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# THESE

Presented by

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**DOCTORAT IN SCIENCES**

**Filière : Biology**
**Specility: Animale Physiology**

# Comparative assessment of the effects of Ramadan fasting on the anthropometric, biochemical and haematological parameters of athletes, sedentary individuals and sedentary smokers

Publically presented on ……./……./……

**Jury:**

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**الملخص**

**المقدمة:** يعتبر شهر رمضان مناسبة دينية أساسية في الإسلام، يمتنع خلاله المسلمون عن الأكل والشرب من الفجر حتى المغرب بهدف تنمية الروحانيات وتعزيز التعاطف مع الآخرين. على الرغم من الأهمية الدينية والروحية لهذا الشهر، فإن التأثيرات الفسيولوجية للصيام على الصحة، خصوصًا بين فئات متباينة كالرياضيين والأشخاص ذوي النشاط البدني المحدود، بما في ذلك المدخنون وغير المدخنين، لم تحظ بالدراسة الكافية. تبين الأبحاث السابقة وجود تغيرات في المؤشرات الهيماتولوجية والبيوكيميائية للصائمين، لكن تأثيرات الصيام على الأشخاص ذوي أنماط الحياة الخاملة، وبخاصة المدخنين منهم، ما زالت تحتاج إلى مزيد من الفحص والتحليل.

**الأهداف** :تهدف الدراسة الحالية إلى سد الفجوة المعرفية المتعلقة بتأثير الصيام خلال رمضان على مختلف المؤشرات الفسيولوجية والبيوكيميائية لدى مجموعات متنوعة تشمل الرياضيين، المدخنين، والأفراد ذوي النشاط البدني المحدود. تسعى هذه الدراسة لفهم كيف يؤثر الصيام مع مستويات مختلفة من النشاط البدني والتدخين على الصحة العامة، بهدف تقديم توصيات محددة تساهم في تحسين الرفاهية والصحة خلال شهر رمضان.

**المنهجية** :تقوم منهجية البحث على دراسة تأثيرات الصيام في رمضان على ثلاث مجموعات: الرياضيون، المدخنون الخاملون، والأشخاص غير المدخنين ذوي النشاط البدني المحدود. تم اختيار المشاركين وفقًا لمعايير دقيقة وخضعوا لفحوصات صحية شاملة. تم جمع البيانات خلال سبع جلسات تقييم قبل رمضان، خلاله وبعده، متضمنة تحاليل الدم وقياسات أخرى. تضمنت الدراسة استخدام أساليب تحليلية متقدمة لضمان دقة النتائج.

**النتائج والمناقشة** :كشفت النتائج عن تغيرات ملحوظة في القياسات الأنثروبومترية والمؤشرات الهيماتولوجية والبيوكيميائية بين المجموعات المختلفة. لوحظ أن الرياضيين شهدوا تغيرات في كتلة الجسم ومستويات الدهون، بينما كانت الاستجابات مختلفة لدى المدخنين وغير المدخنين من ذوي النشاط البدني المحدود. توصلت الدراسة إلى أن الصيام يؤثر بشكل ملحوظ على مستويات الهيموغلوبين وملفات الدهون، مما يسلط الضوء على الحاجة إلى نهج مخصص في الإرشادات الغذائية والصحية خلال رمضان.

**الخاتمة** :تبرز هذه الدراسة الأثر الشامل للصيام خلال رمضان على مختلف المؤشرات الصحية والبيوكيميائية، مع التأكيد على التباين في الاستجابات بين الرياضيين والأشخاص ذوي النشاط البدني المحدود. تؤكد النتائج على أهمية التغذية المناسبة والإرشادات الصحية المخصصة لكل فئة، خاصة خلال فترات الصيام، لضمان الحفاظ على الصحة والرفاهية. تقدم هذه الأطروحة مساهمة قيمة في مجالات علم الرياضة، الصحة العامة، وعلم التغذية، وتوفر أساسًا لمزيد من البحث وتطوير الإرشادات العملية.

**الكلمات المفتاحية** :صيام رمضان، الأنثروبومترية، الهيماتولوجيا، البيوكيمياء، الرياضيون، نمط الحياة الخامل، التدخين، الصحة الأيضية

## Abstract

**Background**: Ramadan, a fundamental practice in Islam, involves fasting from dawn until sunset, aiming to enhance spirituality and empathy. Despite its significance, the physiological impacts of Ramadan fasting, especially on diverse populations like athletes, sedentary non-smokers, and sedentary smokers, are not fully understood. Prior studies have shown changes in haematological and biochemical responses during fasting, including variations in lipid profiles among athletes. However, the effects on sedentary individuals, particularly smokers, remain less explored.

**Aims**: This research seeks to fill the gap by rigorously evaluating the effects of Ramadan fasting on various anthropometric, haematological, and blood parameters across these distinct groups. The study aims to understand how fasting interplays with physical activity levels and smoking habits, potentially affecting health outcomes. By conducting a comprehensive analysis, this thesis aims to contribute valuable insights into sports science, public health, and nutritional science, informing tailored guidelines for managing health and well-being during Ramadan.

**Methodology**: The methodology involves evaluating Ramadan fasting effects on athletes, sedentary smokers, and non-smokers through a structured approach. Participants were selected based on specific inclusion criteria and underwent health screenings. Data were collected across seven sessions, encompassing anthropometric, haematological, and biochemical measurements, before, during, and after Ramadan. The study employed automated and spectrophotometric analyses for blood counts and biochemical markers, respectively. Statistical analysis included ANOVA and Duncan's Multiple Range Test to identify significant differences between groups, ensuring a precise examination of fasting impacts.

**Results and discussion**: The first result shows changes in anthropometric measures among groups. Athletes experienced a decrease in body mass by 1.23 kg during Ramadan, which increased by 0.89 kg post-Ramadan. Sedentary smokers had a slight increase of 0.41 kg, while sedentary non-smokers gained 0.71 kg. Body mass index changes were minimal across groups, with a notable decrease in body fat percentage among athletes by 1.7% during Ramadan, stabilising post-Ramadan. These findings illustrate the varied physiological responses to fasting based on lifestyle and smoking habits, highlighting the importance of tailored health advisories during Ramadan.

The study showed haemoglobin levels in athletes decreased from 15.25 g/dl to 13.63 g/dl during Ramadan, indicating a significant impact of fasting on oxygen transport. Sedentary non-smokers had a slight decrease to 12.95 g/dl, then increased post-Ramadan, showing resilience. Sedentary smokers saw an increase to 14.22 g/dl, suggesting a compensatory response to fasting and smoking. These variations highlight the complex effects of fasting, physical activity, and smoking on haematological parameters.

The biochemical analysis revealed distinct changes in lipid profiles and liver enzymes. Total cholesterol levels in athletes decreased from 4.85 mmol/L pre-Ramadan to 4.45 mmol/L, while sedentary smokers showed an increase to 5.1 mmol/L. LDL cholesterol in athletes also decreased, signifying a positive effect of fasting combined with physical activity. These results highlight the metabolic flexibility and resilience in response to fasting, with significant implications for dietary and lifestyle recommendations during Ramadan.

**Conclusion**: This research underscores the multifaceted impact of Ramadan fasting on physical and metabolic health across different lifestyles. It reveals that fasting induces significant physiological changes, particularly in athletes, suggesting the importance of tailored nutritional support. For sedentary individuals, the findings suggest that fasting effects are modulated by smoking habits, highlighting the need for specific guidelines for smokers. The study contributes to a deeper understanding of fasting health implications, offering a foundation for future research and practical guidance to optimise health outcomes during Ramadan.

**Keywords**: Ramadan fasting, Athletes, Sedentary lifestyles, Smoking, Metabolic health, Biochemistry, Anthropometry, Haematology.

**Résumé**

**Contexte** : Le Ramadan, une pratique fondamentale dans l'Islam, implique le jeûne du lever au coucher du soleil, visant à renforcer la spiritualité et l'empathie. Malgré son importance, les impacts physiologiques du jeûne du Ramadan, en particulier sur des populations diverses telles que les athlètes, les non-fumeurs sédentaires et les fumeurs sédentaires, ne sont pas entièrement compris. Des études antérieures ont montré des changements dans les réponses hématologiques et biochimiques pendant le jeûne, y compris des variations dans les profils lipidiques chez les athlètes. Cependant, les effets sur les individus sédentaires, en particulier les fumeurs, restent moins explorés.

**Objectifs** : Cette recherche vise à combler cette lacune en évaluant rigoureusement les effets du jeûne du Ramadan sur divers paramètres anthropométriques, hématologiques et sanguins à travers ces groupes distincts. L'étude cherche à comprendre comment le jeûne interagit avec les niveaux d'activité physique et les habitudes de tabagisme, affectant potentiellement les résultats de santé. En menant une analyse complète, cette thèse vise à contribuer des aperçus précieux dans les sciences du sport, la santé publique et la science nutritionnelle, informant des directives personnalisées pour gérer la santé et le bien-être pendant le Ramadan.

**Méthodologie** : La méthodologie implique d'évaluer les effets du jeûne du Ramadan sur les athlètes, les fumeurs sédentaires et les non-fumeurs à travers une approche structurée. Les participants ont été sélectionnés sur la base de critères d'inclusion spécifiques et ont subi des dépistages de santé. Les données ont été collectées sur sept sessions, englobant des mesures anthropométriques, hématologiques et biochimiques, avant, pendant et après le Ramadan. L'étude a employé des analyses automatisées et spectrophotométriques pour les comptes sanguins et les marqueurs biochimiques, respectivement. L'analyse statistique comprenait l'ANOVA et le test de rang multiple de Duncan pour identifier les différences significatives entre les groupes, assurant un examen précis des impacts du jeûne.

**Résultats et discussion** : Le premier résultat montre des changements dans les mesures anthropométriques parmi les groupes. Les athlètes ont connu une diminution de la masse corporelle de 1,23 kg pendant le Ramadan, qui a augmenté de 0,89 kg après le Ramadan. Les fumeurs sédentaires ont eu une légère augmentation de 0,41 kg, tandis que les non-fumeurs sédentaires ont gagné 0,71 kg. Les changements d'indice de masse corporelle étaient minimaux entre les groupes, avec une diminution notable du pourcentage de graisse corporelle chez les athlètes de 1,7 % pendant le Ramadan, se stabilisant après le Ramadan.

Ces résultats illustrent les réponses physiologiques variées au jeûne en fonction du mode de vie et des habitudes de tabagisme, soulignant l'importance de conseils de santé personnalisés pendant le Ramadan. L'étude a montré que les niveaux d'hémoglobine chez les athlètes ont diminué de 15,25 g/dl à 13,63 g/dl pendant le Ramadan, indiquant un impact significatif du jeûne sur le transport d'oxygène. Les non-fumeurs sédentaires ont eu une légère diminution à 12,95 g/dl, puis ont augmenté après le Ramadan, montrant une résilience. Les fumeurs sédentaires ont vu une augmentation à 14,22 g/dl, suggérant une réponse compensatoire au jeûne et au tabagisme. Ces variations mettent en évidence les effets complexes du jeûne, de l'activité physique et du tabagisme sur les paramètres hématologiques. L'analyse biochimique a révélé des changements distincts dans les profils lipidiques et les enzymes hépatiques. Les niveaux de cholestérol total chez les athlètes ont diminué de 4,85 mmol/L avant le Ramadan à 4,45 mmol/L, tandis que les fumeurs sédentaires ont montré une augmentation à 5,1 mmol/L. Le cholestérol LDL chez les athlètes a également diminué, signifiant un effet positif du jeûne combiné à l'activité physique. Ces résultats mettent en évidence la flexibilité métabolique et la résilience en réponse au jeûne, avec des implications importantes pour les recommandations diététiques et de style de vie pendant le Ramadan.

**Conclusion** : Cette recherche souligne l'impact multifacette du jeûne du Ramadan sur la santé physique et métabolique à travers différents modes de vie. Elle révèle que le jeûne induit des changements physiologiques significatifs, en particulier chez les athlètes, suggérant l'importance d'un soutien nutritionnel sur mesure. Pour les individus sédentaires, les résultats suggèrent que les effets du jeûne sont modulés par les habitudes de tabagisme, soulignant la nécessité de directives spécifiques pour les fumeurs. L'étude contribue à une compréhension plus profonde des implications sanitaires du jeûne, offrant une base pour des recherches futures et des conseils pratiques pour optimiser les résultats de santé pendant le Ramadan.

**Mots-clés** : Jeûne du Ramadan, Athlètes, Modes de vie sédentaire, Tabagisme, Santé métabolique, Biochimie, Anthropométrie, Hématologie.

## LIST OF TABLES



## LIST OF FIGURES

# TABLE OF CONTENTS

## Chapter 01. Effect of Ramadan fasting on anthropometric parameters

# INTRODUCTION

## Introduction

Ramadan, the ninth month of the Islamic calendar, is distinguished by fasting, a pivotal practice in Islam and one of its Five Pillars. These pillars Shahada (declaration of faith), Salah (praying five times a day), Zakat (giving of alms), Sawm (fasting during Ramadan), and Hajj (pilgrimage to Makkah) are the foundations upon which a muslin's faith and actions, underpinning the community, spirituality, and devotion.

Fasting during Ramadan, obligatory for all healthy adults, entails abstaining from food, drink, and other physical needs from dawn until sunset. This discipline aims to purify the soul, enhance God-consciousness, and engender empathy for the less fortunate. It's a time dedicated to spiritual reflection, intensified prayer, and engagement with the Quran. The Holy Quran explicitly states, "O you who believe, fasting is prescribed for you as it was prescribed for those before you, that you may develop God-consciousness." The Holy Quran. Sûrah al-Baqarah. 2: 183-5

Thus, Ramadan is a period of Muslims to cleanse their spirits, seek forgiveness, and deepen their connection with Allah. The essence of Ramadan and the adherence to these pillars highlight the commitment to faith, discipline, and the communal bond within the Muslim community worldwide.

For an entire month, from dawn until dusk, Muslims globally abstain from specific behaviours and habits, such as eating, drinking, taking oral medications, engaging in sexual activity, and smoking. However, certain individuals are exempt from fasting during Ramadan. These exemptions include children, women experiencing their menstrual cycle or postnatal bleeding, travellers, pregnant or breastfeeding women who perceive that fasting for extended hours could harm themselves or their infants, the elderly who find fasting intolerable, individuals with mental disabilities, and the ill for whom fasting would worsen their condition. Where feasible, missed fasting days ought to be compensated for before the subsequent Ramadan. The month of Ramadan adheres to the lunar calendar, and its duration, influenced by the lunar phase, can span either 29 or 30 days. Depending on a Muslim's geographic location, the duration of the daily fast can extend up to 20 hours. Annually, Ramadan shifts earlier by approximately 11 days, potentially taking up to 33 years to cycle through all the seasons. Islam ranks as the world's most rapidly expanding religion. In 2010, the Muslim population accounted for nearly 1.6 billion individuals, representing 23% of the global population, with projections indicating 2 a 73% increase by 2050. According to a Pew Research Center survey involving more than 38,000 Muslims worldwide, a vast majority (93%) observe fasting during Ramadan. This month is sacred to Muslims, not only because it enables the practice of the fourth pillar of Islam- fasting-but also because it marks the period during which the Quran, Islam's holy book, was revealed. Muslims globally eagerly await Ramadan, viewing it as a time for cultivating selfrestraint against indulgence in everyday pleasures, enhancing self-discipline, Godconsciousness, and self-control, purifying the body, and fostering empathy towards the impoverished and hungry.

Smoking is widely recognised as a significant risk factor for cardiovascular diseases. The prevalence rates of smoking and cardiovascular diseases vary by gender, sex, race, and other sub-categories ((Jamal et al., 2018); (Office, 2020). Nonetheless, in examining the epidemiological relationship between smoking and cardiovascular disease, researchers must also account for other potential risk factors. These associative risk factors can provide insights into individuals who are at the greatest risk of developing diseases based on their biological profile. There is always the possibility of encountering random cases that deviate from the norms established by research-based conclusions. However, identifying statistically significant differences while considering potential risk factors can inform us about which individuals are at an increased risk of developing these diseases. Previous studies have explored the effects of Ramadan fasting and physical activity on haematological-biochemical responses during ritual fasting periods like Ramadan. Notably, variations in haematocrit and haemoglobin levels during Ramadan have been observed, with reports indicating increases, decreases, and no changes. Furthermore, Ramadan fasting has been shown to affect the lipid profiles of athletes, with total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) levels experiencing elevations in elite judokas. Additionally, free fatty acid levels have been observed to increase in middle-distance runners. Given that blood lipid levels can undergo significant changes during Ramadan, it is advisable to monitor the lipid profile regularly throughout this period. However, the primary factor influencing changes in the lipid profile remains unclear. Diverse outcomes have been reported: total cholesterol levels have been found to decrease during weight loss and/or Ramadan fasting, remain unchanged, or even increase. (Adlouni et al., 1997) reported that fasting during Ramadan led to a significant decrease in serum total cholesterol, triglycerides, and LDL-C, alongside a significant increase in serum HDL-cholesterol within this month.

Conversely (Maislos et al., 1993) observed no changes in LDL-C, very low-density lipoprotein (VLDL), and total cholesterol, while noting a 3 significant increase in HDL-cholesterol levels and a reduction in the LDL/HDL and TC/LDL ratios by the end of Ramadan.

