral factors. This situation results in a biologically meaningful relationship failing to reach statistical significance due to a limited sample size.

Ecological and Health Implications

From an ecological perspective, the absence of significant differences between locations suggests that the *M. fascicularis* population remains in a relatively stable metabolic state. This indicates that environmental stressors, including provisioning, have not yet caused systemic physiological disruptions in the observed population; a similar pattern was observed in natural *M. fascicularis* populations in Mauritius, where blood biochemical values remained within normal ranges despite individual variation (Tattersall et al., 1981). Nevertheless, descriptive patterns revealing inter-location differences and high individual variability still suggest that metabolic responses vary according to environmental conditions. Age and sex are biologically known to influence glucose metabolism and insulin sensitivity. In *M. fascicularis*, fasting plasma glucose levels and lipoprotein profiles differ significantly between males and females and change with age (Yue et al., 2016). In the present study, these variables were not analyzed separately due to limited sample sizes within each category; this limitation likely contributed to the high data variability observed (Yue et al., 2016; Miroshnikov & Sultanova, 2023).

Furthermore, limitations in the study design, such as the relatively small sample size (n= 23) and the cross-sectional approach, may constrain the analysis's ability to detect subtle differences between groups. Studies on non-human primates indicate that small sample sizes (3–8 individuals per group) are highly susceptible to individual variability, often leading to a failure to detect actual differences (Huber et al., 2020). Therefore, although no statistically significant differences were found, the possibility that provisioning influences metabolic parameters cannot be entirely ruled out; such effects may simply have gone undetected under the conditions of this study. Furthermore, the physiological stress response mediated by the HPA axis, which in *M. fascicularis* is strongly influenced by social rank and a despotic social style, can lead to inter-individual fluctuations in glucose and insulin levels (Jimenez *et al*., 2017; Sadoughi *et al*., 2021), thereby complicating the interpretation of results.

CONCLUSION

Based on the research results, no statistically significant differences were found in blood glucose levels or insulin concentrations among *Macaca fascicularis* across the study sites: Belakang Balok (BB), Bukik Cangang Kayu Ramang (BCKR), and Birugo (BR). Although there was variation in the mean rank of blood glucose levels among locations, with the highest value at BB (15.56), followed by BCKR (11.88) and BR (8.07), this variation was not statistically significant ($p = 0.102$). Similarly, while blood glucose levels showed a positive correlation with insulin concentrations ($\rho = 0.349$), this relationship was not statistically significant ($p = 0.102$). These findings indicate that provisioning intensity at the study sites cannot yet be identified as a significant factor associated with variation in blood glucose levels or insulin concentrations in *M. fascicularis*. However, the lack of statistical significance does not necessarily imply that provisioning has no physiological impact; metabolic responses can be influenced by various other factors, including diet composition and quality, feeding frequency, body condition, age, sex, daily activity, and individual stress levels. Therefore, further research, utilizing larger sample sizes, longitudinal designs, quantitative characterization of provisioning intensity and composition, and more comprehensive measurements of metabolic and physiological biomarkers, is required to more robustly examine the links between human interaction, provisioning, and the metabolic health of *M. fascicularis*.

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