The human body fundamentally requires movement and physical activity, yet our contemporary lifestyle has markedly decreased our daily activity levels, leading to a host of health issues. Presta et al. (2023) in this Research Topic elucidated that "engaging in regular physical activity (by playing sports and being as active as possible during the daily routine)" significantly guards against "NCDs and NCD-related risk factors, including overweight and obesity, and hypertension." The interplay of obesity and sedentary behaviour has been adversely linked to longevity and life expectancy. General activity has also been associated with improved quality of life. A study within this Research Topic by (Shi et al., 2022) discovered that a combination of a good level of physical activity and reduced sedentary behaviour positively influence the quality of life among children and adolescents. The impact of prolonged sedentary behaviour, especially in occupational settings, has been thoroughly investigated. Musculoskeletal disorders, such as back pain, neck pain, and joint issues, are prevalent among individuals with sedentary occupations. Excessive occupational sitting places undue strain on the spine and muscles, leading to postural imbalances and chronic pain. Additionally, the study highlighted that insufficient physical activity and increased sedentary time might heighten the risk of mental health problems. Research featured in this topic by (Huang et al., 2020) found that screen-based sedentary behaviour correlates with anxiety symptoms among college students. Further studies have established a clear connection between sedentary behaviour and elevated levels of anxiety and depression, alongside diminished cognitive function. The underlying mechanism suggests that a lack of physical activity restricts the release of endorphins, serotonin, and other moodenhancing chemicals, thereby elevating the risk of mental health disorders.

The primary objective of this work is to rigorously evaluate and examine the effects of Ramadan fasting on various anthropometric, haematological, and blood parameters across distinct groups, including athletes, sedentary non-smokers, and sedentary smokers. Given the unique physiological demands placed on individuals who observe fasting during Ramadan, it is imperative to understand how this religious practice influences key health indicators across populations with varying levels of physical activity and smoking habits. Athletes, who typically undergo rigorous training regimens, may experience different changes in their physiological parameters compared to sedentary individuals due to the compounded effects of fasting and physical exertion. Similarly, the impact of fasting on sedentary non-smokers versus sedentary 4 smokers may reveal critical insights into how lifestyle choices, such as smoking, interact with fasting to affect health outcomes. By conducting a comprehensive analysis of these diverse groups, this study aims to uncover the multifaceted effects of Ramadan fasting, thereby contributing valuable knowledge to the fields of sports science, public health, and nutritional science. This research not only has the potential to inform tailored nutritional and training guidelines for athletes during Ramadan but also offers broader implications for the management of health and well-being among the general population engaging in fasting practices.

# LITERATURE REVIEW

## 1. Ramadan fasting

Ramadan, one of the central pillars of Islam, is observed during the ninth month of the lunar (Hijri) calendar. Adult Muslims partake in fasting during this period, abstaining from food, drink, smoking, and sexual activities from dawn until dusk. While fasting in Ramadan is mandatory for every healthy adult Muslim, exceptions exist for those with serious medical conditions. The practice of fasting in Ramadan is a religious observance rather than a means for food restriction or longevity enhancements.

During Ramadan, Muslims typically have two meals per night: Iftar, which is consumed after dusk to break the fast, and Sohour, taken before dawn to commence fasting. This routine of diurnal fasting brings significant changes in the total intake of food, physical activity, sleep patterns, and other lifestyle behaviours throughout the month. Moreover, Ramadan fasting is not only a religious practice but also an opportunity for Muslims to focus on their wellbeing. Islam emphasises maintaining a healthy lifestyle, advocating for a safe and well-balanced diet. Ramadan, therefore, presents a unique chance for adherents to reorient towards a more balanced and healthier lifestyle.

Globally, over 1.8 billion Muslims observe Ramadan fasting annually, a figure estimated in 2015. Specifically, around 148 million Muslims with diabetes choose to fast during Ramadan each year. A study conducted across 13 countries found that 78.7% of Muslims with diabetes fast for at least 15 days during Ramadan (ref). The Islamic calendar, being lunar-based, is shorter than the Gregorian calendar by 11 or 12 days, leading to a shift in Ramadan's occurrence over the seasons every eight years. This shift affects the fasting duration and prevailing environmental conditions, consequently impacting dietary habits, sleep schedules, and potentially leading to metabolic changes in individuals, both with and without diabetes figure 01.

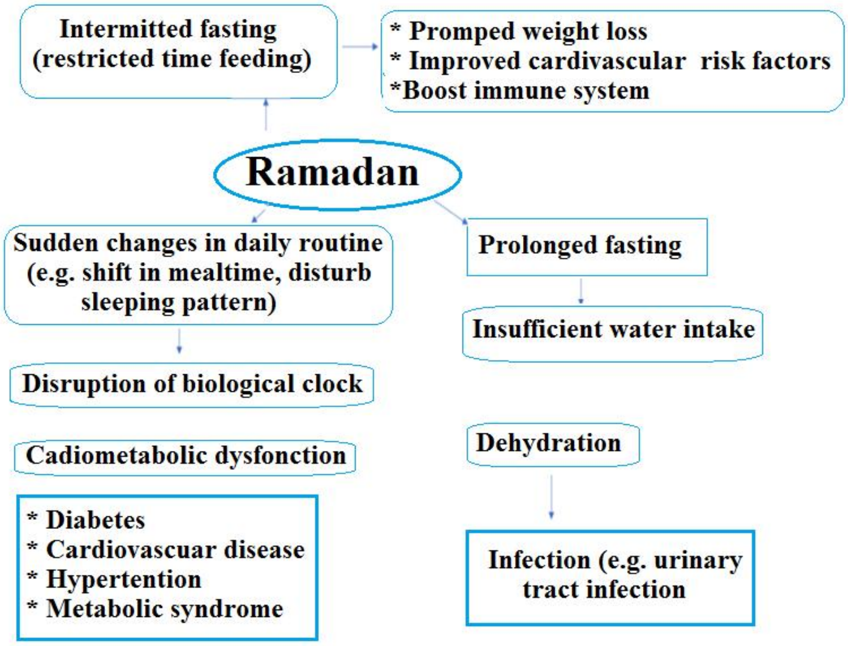


**Figure 01**. Potential mechanisms by which Ramadan fasting might influence health outcomes (Almulhem et al., 2020).

In recent times, there has been a surge in scientific interest regarding the effects of Ramadan fasting on human health figure 02. For instance, a search in the Web of Science database using the term "Ramadan" in titles, abstracts, author keywords, and keywords yielded 1691 publications from January 1970 to November 2019. While the volume of publications remained modest over the past five decades, there has been a notable increase in research output in recent years, highlighting the growing academic curiosity in this area.

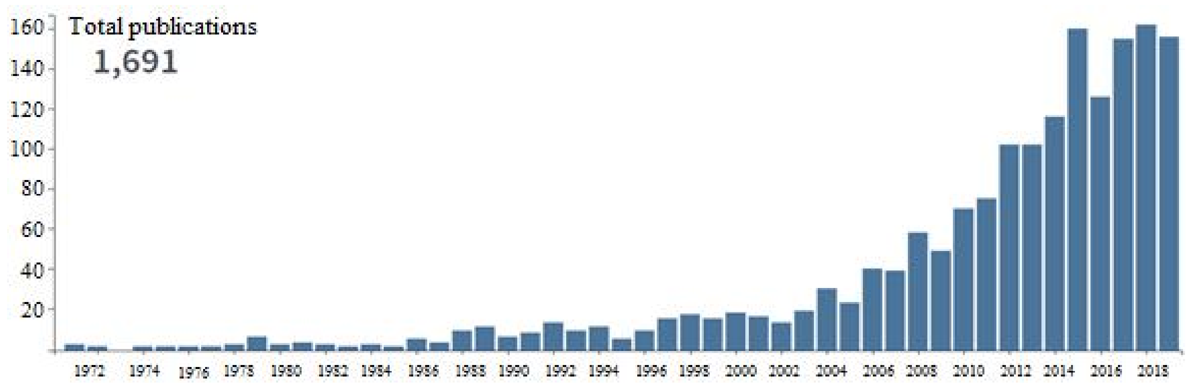


**Figure 02.** Report reflecting publications per year about "Ramadan" in the Web of Science database(Latiri et al., 2017).

## 2. Role of fasting in health and athletic performance

The pervasive issue of obesity and overweight, with their associated health risks like metabolic disorders, diabetes, cancer, and cardiovascular diseases, is increasingly concerning (Calle & Kaaks, 2004; Persynaki et al., 2017). This problem is likely to escalate due to the growing trend of physical inactivity. Nevertheless, non-drug approaches such as fasting and exercise training provide cost-effective strategies to mitigate complications related to these conditions (Wallis & Gonzalez, 2019). Fasting, undertaken for health, religious, or cultural motives (Persynaki et al., 2017) is the practice of voluntarily abstaining from food and drinks over varying time spans, ranging from several hours to weeks (Horowitz et al., 1999). The precise onset of fasting post food or drink consumption is not definitively established (Maughan et al., 2010). Fasting is linked to prolonged life expectancy, owing to its multiple health and aging benefits (Persynaki et al., 2017). It is recognised as a potent method for managing both chronic and acute illnesses in traditional and contemporary medical practices. Fasting serves as a lifestyle approach beneficial for various chronic, non-communicable diseases(Michalsen & Li, 2013). It's also employed in research for studying intermediary metabolism (Wallis & Gonzalez, 2019). The impact of extended fasting on health and physical performance is negative, yet it's uncertain whether intermittent fasting duration is detrimental.

### 2.1. Prevalence and risks of overweight and obesity

Studies on the impact of fasting on elite athletes' performance began in 2007driven by the widespread belief that fasting hinders athletic performance (Chaouachi et al., 2009). Different fasting methods have been explored for their effects on athletic performance, with Ramadan fasting, as practised in Islam, becoming particularly noteworthy due to its distinctive characteristics (Persynaki et al., 2017),(Chaouachi et al., 2009). Interest in this form of intermittent fasting was renewed during major sporting events like the 2012 London Olympics and the 2014 FIFA World Cup, both coinciding with Ramadan(Chaouachi et al., 2009; Longo & Panda, 2016; Maughan et al., 2010).

### 2.2. Diverse methods and effects of intermittent fasting

Among dietary restrictions, daily caloric restriction is the most studied, yet intermittent fasting is also prevalent (Longo & Panda, 2016). Intermittent fasting involves abstaining from food at certain times of the day or week. It's characterised by energy restriction, regardless of its daily practice. Common intermittent fasting methods include intermittent calorie restriction (ICR), alternate day fasting (ADF), and time-restricted feeding (TRF), each with different fasting and feeding periods (Longo & Panda, 2016).

#### 2.2.1. Intermittent calorie restriction

Intermittent calorie restriction (ICR), also known as whole day fasting, is a straightforward intermittent fasting method, involving fasting for over 24 hours, two or three times a week, interspersed with days of unrestricted eating, and a week's gap between cycles(de Toledo et al., 2019). There are two ICR variants: 2:5 (two days of caloric restriction per week, regular diet for five days) and 3:4 (three days of restriction, regular diet for four days). Some protocols allow about 25% (400–600 kcal/day) of total energy expenditure on fasting days(de Toledo et al., 2019).

#### 2.2.2. Alternate Day Fasting

Alternate day fasting (ADF)'s popularity is growing (John F Trepanowski et al., 2017) where non-fasting days of free eating alternate with fasting days of consuming about 25% of the regular dietary intake (~500 kcal), (Azizi, 2010). Nevertheless, some ADF variations prohibit any calorie intake on fasting days.

#### 2.2.3. Time restricted feeding

Time restricted feeding (TRF) allows small food amounts (~25% of daily caloric needs) during fasting hours (John F Trepanowski et al., 2017). It involves daily fasting for set hours, with feeding allowed in the remaining time. TRF variants include 16/8 (16-hour fast, 8-hour feeding window), 18/6 (18-hour fast, 6-hour window), and 20/4 (20-hour fast, 4-hour window). TRF is linked to circadian rhythms and chrononutrition, which relates meal timing to the circadian system influencing physiology, metabolism, and behaviour.21 Ramadan fasting, a key TRF example, involves daily fasting from dawn to sunset during Islam's ninth lunar month, with fasting duration varying by geographical location and season, typically lasting 10 to 18 hours (Azizi, 2010).

These fasting protocols differ in caloric restriction severity, daily food/beverage abstinence, and weekly frequency of caloric restriction. ADF involves alternating ad libitum feeding days with fasting days, typically including a single meal providing about 25% of baseline caloric needs. Most TRF protocols involve fasting for 16–20 hours daily, with 4–8 hours for eating.

Whole day fasting protocols require complete fasting or severe caloric restriction one or two non-consecutive days per week (de Toledo et al., 2019).

## 3. Metabolic adaptations and body composition changes during fasting

Fasting triggers metabolic adaptations to conserve carbohydrates and increase reliance on fat for energy, but may also lead to cognitive decline (Hussin et al., 2013). Marked metabolic changes occur during fasting. Post-eating glucose levels are initially elevated but remain low for the subsequent 16 hours. Tissue glucose utilisation rate is ~ 2 mg/kg/min post-absorptively. Fasting can modestly reduce serum glucose levels (3.3 to 3.9 mmol/L; normal range 3.5–5.5 mmol/L), likely due to reduced hepatic glycogen synthesis and glycolysis. These changes result from decreased insulin and increased glucagon levels and sympathetic activity (Klempel et al., 2012). During fasting, systemic free fatty acid (FFA) and ketone levels rise, accompanied by activated gluconeogenesis.

Fasting decreases circulating insulin and insulin-like growth factor-1 levels while elevating glucagon levels, favouring hepatic gluconeogenesis. In fasting, FFA and ketones become primary energy sources, termed intermittent metabolic switching or the glucose-ketone (G-to-K) switchover. Post-meal, the ketone-glucose (K-to-G) switch occurs (Maughan et al., 2010). Starvation increases acylcarnitine species and oxidised amino acid cystine levels, reducing plasma tryptophan, choline phosphate, hippuric acid, and glycerophosphocholine. Severe calorie restriction significantly heightens protein metabolism's energy contribution, with cognitive function decline possibly linked to lower blood glucose levels (Klempel et al., 2012).

Fasting's influence on body composition and chronic effects have been extensively studied. ICR studies combine intermittent fasting with caloric restriction (hypocaloric diet) or modified fasting allowing limited food intake even on fasting days. Significant decreases in body weight (Fitzgerald et al., 2018) and body fat (Teng et al., 2011) were observed, except in Fitzgerald et al. (2018). ICR effectiveness varies due to different fasting days per week, subject demographics, and other factors (de Toledo et al., 2019).

ADF significantly reduces body weight (Trepanowski et al., 2017), fat mass (Solianik et al., 2016), and fat-free mass (Cherif et al., 2016) in both obese/overweight (Solianik et al., 2016) and normal-weight individuals (Teng et al., 2013). Study design, fasting duration, participant characteristics, and other variables contribute to these results. Animal studies are prevalent in ADF research (Hussin et al., 2013) highlighting control challenges in human studies.

TRF outcomes show significant weight and fat mass reductions and no notable changes in other cases (Eshghinia & Mohammadzadeh, 2013). Differences arise from varying fasting duration, participant demographics, and caloric intake.

Ramadan fasting studies reveal mixed effects on body weight. A systematic review of 35 studies found small but significant weight loss during Ramadan, often regained post-Ramadan (Latiri et al., 2017). Inconsistencies may stem from diverse eating habits, sociocultural factors, and participant health profiles (Mazidi et al., 2015).

Fasting's metabolic adaptations are significant. Ramadan fasting enhances lipid metabolism in healthy individuals (Adlouni et al., 1997), as do other TRF protocols. Fasting impacts serum lipid profiles, with varying effects reported across studies(Hammouda et al., 2014). Differences in fasting protocols, durations, and participant backgrounds contribute to these variances. Ramadan fasting affects biochemical responses and feeding behaviours. Carbohydrate metabolism adaptations during fasting include decreased glucose metabolism in healthy subjects after ADF and Ramadan fasting (Larijani et al., 2003). Blood glucose reductions occur after 12 and 72 hours of fasting, while some studies report no changes (Mohsen Nematy et al., 2012). A meta-analysis by Kul et al.78 noted Ramadan fasting lowered blood glucose levels.

Protein metabolism changes during fasting are less explored. Ramadan studies show no plasma protein concentration reductions in healthy subjects (Mohsen Nematy et al., 2012). ADF studies indicate no protein metabolism effects in obese subjects, but some report fat-free mass loss potentially linked to protein catabolism (Vicente-Salar et al., 2015). Athlete studies, like Chaouachi et al. (2008), highlight lean tissue loss due to gluconeogenesis. Other studies, like Soeters et al. (2009), suggest fasting affects protein catabolism only after initial days, with energy primarily derived from glycogen and fat metabolism. Study findings vary from significant to non-significant protein metabolism alterations, influenced by similar factors affecting glucose and lipid metabolism studies.

## 4. Evaluating fasting's impact on athletic endurance and performance

Ramadan fasting induces transient metabolic adaptations, including improved lipid profiles and decreased glycaemia. Chennaoui et al. (2009) studied middle-distance athletes, noting significant hormonal and metabolic changes influenced by altered sleep and eating patterns during Ramadan. Ba et al. (2005) found that Ramadan fasting had minimal impact on glucose metabolism in endurance athletes compared to sedentary individuals, suggesting better glucose regulation in athletes.

Regarding fasting's impact on performance, limited studies (Table 1) show varied effects on trained athletes' endurance performance post-Ramadan fasting, with both decreases63,86 and no changes observed (Png et al., 2014). Asl (2011) uniquely reported a small endurance performance improvement. Factors like sleep deprivation or fatigue during Ramadan might explain these varied outcomes. Aziz et al. (2010) highlighted individual differences in response to Ramadan fasting, with fitter individuals showing better resilience. Studies by Brisswaleter et al. (2011) and Png et al. (2014) reported minimal endurance performance changes post-Ramadan fasting.

Research on the impact of fasting on the endurance capabilities of trained athletes is relatively scarce (referenced in Table 1). The findings are mixed, with some studies reporting a decline in performance while others observed no significant changes(Png et al., 2014). A unique study by Asl (2011) noted a minor improvement in endurance performance. The variability in these outcomes could be attributed to factors like sleep deprivation or fatigue during Ramadan. Aziz et al. (2010) noted that the effects of Ramadan fasting vary among individuals, with fitter individuals less affected by its physiological and psychological challenges. Studies like those by Brisswaleter et al. (2011) and Png et al. (2014) found a minimal impact on endurance performance during Ramadan. Brisswaleter et al. (2011) observed a reduction in muscular performance and an increase in oxygen kinetics during Ramadan fasting, but no change in VO2max or performance among middle-distance runners. Conversely, Asl (2011) reported that Ramadan fasting slightly but significantly enhanced endurance running performance in male athletes, with no notable changes in various physical parameters including body weight and fat-free mass.

**Table** 01: Effects of fasting on endurance performances in endurance trained athletes (Latiri et al., 2017).

| **Author** | **Participants** | **Study Design** | **Main Findings** |
|---|---|---|---|
| Png et al (2014)[88] | 12 active male runners Age: 27.9 ± 7.2 years | 60 min of continuous run during the Ramadan month after ingesting<br>→ Low glycemic index<br>→ Normal mixed carbohydrate food as the sahur meal (post 12 hrs). | NS variations in metabolic and physiological measures.<br>↓Distance ran was in low glycemic index versus control meal trial |
| Brisswalter et al (2011)[8] | 18 well trained males, middle-distance runners<br>-Ramadan fasting, n=9<br>- CG, n=9<br>Age: 23.6 ± 2.9 years | →The maximal running test<br>→Maximal voluntary contraction of knee extensor<br>→2 rectangular submaximal exercises on treadmill for 6 mins<br>→Running performance test (5000 m)<br>(Before and at the last week of Ramadan) | NC in running efficiency or MAP. |
| Asl (2011)[46] | 15 male endurance runners<br>Age: 22.5 ± 1.14 years | In the first week and in the middle of Ramadan<br>The aerobic power was measured by using30 mins running in stationary bike. | Small significant effect (P< 0.05) |
| Aziz et al (2010)[89] | 10 moderately men trained runners<br>Age: 27.3±7.2 years | Comparing the subjects (60 min runs on a treadmill) during the Ramadan month in the fasted state and non-fasted conditions.<br>The 60 min continuous endurance running: 30 min preloading run at 65% maximum oxygen consumption intensity speed + 30 min where subjects adjusted their speeds | ↑in the second 30 min in the control compared to Ramadan condition (5649±715 versus 5448±847 m, P=0.023).<br>↓ Blood glucose (4.5±0.3 versus 4.9±0.4 mmol/l, p=0.003) at the start of exercise in the Ramadan condition.<br>NS changes in HR, blood lactate and RPE between the two conditions. |
| Chennaoui et al (2009)[63] | 8 male middle-distance athletes<br>Age: 25.0 ± 1.3 years | The MAV test: 5 days before Ramadan and on days 7 and 21 of Ramadan. | ↓MAV values at days 7 and 21 (p < 0.05) |
| Loon et al (2004)[90] | 8 male cyclists<br>Age: 22.8 ± 0.8 years | Following an overnight fast, subjects were studied at rest, during 120 min of moderate intensity exercise (60% maximal oxygen uptake) and 120 min of post-exercise recovery. | ↑Free fatty acid oxidation rates increased during exercise.<br>↓Use of other fat sources and muscle glycogen with the duration of exercise (P<0.001)<br>↑Plasma glucose production and utilization (P < 0.001). |
| Mehdioui, et al (1996)[86] | 10 male distance runners | The maximal oxygen intake was measured in the beginning and the end of Ramadan | NC in maximal oxygen intake,<br>↑Endurance effort |

For untrained and non-endurance-trained athletes, the effects of fasting on endurance performance are equally mixed. Some studies, like those by Chaouachi et al. (2008) and Fouad (2008), observed no significant changes in performance. However, other studies reported either improvements (Sweileh et al., 1992) or decrements in performance. Hammouda et al. (2014), for instance, found a notable decrease in performance during the Yo-Yo level 1 test in male professional soccer players after Ramadan fasting. These findings are attributed to various factors, including the choice of fuel substrate during exercise, the level of physical conditioning, and training routines. Notably, some athletes tend to consume more calorie-rich foods and energy-dense drinks after breaking their fast. Moreover, changes in the training regimen during Ramadan, such as reduced intensity and tactical training, can also impact athletes' physical capacity by the end of Ramadan.

The intersection of physical training and fasting is gaining recognition for its beneficial effects on body composition and overall health (Donnelly et al., 2009). Aerobic exercise and fasting are key strategies for enhancing lipolysis in adipose and muscle tissues, thereby reducing body fat mass. This is crucial for athletes who aim to optimise the balance between lean and fat body mass for better performance (Goodpaster et al., 2003). Fat and carbohydrates are primary fuel sources for ATP synthesis in skeletal muscles during aerobic metabolism (Van Loon et al., 2003). The endurance capacity of an athlete is largely determined by maximal cardiac output and the ability to oxidise fat and carbohydrate stores. The endurance of exercise is limited by skeletal muscle metabolism and the body's glycogen storage capacity. Athletes may need to adapt their metabolic training strategies for long-duration events to increase glycogen stores and boost fat oxidation capacity.

Regarding metabolic regulation during fasting and exercise, fasting reduces insulin levels while promoting hepatic glycogen breakdown, leading to increased fat utilisation during endurance training compared to the fed state(De Bock et al., 2005). Exercise in a fasted state activates fat burning pathways, marked by increased plasma glycerol and FFA levels. This is facilitated by hormones like catecholamines and glucagon, while being inhibited by insulin. Regular exercise in a fasting state also leads to enhanced muscle fat oxidation due to upregulation of genes related to fatty acid transport and β-oxidation. However, it's essential to note that prolonged fasting can deplete hepatic glycogen stores and potentially lead to dysregulated glucose metabolism and hypoglycaemia during extended exercise (Van Proeyen et al., 2011).

In terms of performance, studies have shown that short-term fasting may lead to decreased physical performance, possibly due to factors like dehydration, prolonged exhaustive exercise, or high-intensity activity. However, other research indicates that habitual fasting combined with training can stimulate physiological muscle adaptations, potentially improving endurance exercise performance in untrained or recreationally active individuals. In contrast, the impact of fasting on performance in highly trained athletes requires further investigation, as most existing studies focus on untrained subjects.

Chtourou & Souissi (2012) conducted a study on the effects of Ramadan fasting on highly trained runners, revealing that training in the afternoon during Ramadan might be more effective in enhancing aerobic performance compared to training in the morning or evening. This could be attributed to normal diurnal rhythms, increased muscle temperature, and better mobilisation of glycogen and FFA during afternoon sessions. However, more research is needed to confirm whether endurance training while fasting can consistently improve performance in highly trained athletes (Aragón-Vargas, 1993).

Metabolic Syndrome (MetS), as defined by the American Heart Association (AHA), is diagnosed when an individual exhibits three or more of the following risk factors: insulin resistance, evidenced by fasting glucose levels exceeding 100 mg/dl; hypertension with readings above 135/85 mm Hg; hypertriglyceridemia with levels greater than 150 mg/dl; low high-density lipoprotein cholesterol (HDL-C) levels (under 40 mg/dl for men and under 50 mg/dl for women); and increased waist circumference (over 102 cm for men and over 88 cm for women), (Grundy, 2005). In the 21st century, Shas become a leading risk factor for atherosclerotic cardiovascular disease (ASCVD), (Wang et al., 2020). The global surge in these metabolic risk factors over the last five decades has escalated MetSto pandemic proportions, posing a significant public health challenge (Bluher, 2019; Lloyd & Ely, 2023; *Quick Facts: Advancing HIV Prevention*, 2004). In the United States, diabetes, hypertension, and ischaemic heart diseases have been consistently among the top causes of death and disability for the past twenty years ("Pan American Health Organization (PAHO)," 2008). Effective weight management is key in mitigating these risk factors (Ryan & Yockey, 2017), making strategies focused on energy balance and weight reduction essential in nutritional guidance (Wylie-Rosett et al., 2007).

Lifestyle changes including increased physical activity, psychological interventions to modify unhealthy behaviours, and dietary adjustments designed to foster weight loss and prevent weight regain are integral in obesity management (*CDC Yellow Book 2024*, 2023). Dietary patterns such as the Dietary Approaches to Stop Hypertension (DASH) and the Mediterranean diets have shown positive effects on metabolic indicators, improving lipid profiles and blood pressure (BP), (Kastorini et al., 2011; Siervo et al., 2015). Similarly, the Nordic diet, rich in mushrooms, fish, fruits, and vegetables, has been effective in enhancing lipid profiles (Uusitupa et al., 2013). Plant-based diets, including vegan diets, have also demonstrated protective effects against MetS (Wang et al., 2020).

## 5. Effects of IF on body weight, body fat and BMI

Many studies evaluating the impact of Intermittent Fasting (IF) on body weight (BW), body fat (BF) and Body Mass Index (BMI). These studies encompassed 10 to 150 participants, all overweight or obese, with study duration ranging from 1 to 60 weeks. Out of these, 14 studies observed a decrease in BW following IF implementation (Antoni et al., 2018; Bhutani et al., 2013; Byrne et al., 2018; Carter et al., 2018, 2019; Chair et al., 2022; Gabel et al., 2020; Harvie et al., 2011; Kahleova et al., 2014; McAllister et al., 2020; Schubel et al., 2018; Sundfor et al., 2018; Wilkinson et al., 2020). Among them, eight studies showed more significant weight loss in IF groups compared to controls (Bhutani et al., 2010; Byrne et al., 2018; Gabel et al., 2018; Kahleova et al., 2014; Kunduraci & Ozbek, 2020; Moro et al., 2016; Schubel et al., 2018; Varady et al., 2013), while another eight found no notable difference in weight loss between IF and control groups (Antoni et al., 2018; Carter et al., 2016, 2018, 2019; Catenacci et al., 2016; Harvie et al. 2011; Sundfor et al., 2018; J. F. Trepanowski et al., 2017). Time-Restricted Eating (TRE) and Alternate-Day Fasting (ADF) consistently indicated reductions in BW, BF, and BMI, whereas the results for Intermittent Energy Restriction (IER) were more variable. TRE particularly showed promising results in reducing BW in both obese and overweight participants compared to their baseline, when no control group was involved (Bhutani et al., 2010; Gabel et al., 2020; Wilkinson et al., 2020). However, these studies didn't focus on specific BMI categories. Several Randomised Controlled Trials (RCT) using control groups with no dietary intervention found CCR, ADF, and TRE effective in lowering BW and BMI across the general population (Bhutani et al., 2013; Moro et al., 2016; Schubel et al., 2018). It's important to highlight that the study of Moro et al. (2016) included 34 resistance-trained men, which might influence the interpretation of the diet interventions' effectiveness. Varady et al. (2013) showed that ADF significantly reduced BW and BF in normal BMI individuals, suggesting IF's benefits extend beyond overweight or obese individuals. When comparing IF to Continuous Energy Restriction (CER)/Continuous Calorie Restriction

(CCR), findings were mixed. Two RCT noted BMI reduction in both CER and ADF groups without significant weight loss differences (Catenacci et al., 2016; J. F. Trepanowski et al., 2017), but these studies were limited to healthy overweight/obese individuals, excluding those with cardiovascular risk factors. Six RCT observed BMI reduction in both CER and IER groups, but no substantial differences were found (Antoni et al., 2018; Carter et al., 2016, 2018, 2019; Harvie et al., 2011; Sundfor et al., 2018). Notably, half of these RCT(Carter et al., 2016, 2018, 2019) involved diabetic patients, and Sundfor et al. (2018) included individuals with at least one comorbidity. This suggests that IER may not be superior to CER in populations with health issues. Only two RCTshowed IER's superiority over CER in weight reduction (Byrne et al., 2018; Kunduraci & Ozbek, 2020). However, Byrne et al. (2018)was limited to sedentary males at baseline, affecting its wider applicability. A notable RCT Chair et al. (2022) reported ADF's greater effectiveness compared to TRE in reducing BW after a 3-week follow-up, but the short duration necessitates cautious interpretation. Most RCT did not consider behavioural lifestyle modifications, and the Hawthorne effect and observer bias could have influenced studies reliant on nutritionist interviews and self-reported food logs.

Regarding the eight meta-analyses discussing IF's effect on BW (Table 3), they integrated 6 to 43 studies. Three studies (Cho et al., 2019; Moon et al., 2020; Patikorn et al., 2021) indicated BMI and BW reduction in IF groups compared to the baseline, while five (Ashtary-Larky et al., 2021; Borgundvaag et al., 2021; Enriquez Guerrero et al., 2021; Gu et al., 2022; Harris et al., 2018) showed reductions compared to control groups. However, one meta-analysis (Gu et al., 2022) found no difference in weight loss between IF and calorie restriction groups. The diversity of IF types limited focus on long-term effects in these analyses weaken their statistical significance.

## 6. Effects of IF on glycaemia

In our review, we found 18 studies exploring IF's effects on fasting glucose (FG), insulin levels, and hba1c, involving 8 to 137 overweight or obese participants over periods ranging from 4 days to 60 weeks. These studies presented varied results. Eight (Carter et al., 2016, 2018; Catenacci et al., 2016; Hutchison et al., 2019; Kahleova et al., 2014; Kunduraci & Ozbek, 2020; Sutton et al., 2018; Wilkinson et al., 2020) reported improved glycaemia IF groups compared to the baseline. Four (Bhutani et al., 2013; Harvie et al., 2011; Jamshed et al., 2019; Kahleova et al., 2014) showed positive effects of IF on blood glucose levels compared to CER or no-intervention groups. However, seven studies (Carter et al., 2016, 2018; Catenacci et al., 2016; Chair et al., 2022; Gabel et al., 2018; Kunduraci & Ozbek, 2020; J. F. Trepanowski et al., 2017) found no significant glycaemic differences between IF and control groups, whether they were no-intervention or CER groups. Three studies (Carter et al., 2019; Gabel et al., 2020; McAllister et al., 2020) reported no effect of IF on blood glucose and insulin, while one (Antoni et al., 2018) even indicated an increase in FG. TRE and ADF mostly showed positive impacts on glycaemia, whereas IER's effects were inconsistent. Wilkinson et al. (2020) demonstrated FG and insulin level reductions with TRE, while Gabel et al. (2020) found no effect. ADF was linked to improved FG compared to a no-intervention diet, supported by Bhutani et al. (2013). Comparisons between ADF and CER/CCR showed no significant differences in glucose metabolism (Catenacci et al., 2016; J. F. Trepanowski et al., 2017), but these studies were limited to healthy individuals without diabetes or prediabetes. Contradictory results emerged when comparing IER to CER/CCR. Carter et al.'s two rcts (Carter et al., 2016, 2018) observed hba1c reductions in both groups, but no superiority was established. In their second RCT (Carter et al., 2018), including diabetic patients followed over 116 weeks, hba1c improvements were more pronounced when baseline levels were above 8% ($p < 0.001$). Harvie et al. (2011) found improved fasting insulin levels in the IER group versus the CER group among healthy women with BMI >25 kg/m^2, but this was not extrapolated to unhealthy populations or men. Another RCT (Antoni et al., 2018) indicated a worsening trend in fasting glucose in the IER group compared to the CER group, but this study was limited by its small size.

Six meta-analyses offered mixed findings. Two showed FG reductions in IF groups (Cho et al., 2019; Moon et al., 2020), while another found no significant difference in blood glucose levels between IF and CER groups (Harris et al., 2018). Borgundvaag et al. (2021) observed no significant hba1c reduction difference between IF and no-intervention groups. TRE was more effective in reducing FG levels compared to no-intervention groups (Pureza et al., 2021). Gu et al. (2022) found no difference in blood glucose levels between IF, CR, and no-intervention groups, but noted reductions in fasting insulin levels and insulin resistance. The larger scale of the meta-analysis showing significant FG reductions suggests that smaller studies may lack sensitivity. Additionally, Cho et al. (2019) focused only on healthy individuals, limiting the applicability of these findings to those with metabolic diseases who might benefit from IF diets.

Recent research indicates that meal timing, along with dietary content, can influence chronic disease progression (Andrzejczak et al., 2011). This has brought intermittent fasting (IF) into focus as a dietary method for weight control (Harris et al., 2018), diabetes management (Borgundvaag et al., 2021), dyslipidemia treatment (Meng et al., 2020), and reducing cardiovascular risks (Harris et al., 2018). However, meta-analyses and randomised clinical trials (TCT) exploring IF's impact on cardiovascular risk factors have yielded mixed outcomes. Some studies report significant weight loss benefits (Cho et al., 2019; Enriquez Guerrero et al., 2021), while others find no marked advantage over continuous calorie restriction (Catenacci et al., 2016). The effect of IF on blood sugar levels also varies, with some research indicating improvements (Wilkinson et al., 2020) and others showing no significant changes (Gabel et al., 2020). The influence of IF on lipid profiles has been similarly inconsistent, leaving the efficacy of various IF regimes in question (Carter et al., 2016).

## 7. Effects of IF on lipid levels

Our review included 15 studies that focused on the impact of Intermittent Fasting (IF) on lipid levels, involving 8 to 137 participants across duration of 4 days to 116 weeks. TRE, among the three IF methods, yielded the most positive results on lipid profiles. However, these studies displayed considerable variation in design, measured parameters, participant numbers, and baseline characteristics, introducing potential biases like selection, confounding factors, and observers influence on the outcomes.

McAllister et al. (2020) and Jamshed et al. (2019) found that TRE, whether calorie-controlled or not, led to higher HDL-C levels ($p = 0.005$ and $p = 0.03$, respectively). In contrast, Gabel et al. (2018) and Sutton et al. (2018) noted no significant changes in LDL-C and HDL-C levels ($p = 0.54$, $p = 0.75$ for LDL-C; $p = 0.11$, $p = 0.48$ for HDL-C, respectively) compared to control groups. Kahleova et al. (2014) observed a decrease in LDL-C but no significant difference compared to a six-meals-a-day diet ($p = 0.82$ for LDL-C and $p = 0.3$ for TG).In terms of ADF, Bhutani et al. (2013) reported no notable effects on LDL-C ($p = 0.90$), HDL-C ($p = 0.80$), and TG ($p = 0.30$). Likewise, compared to a CCR diet, ADF showed no significant changes in LDL-C ($p = 0.40$) and HDL-C ($p = 0.99$). However,J. F. Trepanowski et al. (2017) indicated that prolonged ADF led to increased LDL-C compared to a CCR diet, while TG levels were similar between groups.

IER demonstrated some impacts on lipid profiles. Harvie et al. (2011) and Kunduraci and Ozbek (2020) noted improvements in LDL-C and TG levels from the baseline, with no significant differences compared to a CER group, indicating no clear superiority of IER over CER. Carter et al. (2019) found no differences in LDL-C and TG between IER and CER groups but saw an unexpected reduction in HDL-C in the IER group ($p = 0.02$).

**8. Effects of IF on Blood Pressure**

Different studies (Antoni et al., 2018; Bhutani et al., 2013; Gabel et al., 2018; Gabel et al., 2020; Harvie et al., 2011; Kunduraci & Ozbek, 2020; Sutton et al., 2018; J. F. Trepanowski et al., 2017; Varady et al., 2013; Wilkinson et al., 2020), examined the effects of IF on systolic (SBP) and diastolic blood pressure (DBP) were examined. IF, in its various forms, consistently showed significant reductions in SBP and DBP from the baseline. This aligns with the established link between weight loss, observed in most studies, and BP regulation.

TRE positively impacted BP, with several studies (Gabel et al., 2018; Gabel et al., 2020; Sutton et al., 2018; Wilkinson et al., 2020) noting considerable decreases in both SBP and DBP ($p = 0.041$, $p < 0.05$, $p = 0.02$, and $p = 0.03$, respectively).

ADF also led to reduced SBP and DBP compared to non-intervention diets in two studies (Bhutani et al., 2013; Varady et al., 2013), ($p < 0.05$ for SBP and DBP, $p = 0.02$ for SBP, and $p = 0.03$ for DBP, respectively). BP levels decreased under the IER diet, with Harvie et al. (2011) and Kunduraci and Ozbek (2020) observing improvements in SBP and DBP from the baseline, but no significant differences when compared to the regular CER diet. This suggests that BP reduction is more likely due to weight loss rather than IF itself. However, Antoni et al. (2018) found a more significant reduction in SBP in the IER group compared to the CER group over 60 weeks ($p = 0.02$). Consequently, definitive conclusions about the relative benefits of IER versus CER for BP reduction remain inconclusive.

IF shows beneficial impacts on cardiovascular (CV) risk factors. It has been effective in promoting weight loss, enhancing glucose metabolism, improving lipid profiles (by lowering LDL-C and raising HDL-C), and managing both systolic and diastolic blood pressure from the baseline. The efficacy of IF in reducing visceral and abdominal fats, leading to these benefits, stems from creating an energy deficit, which positively alters the leptin/adiponectin ratio and aids in appetite regulation (de Cabo & Mattson, 2019). Additionally, a decrease in adiposity and chronic inflammation plays a significant role in reducing insulin resistance (Albosta & Bakke, 2021). Concerning lipid management, IF decreases the liver's production of very low-density lipoprotein cholesterol (VLDL-C) and triglycerides (TG) while enhancing fatty acid oxidation. This is partly due to the upregulation of peroxisome proliferator-activated receptorgamma (PPAR-γ) and peroxisome proliferator-activated receptor coactivator 1 alpha in the liver, which boosts fatty acid oxidation and Apo A production, and reduces Apo B synthesis, contributing to lower LDL-C and VLDL-C levels (Santos & Macedo, 2018). The positive effects of IF on blood pressure are linked to the stimulation of the parasympathetic nervous system in the brainstem (Malinowski et al., 2019).

Genetic factors influence individual responses to different diets. For instance, the presence of the A-allele of the FTO gene variant rs9939609 in obese individuals can hinder long-term weight maintenance following a low-calorie diet (Woehning et al., 2013). More genetic research is needed to understand how different genes and alleles affect responses to IF across various populations. Despite IF diets not having specific food type recommendations, the intake levels of sugar, saturated fat, cholesterol, and sodium are generally similar to those in more traditional weight-loss diets (Cienfuegos et al., 2020). Moreover, understanding IF's physiological mechanisms, such as the activation of lipolysis and ketogenesis (Sanvictores et al., 2024), and the enhancement of appetite control through increased peptide YY (Hoddy et al., 2016), elucidates how it facilitates successful weight loss. It's well documented that weight loss positively influences blood pressure (Gilardini et al., 2016), glucose levels (Franz, 2017), and lipid profiles (Kiriyama et al., 2021).

Numerous studies indicate that Intermittent Fasting (IF) positively impacts BMI management, glucose metabolism, lipid profiles (notably increase HDL-C and decreasing LDL-C), and blood pressure regulation. Malinowski et al. (2019) found in their comprehensive review that IF helps manage several risk factors including diabetes, lipid profiles, blood pressure, and obesity, which collectively contribute to the prevention of atherosclerotic cardiovascular disease (ASCVD). However, Allaf et al. (2021) in their systematic review, observed that while IF outperforms unrestricted eating in weight reduction, it does not significantly surpass Continuous Energy Restriction (CER) in improving cardiometabolic risk factors, and thus, does not notably reduce ASCVD risk. This highlights the need for more research to explore IF's long-term clinical impact on ASCVD beyond its influence on cardiovascular risk factors. Furthermore, IF, particularly Alternate-Day Fasting (ADF), has been associated with a notable decline in high-sensitivity C-reactive protein (hscrp) levels. Since elevated hscrpis a marker for increased ASCVD event risk, IF could be a beneficial strategy for ASCVD prevention in patients with high hscrp. Identifying patient groups that might gain the most from this diet approach would be of interest. While IF's short-term benefits are acknowledged in some studies, its long-term effects are less clear. There is a risk that such calorie restriction patterns could lead to a reduction in the metabolic rate over time, which could hinder sustained weight loss, aligning with the fasting ancestral theory (Inverse., 2019). Hence, there is a pressing need for long-term prospective studies to track the outcomes of IF over extended periods.

Another critical aspect is the psychological and psychiatric impact of IF. A recent study (Schueler et al., 2023) revealed that individuals who fast are more prone to binge eating compared to those who have never fasted ($p = 0.03$), suggesting a potential link between IF and a heightened risk of disordered eating behaviours. This makes IF a less suitable option for individuals with a history of eating disorders. Moreover, integrating IF into modern lifestyles, especially in social contexts with varied meal timings (Vasim et al., 2022), can be challenging, potentially affecting social interactions and increasing depression risk. Individuals should therefore be guided to select a fasting method that best fits their lifestyle. Notably, glycaemic instability is a significant concern with IF. Research shows that IF heightens the risk of both hypo- and hyperglycemia in diabetic patients (Grajower & Horne, 2019). Thus, IF is not advisable for individuals prone to glycaemic fluctuations, including pregnant women, patients with uncontrolled diabetes, and the elderly, due to the heightened risk of falls and fractures (Dardano et al., 2014).

In another vein, recent studies suggest that IF can reduce androgen levels in both men and women, which could negatively affect libido. Interestingly, this effect may offer benefits for women with polycystic ovary syndrome (Cienfuegos et al., 2022). Lastly, IF has been linked to an increased risk of osteoporosis, suggesting it may not be the best dietary option for older adults (Veronese & Reginster, 2019).

## 9. Anthropometric parameters of smokers

The relationship between smoking and body weight suggests that smoking may lead to weight loss by enhancing metabolic rates, reducing metabolic efficiency, or decreasing calorie absorption, all linked to tobacco use. The metabolic impact of smoking might account for the lower body weight observed in smokers. Studies have shown that smoking a single cigarette can cause a 3% increase in energy expenditure (EE) within 30 minutes (Dallosso & James, 1984). Resting EE rose by 3.3% for 3 hours after smoking four cigarettes, each containing 0.8 mg of nicotine (Collins et al., 1994). In regular smokers monitored in a metabolic ward, consuming 24 cigarettes in a day raised total EE from 2230 to 2445 kcal/day, possibly due to stimulated sympathetic nervous system activity (Hofstetter et al., 1986). However, the impact of smoking on EE was less pronounced in obese individuals (Audrain et al., 1995) and varied with levels of physical activity and fitness (Perkins et al., 1994). Long-term metabolic effects of smoking are less clear, with studies showing mixed results (Ward et al., 2001). Female smokers who quit experienced a 16% decrease in resting metabolic rate after 30 days, leading to weight gain due to reduced metabolic rate and increased caloric intake (Moffatt & Owens, 1991). Other studies, however, did not observe any change in resting EE post-smoking cessation (Stamford et al., 1986). Smokers may have a higher risk of hyperthyroidism, which can also elevate metabolic rate (Åsvold et al., 2007).

Nicotine might also acutely suppress appetite: over a 2-hour period, hunger and food consumption were inversely related to nicotine doses, while satiety and fullness were positively associated (Jessen et al., 2005). Nicotine didn't alter hunger sensations in both smokers and nonsmokers but led to reduced calorie consumption during meals (Perkins et al., 1991). However, caloric intake was higher during a meal following nicotine administration compared to a placebo (Perkins et al., 1992). While increased physical activity boosts metabolic rate and aids weight management, smokers generally exhibit lower physical activity levels than non-smokers (Klesges et al., 1990). In summary, smoking may acutely support weight control through metabolic effects, but its impact on calorie intake is less clear.

Regarding the body weight of heavy versus light smokers, it's expected that more cigarettes smoked would correlate with lower body weight due to smoking metabolic effects. Nonetheless, cross-sectional studies suggest heavy smoking might increase obesity risk (Istvan et al., 1992). For instance, in a cancer prevention study (Rasky et al., 1996) found that while smokers generally weighed less than ever or former smokers, heavy smokers (2 packs/day) were more likely to be overweight than other smokers. In a study of U.S. men, age-adjusted BMI was lower in light and moderate smokers compared to nonsmokers, but higher in heavy smokers (Shimokata et al., 1989). Similarly, in Germany, male heavy smokers had a higher likelihood of obesity compared to male light smokers (John et al., 2005)

# MATERIALS AND METHODS

## 1. Study period and conditions

This study was conducted during the Ramadan fasting period of 2023, focusing on healthy individuals without metabolic diseases. The participants included both athletes and non-athletes, the latter group comprising sedentary individuals, both smokers and non-smokers. The average duration of daily fasting was approximately 15 hours, under ambient conditions with an average temperature of 27±3°C and humidity levels around 50±5%.

## 2. Ethical Considerations

The current study was conducted during the 2023 Ramadan fasting period, with a focus on evaluating the effects of fasting on healthy individuals, free of metabolic diseases. This included a diverse cohort of participants, comprising athletes and non-athletes (sedentary individuals, both smokers and non-smokers). Before participating, all subjects were fully informed (in writing and verbally) about the objectives and the detailed procedures of the study. Written informed consent was obtained from each participant to ensure their understanding and voluntary involvement. Participants were also informed of their right to withdraw from the study at any time if they chose to do so. Furthermore, this research received ethical approval from UMAB University, Mostaganem, Algeria, in accordance with the ethical standards of the 1964 Helsinki Declaration, thus ensuring compliance with international guidelines for ethical research conduct.

## 3. Participants

### 3.1. Selection and Preliminary Data

For this study, we recruited twenty volunteered football athletes, each with a minimum of seven years of experience. These athletes continued their regular training schedules throughout the Ramadan fasting period. Prior to the start of the study, all volunteers underwent comprehensive medical examinations to confirm their physical health and suitability for participation.

To enable a thorough comparative analysis, we carefully formed two control groups. The first group included twenty sedentary but healthy students and the second group, named Sedentary Smokers, consisted of individuals who have been smoking regularly for at least four years. The selection process for both control groups was conducted with precision to ensure that the gender and age of the participants matched those of the athletes. Additionally, all participants in these control groups displayed haematological indices within normal physiological ranges.

The study required participants to visit the laboratory seven times for data collection and analysis. The initial visit was scheduled one week before the beginning of Ramadan fasting, followed by weekly visits during the four weeks of Ramadan, each after about 16 hours of fasting. Two additional visits were arranged after Ramadan to evaluate the return to baseline conditions.

### 3.2. Study protocol

During each visit, participants rested in a seated position for 10 minutes before undergoing anthropometric measurements, which included height, body mass, body mass index, and body fat percentage. Anthropometric measurements in the fasting state were conducted according to standardised protocols (Huang et al., 2023; Zhao & Zhao, 2023; Shahidi et al., 2023; Vélez-Alcázar et al., 2024) by trained professionals. Weight (accurate to 0.1 kg) and body fat percentages were determined using the bioelectrical impedance method (InBody 230, Biospace, Korea). Height (accurate to 0.5 cm) was measured in a standing position without shoes, using a stadiometer. Body Mass Index (BMI) was calculated by dividing the weight in kilograms by the square of the height in metres (Abdelrahim et al., 2023; Said, 2023; Lakhani et al., 2024). Anthropometric measures were performed at the same time as blood sampling.

The variables related to this study, including serum haematological-biochemical parameters and body composition, were assessed at seven intervals: one week before Ramadan (W1), weekly during Ramadan (Week 2, 3, 4, and 5), and two weeks following Ramadan (Week 6 and 7), under identical sampling conditions and were compared to the standard values (Table 2).

Study subjects provided venous blood taken from antecubital veins. Fresh EDTA blood was used to determine various heamorheological parameters. Mean Leucocytes blood cell count (WBC), mean red blood cell count (RBC), haemoglobin (HB), haematocrit (HCT), mean RBC volume (MCV) and mean corpuscular HB concentration (MCHC) were assessed using a haematology analyser (Beckman Coulter AcT 5diff Autoloader, Beckman Inc., USA).

**Table 2:** Complete blood count standard reference values (Grigoriev et al., 1995); (Hoffman et al., 2022)

| Blood component | Abbreviation used | Reference range | SI Reference range |
|---|---|---|---|
| **White bloodcells** | WBC | 4500-11,000/mm3 | 4.5-11.0 x $10^9$/L |
| **Redbloodcells*** | RBC | Male: 4.3-5.9 million/mm3<br>Female: 3.5-5.5 million/mm3 | Male: 4.3-5.9 x $10^{12}$/L<br>Female: 3.5-5.5 x $10^{12}$/L |
| **Haemoglobin*** | HGB | Male: 13.5-17.5 g/dL<br>Female: 12.0-16.0 g/dL | Male: 2.09-2.71 mmol/L<br>Female: 1.86-2.48 mmol/L |
| **Haematocrit*** | HT | Male: 41%-53%<br>Female: 36%-46% | Male : 0.41-0.53<br>Female : 0.36-0.46 |
| **Mean Corpuscular Volume** | MCV | 80-100 µm3 | 80-100 fl |
| **Mean Corpuscular Haemoglobin** | MCH | 25.4-34.6 pg/cell | 0.39-0.54 fmol/cell |
| **Mean Corpuscular Haemoglobin Concentration** | MCHC | 31%-36% Hb/cell | 4.81-5.58 mmolHb/L |
| **Platelets** | Platelets | 150,000-400,000/mm3 | 150-400 x 109/L |

*Values differ depending upon altitude

Afterwards, blood samples were centrifuged, and the resulting supernatant plasma was stored at -25°C. To mitigate day-to-day laboratory variations, all blood samples were analyzed in a single batch. Glucose, total cholesterol (T-Chol), and triglyceride (TG) concentrations were determined using an auto-analyser (Hitachi 911, Boehringer Mannheim, Germany) with standard reagents provided by the manufacturer. High-density lipoprotein cholesterol (HDL-C) levels were enzymatically measured from the supernatant after precipitation of apolipoprotein B-containing lipoproteins (very low-density lipoprotein [VLDL] and LDL) using dextran sulfate and Mg++ (HDL-Cholesterol kit, Sigma Diagnostics, USA).

### 3.3. Health Screening

Prior to the study, all volunteers underwent comprehensive medical examinations to confirm their physical fitness and suitability for participation.

## 4. Data collection protocol

Data collection occurred across seven visits to the laboratory. The initial visit (W01 - Bef-RF) was scheduled a week before the commencement of Ramadan fasting. This was followed by weekly visits during Ramadan (W02 to W05) after roughly 16 hours of fasting. To assess post-fasting conditions, two additional visits were arranged (W06 and W07 - Aft-RF). During each visit, after 10 minutes of seated rest, participants underwent anthropometric measurements, including height, body mass, body mass index, and body fat percentage, following protocols established (Lau et al., 2020; Tabassum et al., 2023).

## 5. Hematological analysis

In addition to the previously described methodologies, hematological analysis played a pivotal role in our study. This analysis focused primarily on the blood cells: erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (platelets). These cells, suspended in plasma, a straw-colored fluid, constitute over half of blood's volume. The tests conducted included a complete blood count (CBC), differential white blood cell count, and a hemoglobin assay. These tests are instrumental in measuring various parameters, such as the number and physical characteristics of different blood cells, as well as hemoglobin concentration. Such analyses are crucial for observing any physiological changes occurring as a result of fasting during Ramadan.

## 6. Complete Blood Count (CBC)

The CBC was conducted using the methodology described byBain (2021). This method involves automated cell counters, which provide accurate and comprehensive data on various blood parameters, including red blood cells, white blood cells, and platelets. It is a fundamental test for evaluating overall health and detecting a wide range of disorders, including anemia and infection.

## 7. Differential white blood cell count

For the differential white blood cell count, the technique outlined by Hoffbrand and Steensma (2019) was utilized. This method employs both automated analyzers and manual microscopic examination to distinguish and count the different types of white blood cells. This analysis is critical for understanding the body's immune response and identifying potential inflammatory or infectious processes.

## 8. Hemoglobin assay

The hemoglobin concentration was measured using the cyanmethemoglobin method, as described by Van Kampen (1987). This method involves the conversion of hemoglobin to cyanmethemoglobin, which can be measured spectrophotometrically, providing an accurate assessment of hemoglobin levels. This test is vital for diagnosing anemia and monitoring overall blood health.

## 9. Biochemical Analysis

Complementing the hematological analysis, biochemical analysis of blood was also conducted. This aspect delved into the chemical components of the blood, examining the presence and concentration of enzymes, proteins, lipids, glucose, and electrolytes in the blood serum or plasma (table 03).

**Table 3:** Red blood cell (RBC) indices (Grigoriev et al., 1995; Vajpayee et al., 2022)

| Parameter | Definition | Units | Formula |
|---|---|---|---|
| **Mean Cell Volume (MCV)=VGM** | Average volume of the red blood cell (RBC) | Femtoliters (fL) or 10-15Liter | MCV (fL) = Hematocrit (in %) × 10 / RBC (in 1012/L) |
| **Mean Cell Haemoglobin (MCH)=CMH** | Average weight of haemoglobin (Hb) in the RBC | Picograms (pg) or 10-12 grams | MCH (pg) = hemoglobin (in g/dL) × 10 / RBC (in 1012/L) |
| **Mean Cell Haemoglobin Concentration (MCHC)** | Average concentration of Hb in the RBC volume | Grams/deciliter (g/dL) | MCHC (g/dL) = hemoglobin (in g/dL) × 100 / Hematocrit (in %) |

## 10. Statistical Analysis

The present investigation employed a rigorously structured, completely randomized design to collect data, with subsequent analysis conducted using advanced statistical techniques. This section delineates the methodology and analytical approaches utilized to interpret the data, focusing on the effects of Ramadan fasting on various health parameters in distinct participant groups.

### 10.1. Methodological framework

Data acquisition was executed following a completely randomized design, essential for ensuring the integrity and reproducibility of the study. This approach facilitated unbiased data collection, vital for the subsequent statistical analysis.

### 10.2. Primary satistical analysis: analysis of variance (ANOVA)

The core statistical method utilized was the Analysis of Variance (ANOVA). This technique is particularly adept at discerning variations among group means. In this context, ANOVA was employed to examine changes in body mass, body mass index (BMI), and body fat percentage across different temporal checkpoints in relation to Ramadan fasting. The participant cohorts included football athletes, sedentary individuals, and sedentary smokers.

#### 10.2.1. Post-Hoc Analysis: Duncan's Multiple Range Test

Upon identifying significant differences through ANOVA, Duncan's Multiple Range Test was employed for post-hoc analysis. This test is essential for performing pairwise comparisons between group means, allowing for a detailed understanding of significant differences highlighted by ANOVA. The application of this test was crucial in elucidating the specific impacts of fasting on hemorheological parameters within the study's population.

#### 10.2.2. Employing single degree of freedom contrasts

Further, the study incorporated single degree of freedom contrasts. This statistical approach is invaluable for examining differential impacts across groups, particularly in the context of anthropometric and metabolic responses to fasting. By isolating specific contrasts, this method provided insights into the nuanced effects of Ramadan fasting on various health parameters.

#### 10.2.3. Statistical Significance and Software Application

All statistical analyses adhered to a stringent significance threshold, with a p-value set at $< 0.05$. This criterion ensured that the study's findings were statistically robust and reliable. Analyses were conducted using SAS software (SAS, 2008).

# CHAPTER 01.

# EFFECT OF RAMADAN FASTING ON ANTHROPOMETRIC PARAMETERS

## 1. Age and height

In our analysis, we examined age and height variables among athletes (figure 01), sedentary non-smokers, and sedentary smokers, uncovering key patterns that have implications for understanding their physical characteristics and potential health outcomes. Athletes and sedentary non-smokers displayed similar mean ages, with athletes being marginally older, whereas sedentary smokers were notably older, indicating a possible demographic or lifestyle influence on age distribution. The error bars revealed less variability in age among sedentary smokers compared to the other groups, suggesting a more homogeneous age group or more accurate age measurements for sedentary smokers.

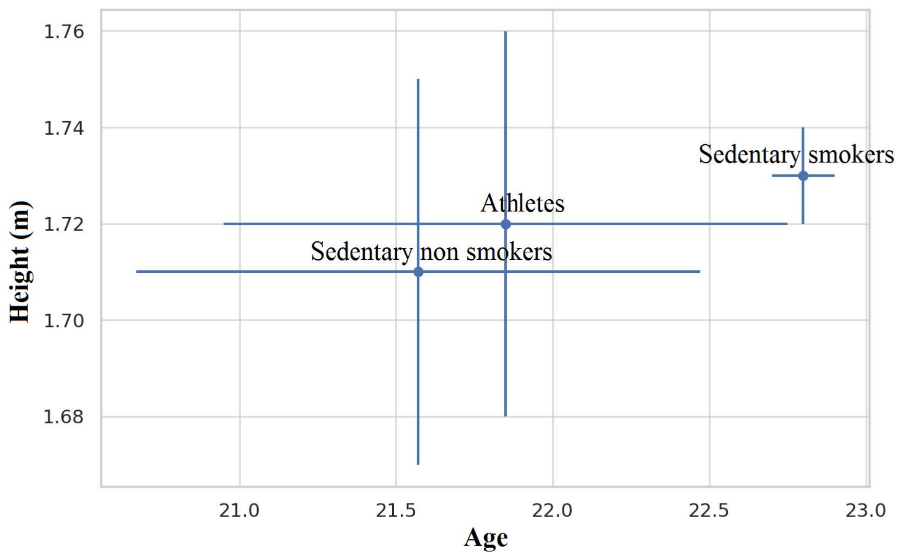


**Figure 03.**Scatter plot of age and height of different groups

Height analysis showed that athletes were slightly taller than sedentary non-smokers, with sedentary smokers being the tallest on average. The small error bars across all groups indicate consistent height measurements within each group, suggesting that high variability is minimal and may not significantly affect health outcomes or physical performance comparisons among these groups.

The findings suggest that while age and height differences exist among the groups, the implications for health outcomes and physical performance may require further investigation. The reduced variability in age among sedentary smokers and the consistent height measurements across groups highlight the importance of considering these variables in future health-related research.

## 2. Body mass

The study examines the impact of Ramadan fasting on body mass across three groups: athletes, sedentary smokers, and sedentary non-smokers, over a seven-week period. Data from Figure 1 highlight different responses among the groups influenced by lifestyle factors and fasting.

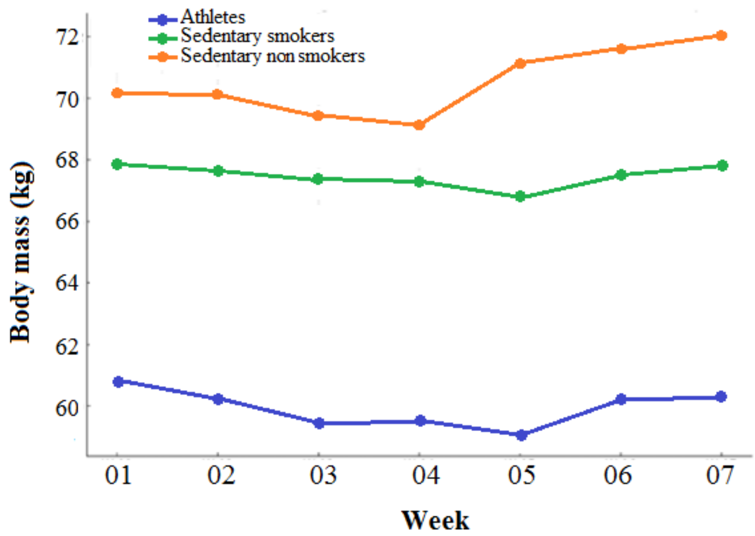


**Figure 04.** Comparative analysis of body mass variation in athletes and sedentary (smokers and non-smokers) individuals during Ramadan fasting.

Athletes exhibited a decrease in body mass during the fasting weeks (W02-W05), likely due to a calorie deficit from maintaining exercise regimes without compensatory caloric intake adjustments. Post-Ramadan, their body mass significantly rebounded ($p<0.05$) to baseline levels by W06-W07 (figure 02), suggesting a resumption of normal dietary habits or increased caloric intake post-fasting. This pattern aligns withZerguini et al. (2007), who reported weight loss during Ramadan among athletes, attributed to caloric intake challenges, followed by weight regain post-Ramadan upon returning to regular dietary and exercise patterns.

Sedentary smokers maintained relative body mass stability during fasting, with a slight increase observed, followed by a more pronounced rise post-Ramadan. This trend may result from nicotine's appetite-suppressing effects, modified meal timing, and frequency during fasting, and post-Ramadan compensatory eating behaviours or metabolic rate decreases. This observation is comparable toChaouachi et al. (2012), who noted that nicotine might mitigate fasting appetite-suppressing effects, with post-Ramadan weight gain potentially due to overeating common after fasting periods.

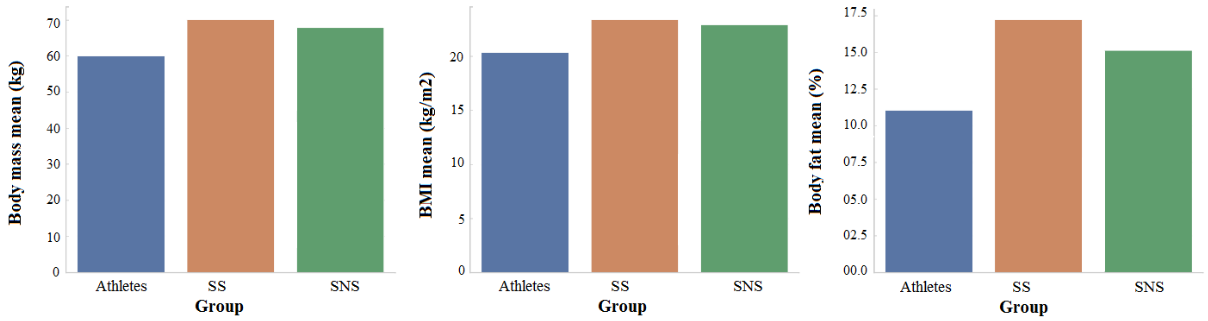


**Figure 05**: Average of body mass, body mass index and body fat of three groups. BMI: body mass index, SS: sedentary smokers, SNS: sedentary non smokers.

Sedentary non-smokers showed a consistent body mass increase throughout the study, indicating potential decreases in physical activity and increased caloric intake during non-fasting hours without the appetite modulation from smoking. This contrasts with(Trabelsi et al., 2012), who found no significant weight gain among sedentary individuals during Ramadan, suggesting that the current study's findings might relate to calorie density or population differences.

Comparative analysis with existing literature, such as Alkandari et al. (2012), reveals varied Ramadan fasting effects on body mass, emphasizing the role of baseline activity levels in weight maintenance or regulation. The observed weight gain in sedentary groups post-Ramadan underscores the potential for fasting to alter eating behaviours, leading to weight gain when normal eating resumes, a phenomenon supported by(Fernando et al., 2019), who attributed post-Ramadan weight gain to overcompensation in food intake following perceived deprivation.

## 3. Body mass index

The investigation delineates (figure 03) the differential impact of Ramadan fasting on Body Mass Index (BMI) across three distinct cohorts: athletes (Ath), sedentary smokers (S), and sedentary non-smokers (SS). Initial BMI assessments reveal inherent disparities: athletes at 21 kg/m², sedentary smokers at 23 kg/m², and sedentary non-smokers at 23.2 kg/m², suggesting lifestyle-related compositional differences.

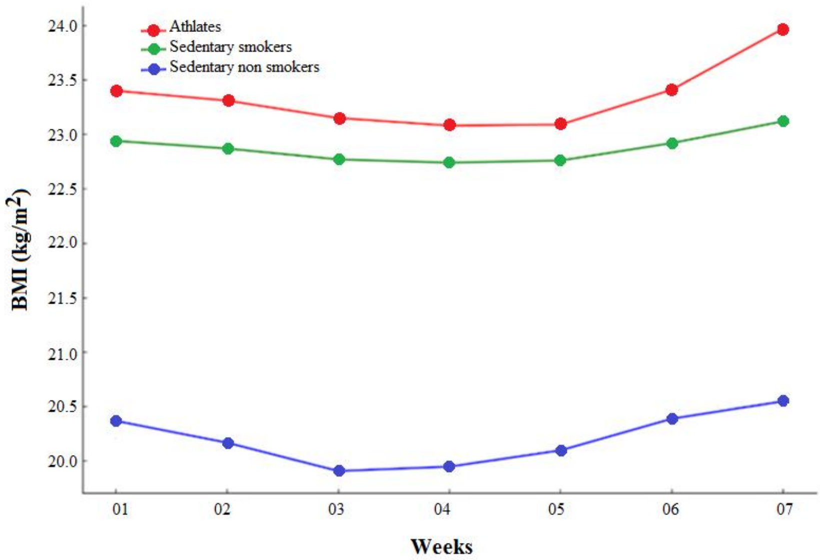


**Figure 06.** Body mass index (BMI) trends in athletes, sedentary smokers, and sedentary non-smokers throughout Ramadan fasting.

Throughout Ramadan (DRf–week 02 to 05), a decrement of 1.2% in athletes' BMI was observed, likely reflecting caloric intake reduction against sustained energy output from continued training activities. Their strategic adaptation to fasting, by modifying eating schedules and maintaining energy balance facilitated this decrease.

Conversely, sedentary smokers experienced a notable BMI increase of 2.2% ($p<0.05$), potentially due to nicotine's appetite-stimulating effects and its complex interaction with metabolism, which, coupled with increased smoking frequency during stress, may lead to weight gain. Sedentary non-smokers registered a 1.8% BMI increase, indicating that while smoking exacerbates weight gain, fasting-induced alterations in meal patterns significantly influence weight management in sedentary lifestyles.

Post-Ramadan (ARf–week 06 and 07), athletes demonstrated a swift return to near-baseline BMI levels, suggesting efficient weight regulation mechanisms that facilitate rapid reversion to pre-fasting metabolic norms. In contrast, sedentary smokers and non-smokers continued to exhibit BMI increases, 4.3% and 3.6% above the baseline, respectively, indicating potentially lasting impacts of Ramadan-induced dietary changes.

This study (figure 05) corroborates with existing literature on the individualistic effects of fasting on weight and BMI, influenced by physical activity and smoking habits. Smoking, in particular, is linked to less favourable weight outcomes during and after fasting. The findings underscore the need for personalised dietary and lifestyle interventions to counteract fasting-related BMI increases, especially among sedentary and smoking populations.

In summary, the study presents a divergent pattern of BMI changes during Ramadan fasting, with athletes maintaining their BMI, while sedentary smokers and non-smokers experienced increases. These observations align with(Farooq et al., 2015) and Chaouachi et al. (2012), highlighting athletes' metabolic efficiency and dietary control enabling adaptation to fast regimes. Conversely, the BMI rise in sedentary smokers surpasses findings by(I. Said, 2023), suggesting variations in smoking behaviour or demographic differences may influence weight outcomes. The increase among sedentary non-smokers is greater than reported byTrabelsi et al. (2022), potentially reflecting cultural or dietary differences during Ramadan, as high-caloric intake during Suhoor and Iftar could contribute to weight gain (Roky et al., 2012).

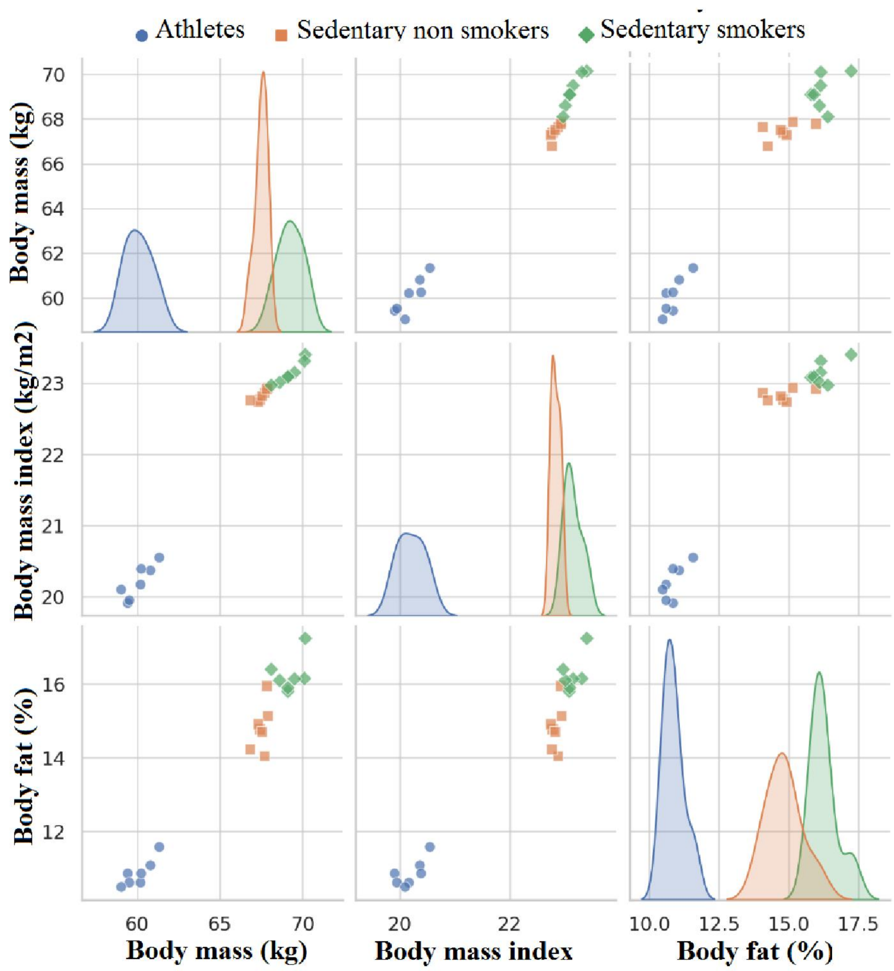


**Figure07.**Effect of fasting on Bm, Bmi and body fat percentage on athletes, sedentary non-smokers and sedentary smokers

## 4. Weekly body Fat percentage response of the experimental populations

In the current investigation, the athletic cohort (Ath) demonstrated an average body fat percentage (BF%) of 10.85 ± 1.73, with a recorded range from 10.48 to 11.57 (refer to Figure 5).

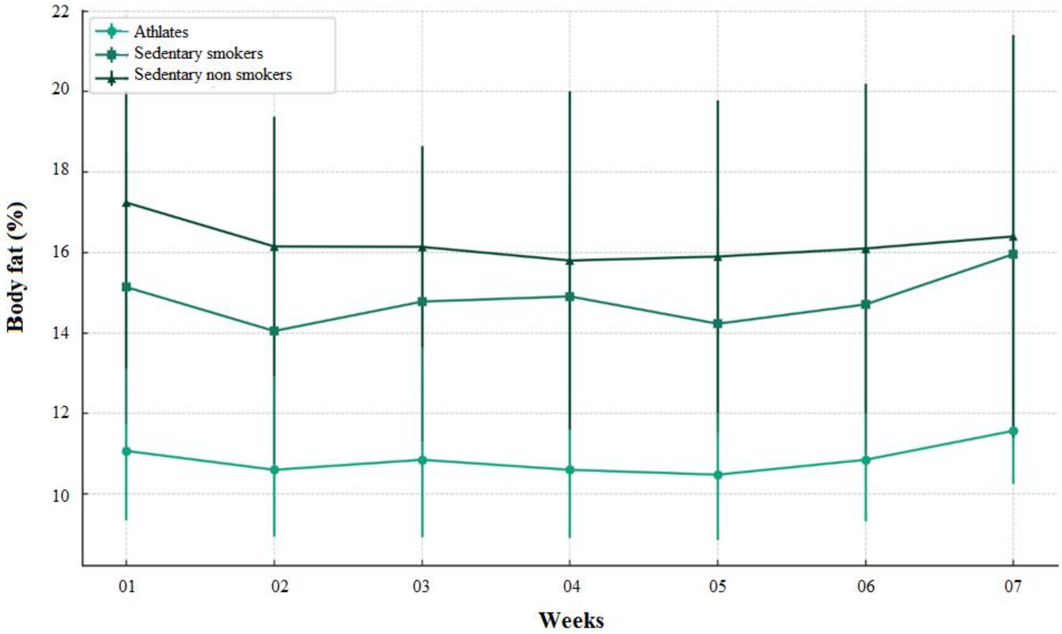


**Figure 8.** Variations of body fat percentage before, during and after Ramadan fasting: a longitudinal study of athletes, sedentary smokers and non-smokers' adults.

This observation aligns with the outcomes reported byTrabelsi et al. (2022), indicating a propensity for lower BF% in athletes throughout the period of Ramadan fasting. Such a trend is likely attributable to strict adherence to training schedules and dietary regulations, enabling athletes to effectively regulate their body composition during fasting intervals. Further,Bougrine et al. (2023) substantiated the capability of athletic individuals to sustain their BF% during Ramadan, highlighting the pivotal role of exercise and nutritional planning in the maintenance of body composition.

Conversely, individuals classified as Sedentary Non-Smokers (S) presented with a mean BF% of 14.78 ± 3.39, with individual values extending from 14.05 to 15.96. This finding is in agreement with the recent analysis byTsitsou et al. (2022), which documented a rise in BF% among the sedentary populace during Ramadan. The noted increase in BF% for this group may be ascribed to a decrease in physical activity coupled with potential shifts in dietary intake during the fasting period, underscoring the imperative for sedentary individuals to remain cognisant of body composition fluctuations during Ramadan.

In the case of sedentary smokers (SS), the observed mean BF% was 16.14 ± 4.12, with a spectrum ranging from 15.8 to 17.24. Research conducted byShaheen et al. (2022)explored the intricate interplay between smoking habits and body composition during Ramadan, noting that the abstention from smoking during daylight hours could prompt an augmented caloric consumption, thereby leading to an elevation in BF%. These insights are congruent with the higher BF% detected in the sedentary smoking cohort within this study, both during and subsequent to Ramadan. Furthermore, these results reiterate the necessity to consider smoking behaviours when evaluating body composition dynamics during periods of fasting, as discussed byTibi et al. (2023).

## 5. Lean Body Mass

Throughout the seven-week period (figure 06), athletes exhibited a fluctuating lean body mass (LBM), beginning with a higher value, experiencing a mid-period dip, and subsequently peaking in the final weekpotentially indicative of temporary lean tissue changes due to modified training regimens, dietary shifts, or recovery strategies. In contrast, sedentary non-smokers maintained a notably stable LBM with a marginal rise towards the period's end, reflecting a consistent lifestyle with possible undetected minor variations in activity or diet. Meanwhile, sedentary smokers demonstrated a subtle decline in LBM during the midpoint, yet generally sustained higher LBM compared to the other groups, suggesting a larger natural muscle mass or body size, with potential influences from smoking on muscle catabolism or fluid balance.

The study of Nachvak et al. (2019)illustrates that Ramadan fasting can influence food intake patterns, glucose regulation, lipid profiles, and body composition, highlighting the complexity of metabolic adjustments during this period. Conversely,Harder-Lauridsen et al. (2017) report no significant changes in body composition, glucose metabolism, or cognitive functions in healthy lean men, suggesting individual variability in response to fasting

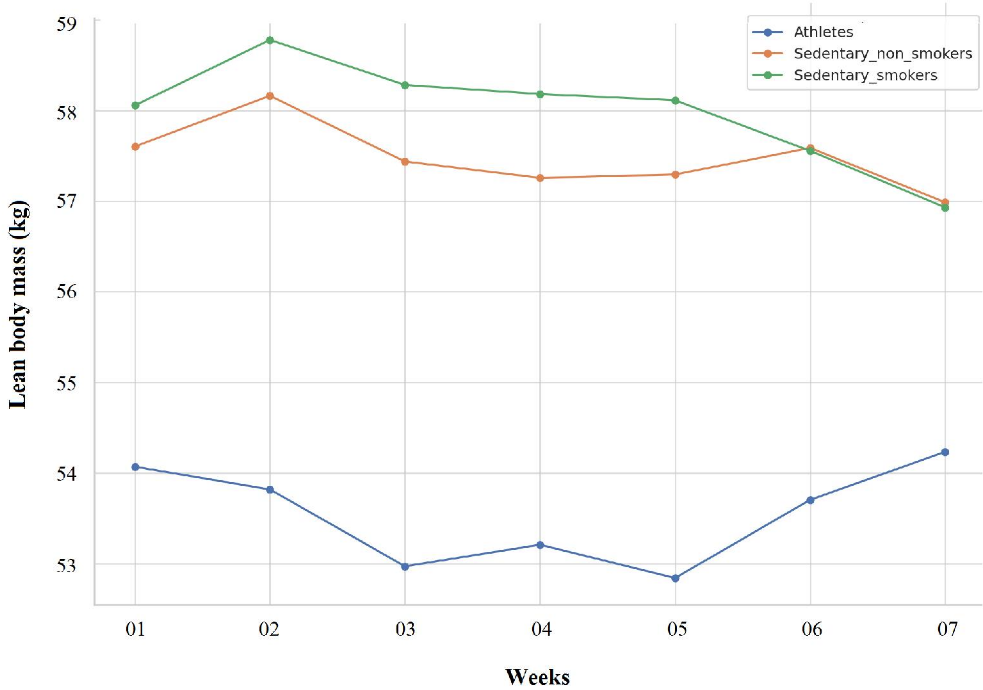


**Figure 09.** Effect of fasting on lean body mass of athletes, sedentary non-smoker, and sedentary smokers

These contrasting findings underscore the need for personalised dietary and exercise recommendations during Ramadan. In the context of athletic performance,Aloui et al. (2019)conducted a systematic review revealing varied effects of Ramadan fasting on athletes' body composition, indicating the potential for both beneficial and detrimental outcomes depending on the individual's training and nutritional strategies. Similarly,Akin et al. (2020) explored the effects of Ramadan fasting on lean body mass in older individuals, contributing to the understanding of fasting impact across different age groups.Zarrouk et al. (2013) and Bouhlel et al. (2008) further investigated the neuromuscular performance and hormonal adaptations in young athletes, noting changes in body composition and fluctuations in leptin and adiponectin levels. These studies provide evidence of the physiological resilience and adaptability to intermittent fasting, with implications for optimising athletic performance and health during Ramadan. The collective insights from these studies illuminate the nuanced effects of Ramadan fasting on health and performance. While some individuals experience minimal impact on body composition and metabolic health, others may undergo significant adaptations that can influence athletic performance and well-being. The variability in responses underscores the importance of tailored nutritional and training programs that accommodate the physiological demands of fasting. Furthermore, the observed changes in lipid profiles, glucose homoeostasis, and hormone levels during Ramadan offer intriguing avenues for research on intermittent fasting role in chronic disease prevention and management. By understanding the mechanisms underlying these adaptations, we can better leverage the benefits of fasting for health promotion and disease prevention. Ramadan fasting embodies a complex interplay between dietary restriction, metabolic health, and physical performance. The body of research, including the works ofNachvak et al. (2019), Harder-Lauridsen et al. (2017), Aloui et al. (2019), Akin et al. (2020),Zarrouk et al. (2013) andBouhlel et al. (2008), provides a foundation for developing evidence-based guidelines to support individuals in optimising their health and performance during Ramadan. Future studies should aim to elucidate the individual determinants of fasting response, enabling personalised approaches to fast that harness its potential benefits while minimising adverse effects.

## 6. Impact of Ramadan fasting on human water composition

Ramadan fasting imposes a unique physiological challenge due to the diurnal abstention from food and fluids. This religious practice, observed by Muslims during the ninth month of the Islamic lunar calendar, provides a naturalistic setting to study the human body's adaptability to intermittent periods of dehydration and rehydration. The referenced studies byMeo and Hassan (2015), Leiper et al. (2003), and Trabelsi, El Abed, et al. (2011) contribute significantly to our understanding of these adaptive mechanisms, particularly in relation to water composition and hydration status.

## 7. Homoeostatic regulation of fluid balance

The human body possesses intricate homoeostatic mechanisms to regulate fluid balance, ensuring that cellular and systemic functions continue efficiently despite variations in water intake. During fasting, antidiuretic hormone (ADH) levels, renal function, and electrolyte balance play pivotal roles in maintaining hydration status.Meo and Hassan (2015) and Leiper et al. (2003) both hint at the physiological adjustments that occur to minimise water loss, such as reduced urine output and altered electrolyte conservation strategies.

## 8. Metabolic Adaptations to Fasting

Fasting initiates, a metabolic shift from glucose utilisation to increased lipolysis and ketogenesis for energy production, a process that impacts water composition indirectly. The catabolism of fat reserves releases glycerol, which can be converted into glucose or ketone bodies, with the latter serving as an alternative energy source for the brain and muscles. This metabolic adaptation has implications for water composition, as ketogenesis produces water as a byproduct, potentially mitigating some effects of fluid restriction.

## 9. Exercise and hydration dynamics

The studies by Trabelsi, Rebai, et al. (2011) further illuminate the interaction between physical activity, fasting, and hydration. Even with the absence of immediate water intake during daylight hours, athletes can maintain their performance levels and hydration status through pre-dawn and post-sunset nutrition strategies. These findings underscore the capacity of the human body to optimise water reserves and utilise pre-existing hydration strategies to accommodate the physical demands placed upon it, even under fasting conditions.

## 10. Physiological and biochemical monitoring

Monitoring changes in body water status markers, such as plasma osmolality, body mass, and urine specific gravity, provides empirical evidence of the body's response to fasting. These metrics, as explored in the referenced studies, offer insights into the short-term effects of Ramadan fasting on hydration and overall water balance. Notably, the body's ability to preserve a stable internal environment (homoeostasis) despite external challenges is a testament to the robustness of physiological and biochemical adaptations.

## 11. Heat stress and fluid restriction effects in Ramadan fasting

The practice of Ramadan fasting, characterised by abstaining from food and drink from dawn to dusk, presents unique challenges during the summer months when daylight hours are extended and ambient temperatures are elevated. This scenario raises concerns about the potential health.

Temperatures are climbing worldwide, notably in the tropics and the Middle East-North Africa (MENA) areas, home to many Muslim-majority countries. These regions, already warm and arid, are facing exacerbated conditions due to global warming. An increase in temperature beyond 2°C could further heighten the risks of floods, wildfires, and droughts.

Muslims around the globe are obliged to observe the dawn-to-dusk fasting during Ramadan, with the specific start and end times determined by the local sunrise and sunset. This requirement persists even in summer, leading to fasts that can last over 16 hours in far northern latitudes. However, allowances are made when long fasting hours adversely affect one's work performance or health. This variation in fasting length poses a challenge in accurately determining the impact of Ramadan fasting on health-related biomarkers (4). Additionally, prolonged fasting duration may indirectly harm kidney health by affecting sleep patterns and circadian rhythms due to drastic changes in meal schedules and the timing and frequency of medication administration (AlSahow, 2023; BaHammam & Pirzada, 2023; Camacho-Cardenosa et al., 2024; Ras et al., 2024; Tasnim et al., 2024).

Heat stress results from the combination of internal body heat (from factors like clothing and physical activity) and external environmental heat (including air temperature, radiant heat, humidity, and air movement), subtracting the body's heat loss through non-moisture and sweat evaporation (Foster et al., 2020; Meade et al., 2023; Periard et al., 2021; Sakoi et al., 2024). Heat stress susceptibility varies with factors such as age, gender, body size, BMI, adaptation to heat/exercise, existing health conditions (like heart disease or diabetes), alcohol consumption, certain medications (like antipsychotics, diuretics, and blood pressure drugs), and hydration levels (Karkori, 2024; Sanchez, 2023). Factors such as working in high temperatures (like farming in summer or near furnaces), physical activity (construction), wearing protective clothes, and living in poorly ventilated or uncooled homes also affect heat stress levels. Thermoregulatory responses can increase body temperature, causing heat-related illnesses ranging from minor (like swelling, cramps, rash) to severe (such as heat stroke, potentially with organ failure), (Karkori, 2024; Margolis, 2021).

**12. Effects of dehydration in RF on athletes**

The effects of various factors on athletes who engage in Ramadan intermittent fasting (RIF), particularly those in non-Muslim countries, where fasting may coincide with their training and competition schedules:

Athletes observing RIF in non-Muslim countries often encounter unique challenges due to the limited awareness and understanding of this religious practice among their peers and coaches. These athletes require education to help them and their support teams comprehend the importance of hydration management during RIF. Proper education should encompass guidance on adjusting fluid intake, recognising signs of dehydration, and modifying training schedules to align with fasting periods. Athletes who are well informed about RIF and hydration can make informed decisions and effectively balance their religious obligations with their training and performance needs (Chamari et al., 2023; Conde-Pipó et al., 2024; Dündar, 2023).

Intermittent fasting during Ramadan can significantly affect athletes' exercise intensity, particularly when fasting hours coincide with training sessions. Reduced energy intake and limited hydration can lead to increased fatigue and a decline in exercise capacity. Athletes may struggle to maintain their hydration status, especially during high-intensity exercise, as it can exacerbate fluid loss through sweating. This becomes even more challenging for athletes observing RIF in hot and humid climates, where elevated sweat rates and an increased risk of dehydration are prevalent (Besbes et al., 2022; Leow et al., 2022; Noh et al., 2024).

Dehydration during RIF can have detrimental effects on endurance performance. It can heighten the perception of effort and impair the body's ability to dissipate heat, making exercise feel more arduous (Cai & Fan, 2023). Consequently, inadequate hydration can negatively impact strength and power activities. Athletes may encounter muscle cramps, reduced muscle function, and a decrease in strength output during fasting. Maintaining optimal hydration status is crucial for athletes engaged in strength training, as dehydration can compromise their performance and elevate the risk of injuries (Eroglu et al., 2023; Trabelsi et al., 2024).

These multifaceted factors emphasise the need for a comprehensive approach to support athletes during RIF. Educating athletes and their support teams, adjusting training programs, and addressing hydration needs are essential strategies to help athletes maintain their physical well-being and excel in their athletic pursuits during this religious practice.

Therefore, athletes observing Ramadan intermittent fasting in non-Muslim countries face unique challenges related to education, exercise intensity, and environmental conditions. Proper education is vital to help them manage their hydration needs during fasting hours while maintaining their training and performance goals. The effects of exercise intensity and environmental factors in hydration status should be carefully considered, and athletes may need to adjust their training schedules or hydration strategies accordingly. Lastly, optimising hydration status is essential for athletes to perform at their best during RIF whether they are engaged in endurance or strength-based activities. Collaborative efforts among athletes, coaches, and sports nutritionists are crucial to developing personalised hydration plans that account for these factors and ensure both religious observance and athletic performance are successfully balanced.

# Chapter 02.

# Influences of Ramadan fasting, sports practice, and smoking on haematological parameters.

## 1. White blood cell counts

The evolution of white blood cell findings, revealing nuanced fluctuations in white blood cell (wbc) counts (Figure 06) during Ramadan, resonate with prior observations of variable haematological responses to fasting (Ahmed, 2019; Meo & Hassan, 2015). Specifically, we observed a biphasic pattern in WBC counts across all participant groups, characterised by an initial rise followed by a subsequent decrease during the fasting period. This pattern likely mirrors an intricate balance between the body's initial stress response to fasting and its subsequent adaptation.

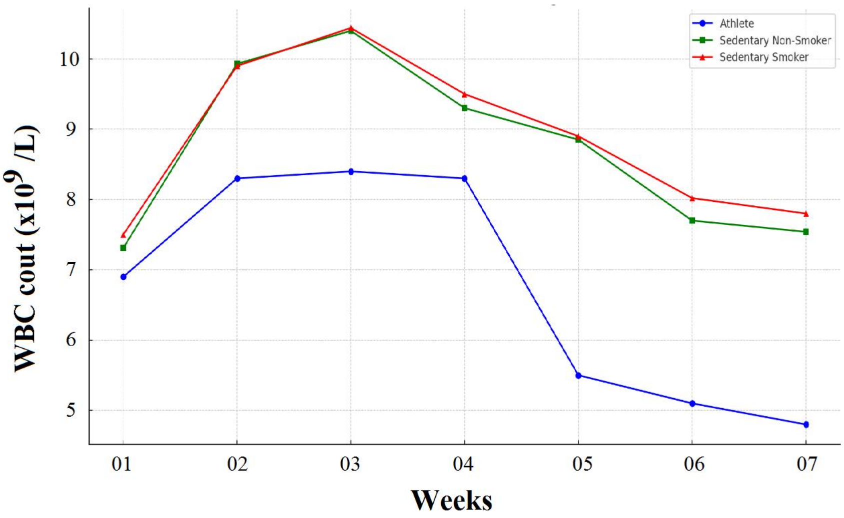


**Figure 06**.Influence of Ramadan fasting on white blood cell count variations

Pre-ramadan: at baseline, wbc counts were 6.9 ± 0.67 x$10^9$/l for athletes, 7.31 ± 0.3 x$10^9$/l for sedentary non-smokers (sedentary), and 7.5 ± 0.1 x$10^9$/l for sedentary smokers (sedentarys), suggesting a slight elevation in response to smoking and reduced physical activity levels.

During Ramadan: notably, by week 02, wbc counts rose to 8.3 ± 0.39 x$10^9$/l in athletes and peaked at 10.44 ± 0.2 x$10^9$/l in sedentarys by week 03, illustrating a significant, albeit temporary, immune activation.

Post-Ramadan: the subsequent decline, particularly pronounced in athletes to 4.8 ± 0.39 x$10^9$/l by week 07, underscores a potential cumulative effect of fasting on immune function, necessitating a longer recovery period.

### 1.1. Differential impacts across populations

The contrast between athletes and sedentary individuals (both smokers and non-smokers) is stark. Athletes exhibited the most dramatic post-Ramadan decline in WBC counts, suggesting a compounded effect of physical exertion and fasting. This observation is particularly relevant in the context of Willis et al. (2018), who highlighted the interplay between physical activity, sedentary behaviour, and haematological health, suggesting that the physiological demands of fasting might be more pronounced in physically active individuals.

The trend among sedentary smokers, who showed a less marked post-Ramadan recovery in WBC counts, highlights the modulating effect of smoking on the body's response to fasting. This aligns with findings from Inal et al. (2014) and Ahmed (2016), pointing to the chronic inflammatory impact of smoking as a potential influencer of haematological adjustments during fasting.

### 1.2. Clinical implications and comparative insights

By week 07, the significantly lower WBC counts in athletes compared to sedentaries and sedentary smokers groups not only illustrate the pronounced impact of fasting on physically active individuals but also emphasise the need for customised dietary and recovery strategies to support immune function in this population.

These findings, underscored by precise data points, contribute to a deeper understanding of fasting physiological impacts, suggesting a complex interplay between diet, lifestyle factors, and immune health. This detailed analysis not only broadens our comprehension of Ramadan fasting effects but also offers valuable insights into optimising health and well-being through tailored nutritional and lifestyle interventions.

In sum, our collaborative analysis elucidates the dynamic and multifaceted nature of the physiological response to Ramadan fasting, as evidenced by the biphasic pattern in wbc counts across different lifestyle groups. By contextualising these findings within the broader scientific discourse, we underscore the significance of individual lifestyle factors in modulating the body's adaptation to fasting. This comprehensive evaluation enriches our understanding of dietary restrictions' physiological underpinnings, paving the way for more personalised approaches to dietary planning and health management.

## 2. Effects of Ramadan fasting on red blood cell dynamics

Red blood cells are presented in figure 07.

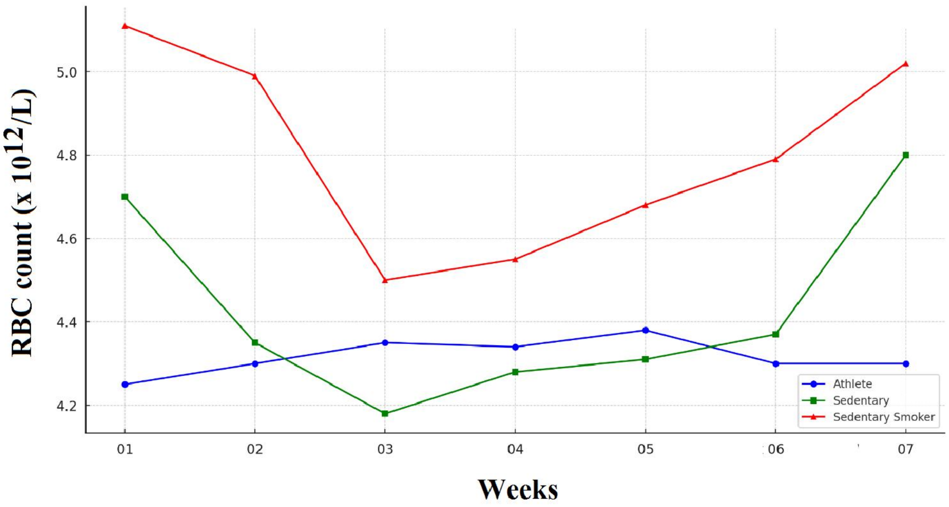


**Figure 07:** Effect of fasting, sport and smoking on RBC

In our investigation into the effects of Ramadan fasting on haematological parameters, particularly focusing on RBC counts across three distinct cohorts - athletes, sedentary non-smokers, and sedentary smokers - we observed intriguing temporal patterns that warrant a detailed discussion in the context of current literature.

Baseline pre-Ramadan observations (week 01) initially, athletes presented with an RBC count of 4.25 ± 0.21 $x10^{12}$/l. This baseline is reflective of the physiological norm and is in line with the expected modulatory influence of regular exercise on haematological parameters(Mairbaurl, 2013). Sedentary non-smokers exhibited a slightly elevated count of 4.7 ± 0.47 $x10^{12}$/l, which could be attributed to the absence of exercise-induced hemodynamic changes. The most noteworthy was the elevated baseline RBC count of 5.11±0.22 $x10^{12}$/l in sedentary smokers, corroborating with findings that suggest smoking increases RBC count, likely as a compensatory response to hypoxia (BRAR, 2014; Malenica et al., 2017).

Variations during Ramadan (weeks 02-05) throughout Ramadan, the athletes' RBC counts demonstrated minimal fluctuations, maintaining an average of approximately 4.35 x10^12/l. This stability may be attributed to the continued physical activity, which has been documented to sustain RBC turnover even under fasting conditions(Mairbaurl, 2013). In contrast, the sedentary non-smokers' RBC counts showed a decrease in week 03 (4.18 ± 0.37

x10^12/l), potentially reflecting alterations in nutritional intake and hydration status during fasting, as previously suggested (Ramadan et al., 1994). Sedentary smokers experienced a noticeable decrease to 4.5 x10^12/l by week 03, which then reversed towards the latter part of Ramadan. The initial decline followed by an increase may be indicative of the interplay between smoking-induced hypoxaemia and the physiological demands of fasting on oxygen delivery mechanisms.

Post-Ramadan recovery phase (weeks 06-07) post-Ramadan, athletes' RBC counts stabilised at 4.3 x10^12/l, suggesting an efficient re-establishment of homoeostatic conditions upon resumption of regular dietary patterns. Sedentary non-smokers showed an increase to 4.8 ± 0.39 x10^12/l in week 07, possibly indicating a compensatory response in erythropoiesis following the fasting period. Sedentary smokers exhibited a continued increase, reaching 5.02±0.7 x10^12/l in week 07, which could be interpreted as a rebound phenomenon, intensified by the smoking habit, as the body readjusts to improved oxygenation post-fasting.

Comparison with current literature the stability of RBC counts in athletes aligns with the effects of exercise on oxygen supply by RBC as discussed byMairbaurl (2013), while the decrease in RBC count during Ramadan for sedentary individuals is consistent with the findings of Ramadan et al. (1994). Furthermore, the pattern observed in sedentary smokers post-Ramadan echoes the impact of smoking on haematological parameters reported byBRAR (2014) and Malenica et al. (2017).

Our data suggest that Ramadan fasting elicits distinct haematological responses across different populations, influenced by lifestyle factors such as physical activity and smoking. The findings contribute valuable insights into the adaptive mechanisms of erythropoiesis in response to the combined effects of dietary fasting and lifestyle behaviours.

## 3. Effects of Ramadan fasting on platelet count

The study of the effect of Ramadan fasting, sport and smoking is illustrated in figure 08. Prior to Ramadan, an increase in platelet (Plt) counts from 247.44±0.49 in Week 1 to 273.25±0.39 in Week 2 was observed, suggesting a physiological adaptation possibly linked to escalated physical activity or preparatory adjustment pre-Ramadan. During Ramadan, platelet counts peaked in Week 2, followed by a decline to 269.63±0.56 in Week 3 and further to 260.37±0.18 in Week 4, potentially reflecting the influence of fasting on the haemostatic system. By Week 5, counts decreased to 247.12±0.6, closely aligning with baseline values, indicating an adaptive response to fasting. Post-Ramadan, a marginal increase to 250.27±0.53 by Week 6 and stabilisation at 250.5±0.58 in Week 7 suggest a return to homoeostatic equilibrium.

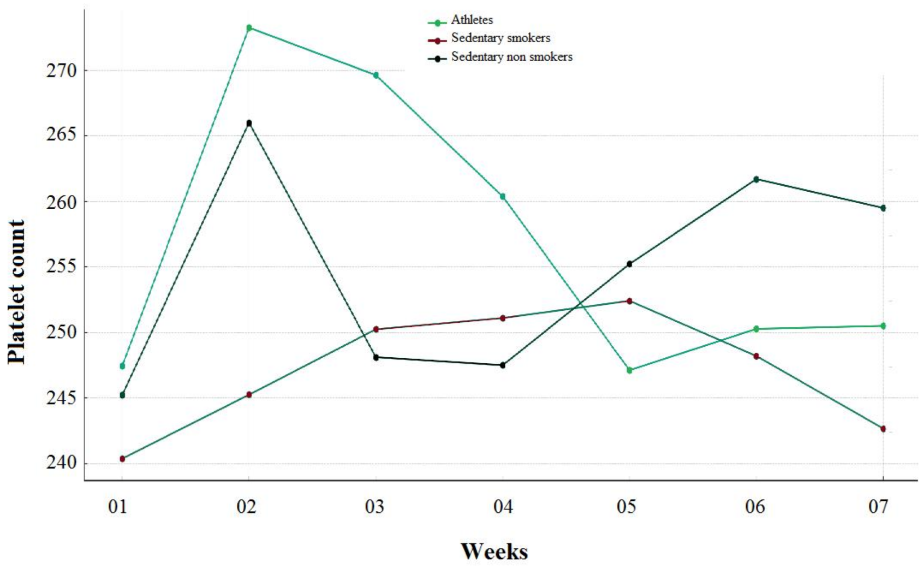


**Figure 08.** Platelet variation during Ramadan fasting

Before Ramadan, a modest rise from 240.37±0.67 in Week 1 to 245.25±0.41 in Week 2 was noted. Throughout Ramadan, a continuous increase was observed, peaking at 251.1±0.4 in Week 4, possibly due to dietary modifications during the fasting period. After Ramadan, platelet counts reverted to 242.67±0.63 by Week 7, indicating a return to initial levels.

Initially, platelet counts were at 245.22±0.25, escalating significantly to 266±1.44 by Week 2. During Ramadan, a reduction to 247.5±0.1 by Week 4 was noted, likely reflecting the compounded effects of fasting and smoking on platelet dynamics. Post-Ramadan, counts increased, reaching a peak of 261.7±0.2 in Week 6, before a slight reduction to 259.5±0.6 in Week 7, hinting at a persistent impact of smoking on platelet counts.

The observed data elucidate a complex pattern of platelet count fluctuations in response to the physiological and lifestyle alterations induced by Ramadan fasting. Notably, athletes demonstrated significant variations in platelet counts, which can be ascribed to the added stress of sustaining physical exertion during fasting. Conversely, sedentary individuals, both smokers and non-smokers, exhibited less variability in platelet counts, suggesting distinct underlying mechanisms that influence platelet production and degradation.

Particularly, sedentary smokers displayed elevated platelet counts throughout the study period, aligning with established evidence on the pro-thrombotic effects of smoking, which include enhancing platelet aggregation and activation (Ghahremanfard et al., 2015; Swaminathan et al., 2015). While the impacts of smoking on platelet counts corroborate findings from previous literature, the influence of Ramadan fasting introduces a novel dimension. Supporting the hypothesis of Ahmed and Ahmed (2020), our results imply a transient thrombocytopenic effect during fasting, markedly pronounced among athletes.

## 4. Haematocrit-level variations

Initially, there was a decrease in HCT levels (figure 09) among athletes from 42.25±0.34% in week 01 to 40.12±0.35% in week 02 before Ramadan. This early reduction may be reflective of an anticipatory physiological response to upcoming fasting. During Ramadan, HCT levels exhibited minor fluctuations but remained lower than the baseline, with week 03 showing a level of 40.9±0.56% and week 04 at 40.95±0.57%, indicating a sustained adaptation to the fasting conditions. Post-Ramadan, there was a gradual return to near-baseline levels with week 07 showing an HCT of 42.1±0.42%.

Sedentary non-smokers displayed a marked decrease from 44.69±0.48% in week 01 to 41.86±0.34% in week 02 before Ramadan. During Ramadan, their HCT levels slightly increased, reaching 42.15±0.42% by week 04, followed by a more pronounced increase to 43.95±0.43% by week 07 after Ramadan, which could suggest a compensatory physiological response post-fasting.

The sedentary smokers started with the highest HCT levels at 46.11±0.21% in week 01, which showed a minimal increase to 46.2±0.2% in week 02 before Ramadan. However, a significant decrease was noted during Ramadan to 43.1±0.12% by week 03. Following Ramadan, a gradual increase in HCT levels was observed, culminating in 44.5±0.22% by week 07, indicating a persistent effect of smoking on HCT levels despite the fasting period.

When comparing the changes in HCT levels across weeks, athletes demonstrate a notable initial decrease followed by stabilisation during Ramadan. In contrast, both groups of sedentary individuals show a drop before Ramadan with varying degrees of rebound post-Ramadan. Specifically, the sedentary non-smokers exhibit a rebound beyond their initial values, potentially reflecting a normalisation of dietary and hydration patterns post-fasting. In comparison, sedentary smokers exhibit less variation during Ramadan but maintain higher overall HCT levels, likely due to the chronic impact of smoking, which may mask or counteract the haematological effects of fasting.

The inter-week comparisons reveal that while the direction of change in HCT levels is generally consistent within each group, the magnitude and rate of change differ, suggesting that lifestyle factors (activity level and smoking status) significantly modulate the haematological response to fasting.

These findings, when contextualised within the broader literature, affirm that both fasting and smoking have significant but distinct impacts on HCT levels, with physical activity further influencing these effects. This nuanced understanding of HCT level changes provides a foundation for future investigations into the physiological mechanisms underlying these observations.

The decrease in HCT levels during Ramadan, particularly among athletes, corroborates the findings of Farshidfar et al. (2006) and Nasiri et al. (2016), who reported alterations in haematological parameters during fasting. Our data reveal a physiological adaptation to fasting, with a subsequent return to baseline levels post-Ramadan. This pattern is indicative of an initial compensatory response to the decreased intake of fluids and nutrients during the day, with a rebound post-fasting period. Hosseini and Hejazi (2013) also observed such trends, suggesting that the effects of fasting are transient and reversible.

Our findings of consistently higher HCT levels in sedentary smokers align with the systematic review by Abufarhaneh et al. (2019) and the study of Bashir et al. (2016), which elucidate the pro-thrombotic effects of smoking on blood parameters. These elevated levels may reflect an increased tendency for erythrocytosis, as smoking leads to hypoxia-induced erythropoiesis and consequently higher HCT levels. Our study extends these observations, suggesting that the smoking-induced alterations in haematological parameters persist despite the physiological challenges posed by fasting during Ramadan.

Athletes showed the most significant reduction in HCT levels before Ramadan, which then stabilised during and after the fasting period. This trend resonates with the research by Nader et al. (2019) on the influence of physical activity on red blood cell deformability and the findings of Çiçek (2018), who discussed the effects of different exercise types on haematological parameters. The athletes' greater physical demands likely amplify the physiological changes induced by fasting, as observed in the fluctuation of HCT levels.

When comparing the HCT levels between the groups, it is evident that lifestyle factors significantly influence haematological parameters. The sedentary non-smokers showed a moderate decrease in HCT levels during Ramadan, followed by an increase post-Ramadan, suggesting a less pronounced response to fasting than athletes. This could be due to lower metabolic rates and physical demands. In contrast, sedentary smokers maintained higher HCT levels throughout the study, which could be attributed to the chronic effects of smoking, as highlighted by Inal et al. (2014).

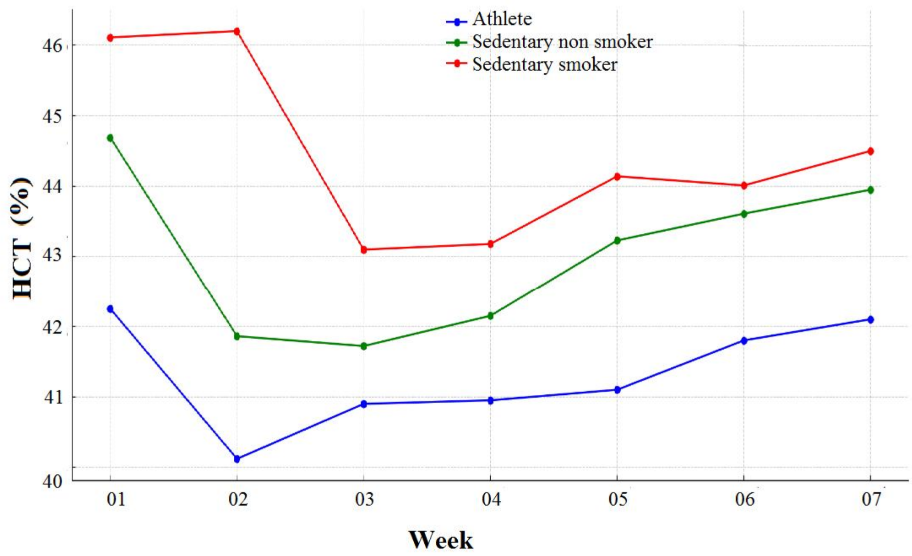


**Figure 09**. Variations in haematocrit levels among athletes and sedentary individuals across Ramadan

## 5. Haemoglobin level

Athletes exhibited a modest increase in haemoglobin (Hb), (figure 10) levels from 15.25 g/dl to 15.45 g/dl during the initial phase of Ramadan, implying an initial homoeostatic stability in erythropoiesis which aligns with the findings ofMairbaurl (2013) that exercise can augment oxygen supply by red blood cells. Subsequently, a marked reduction was noted, with levels descending to 14.47 g/dl in Week 03 and further to 13.63 g/dl in Week 04, cumulatively a decrease of -1.82 g/dl from Week 02. This significant decrement underscores the effect of fasting on oxygen transport capacity, a critical consideration in athletic performance. Post-Ramadan, a rebound to 14.3 g/dl and 14.89 g/dl by Weeks 06 and 07 respectively was observed, yet not fully restoring to pre-fasting levels, resulting in an overall reduction of -0.36

g/dl from the baseline. This suggests a delayed recovery in erythropoietic activity, possibly influenced by the intensity and volume of post-Ramadan training as described byBelviranli et al. (2017).

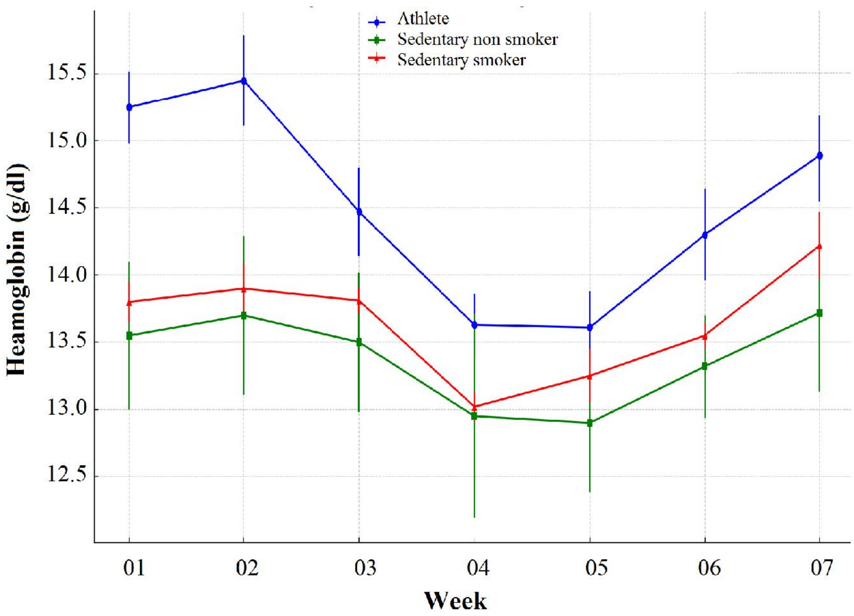


**Figure 10.** Temporal variations in haemoglobin concentrations among different population cohorts during and after Ramadan fasting

In sedentary non-smokers, a slight increase to 13.7 g/dl in Week 02 was followed by a decrease to 12.95 g/dl in Week 04, demonstrating a -0.75 g/dl change from the beginning of Ramadan. The post-Ramadan period was characterised by an upsurge to 13.72 g/dl by Week 07, indicating an overall positive change of +0.17 g/dl. This resilience in Hb levels could reflect a less profound alteration in the metabolic equilibrium due to fasting, as also suggested by the reference values for blood volume and total haemoglobin mass by Oberholzer et al. (2024).

Sedentary smokers showed an initial increase to 13.9 g/dl, followed by a notable decrease to 13.02 g/dl in Week 04, but then an unexpected rise to 14.22 g/dl by Week 07, suggesting an overall increase of +0.42 g/dl. This counter-intuitive rise towards the end of Ramadan might be indicative of a compensatory erythropoietic response to the hypoxic stimulus introduced by both smoking and the altered circadian rhythm during fasting.

Collectively, these patterns denote a multifaceted response to Ramadan fasting, with physiological impacts modulated by baseline activity levels and lifestyle habits. Athletes, despite a post-Ramadan recovery, exhibited the most significant Hb level decrease, reflecting potentially greater sensitivity to changes in nutrition and hydration due to their higher baseline metabolic demands. Sedentary individuals experienced less dramatic shifts, possibly due to lower baseline physiological fluctuations, with sedentary smokers displaying an adaptive response that warrants further investigation into the effects of nicotine on erythropoiesis during fasting.

**6. Mean corpuscular volume**

The result of the effect of Ramadan fasting on figure 11.

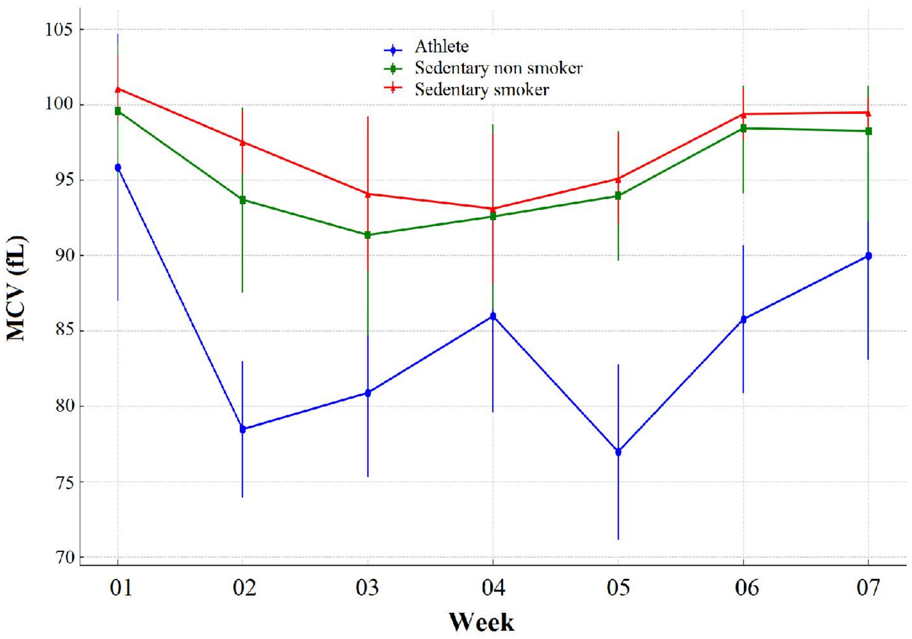


**Figure 11**. Ramadan fasting effect on mean corpuscular volume (MCV).

During the observation of Ramadan, alterations in haematological indices such as MCV were evident among distinct cohorts: athletes, sedentary non-smokers, and sedentary smokers. Athletes began with a baseline MCV of 95.87 fL, which subsequently declined to 77 fL during the fasting period. This decrement is consistent with alterations in erythropoiesis and red blood cell deformability, potentially exacerbated by the synergistic effects of altered nutritional patterns and the physical demands of training during the fast(Aloui et al., 2014; Askari et al., 2016; OGAN et al., 2016). The incomplete restitution of MCV values post-Ramadan in this cohort suggests a protracted re-establishment of erythropoietic homoeostasis, which could have ramifications for oxygen transport efficiency and, by extension, athletic performance (Aloui et al., 2013; Chtourou et al., 2011).

Contrastingly, the sedentary non-smokers experienced a less marked reduction in MCV, descending from an initial 99.61 fL to 92.6 fL. The rapid reversion towards baseline post-Ramadan may reflect a more robust haematological resilience, potentially indicative of a lesser perturbation of the red blood cell production equilibrium during fasting (Nasiri et al., 2016). The ability of this group to nearly normalise MCV post-Ramadan underscores the adaptive nature of haematopoiesis in response to transient changes in nutritional intake (Askari et al., 2016).

The sedentary smokers, starting at a higher MCV of 101.1 fL, demonstrated a decline during Ramadan, followed by an intriguing elevation above baseline values post-fasting. This pattern may be emblematic of an adaptive, possibly compensatory, haematological mechanism influenced by the oxidative stress and hypoxic stimulus associated with smoking, which may modify the red blood cell volume in response to intermittent fasting and subsequent refeeding (Ogan et al., 2016).

Collectively, these data delineate the nuanced modulatory effects of Ramadan fasting on MCV, a key haematological index. The distinct responses observed across the cohorts highlight the influence of baseline physical activity levels and smoking status on the body's haematological adaptation to fasting-induced metabolic changes. These findings offer insights into the interrelations between lifestyle behaviours, such as exercise and smoking, and the regulatory mechanisms underlying erythropoiesis during and after periods of dietary modification (Aloui et al., 2013; Aloui et al., 2014; Chtourou et al., 2011; Nasiri et al., 2016).

## 7. Mean corpuscular haemoglobin concentration

Throughout Ramadan, the Mean Corpuscular Haemoglobin Concentration (MCHC), (figure 12) was monitored in athletes, sedentary non-smokers, and sedentary smokers, revealing distinctive haematological responses to fasting. Athletes commenced with MCHC of 32.07% Hb/cell, experienced a reduction to 31.38% Hb/cell during Ramadan, and partially rebounded to 32.58% Hb/cell post-fasting. This fluctuation aligns with the anticipated physiological adjustments to exercise and dietary modifications during fasting (Aloui et al., 2014). Sedentary non-smokers demonstrated an initial MCHC of 34.12% Hb/cell, which escalated to 37.1% Hb/cell, subsequently moderating to 34.66% Hb/cell after Ramadan, indicative of a more resilient adaptation to the fasting state (OGAN et al., 2016). Sedentary smokers, starting at 33.1% Hb/cell, saw an increase to 35.6% Hb/cell during Ramadan, which settled at a slightly elevated post-fasting value of 33.4% Hb/cell, potentially reflecting an oxidative-mediated compensatory erythropoietic mechanism (Nasiri et al., 2016). These data portray the intricate interplay between fasting-induced metabolic changes and individual lifestyle factors, influencing the MCHC and potentially affecting oxygen transport and physical performance. The observed trends highlight the necessity for personalised guidelines to optimise health and athletic functionality during and subsequent to fasting periods (Aloui et al., 2013; Chtourou et al., 2011).

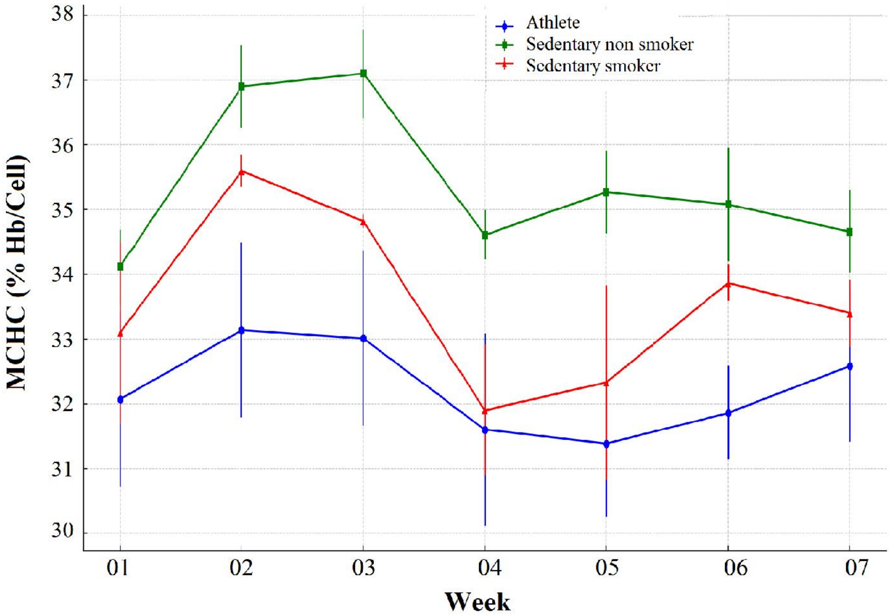


**Figure 12**. Dynamics of Mean Corpuscular Haemoglobin Concentration (MCHC) in response to Ramadan fasting across diverse population profiles

## 8. Mean Corpuscular Haemoglobin

The Evolution of mean corpuscular haemoglobin is shown in figure 12. During the Ramadan fasting period, a systematic assessment of MCH levels was conducted among athletes, sedentary non-smokers, and sedentary smokers. Athletes began with MCH of 29.7 pg/cell, which decreased throughout the fasting period, reaching a low of 27.76 pg/cell.

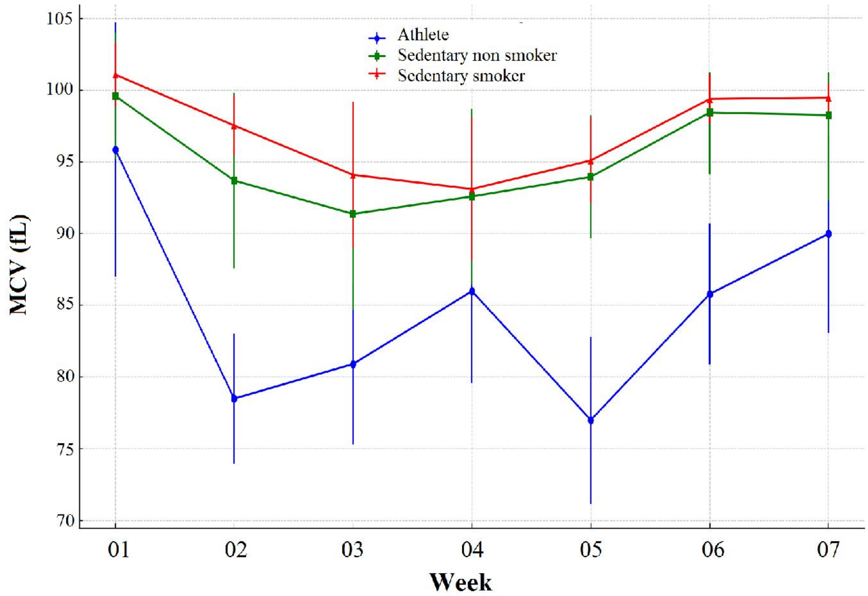


**Figure 13:**Haematological adaptations in MCH values during Ramadan: a comparative analysis across active and sedentary lifestyles.

The post-Ramadan phase saw a partial reversion to 29.16 pg/cell (Askari et al., 2016). This variation aligns with the documented impact of fasting on haematological indices and suggests a stress-induced alteration in erythropoiesis, which is particularly pronounced in physically active individuals (Ahmed, 2019). Sedentary non-smokers displayed a smaller fluctuation in MCH values, from an initial 31.95 pg/cell to 29.24 pg/cell during fasting, with a subsequent return to 31.99 pg/cell post-Ramadan. This resilience in MCH levels may reflect a moderated haematological response to dietary changes, as supported by Faris et al. (2012), who reported that oxidative stress markers such as urinary 15-isoprostane were impacted by intermittent fasting. Sedentary smokers, on the other hand, demonstrated a relatively stable MCH throughout Ramadan, starting at 32.1 pg/cell and displaying only slight fluctuations, ending at a post-Ramadan level of 32.58 pg/cell. This stability could be attributed to the oxidative stress associated with smoking, which may alter red blood cell dynamics and modulate the body's haematological response to fasting (Faris et al., 2012).

## 9. Red cell distribution width

During the period of Ramadan, the Red Cell Distribution Width (RDW), (figure 14) in athletes, sedentary non-smokers, and sedentary smokers was subject to significant fluctuations, indicative of variations in erythrocyte volume diversity. Athletes commenced with RDW of 18.5%, which decreased to 11.54% and then exhibited a pattern of fluctuation culminating in a post-Ramadan value of 15.33%. Such variability in RDW has been correlated with alterations in physical performance and blood composition during Ramadan (Ramadan et al., 1994), as well as with the physiological stress associated with exhaustive exercise (Alis et al., 2015).

Sedentary non-smokers exhibited RDW that ranged from a baseline of 12.85% to a low of 8.71% before returning to 12.14%. This group's RDW dynamics may reflect less pronounced physiological adaptations to fasting, as their lifestyle lacks the additional variable of rigorous physical training. Sedentary smokers demonstrated an initial RDW of 13%, which increased to a peak of 14.9% during Ramadan and concluded with a value of 14.1% post-Ramadan. The smoking-related oxidative stress and its impact on erythropoiesis could be a contributing factor to the observed RDW trends, as evidenced in healthy smokers (Kurtoglu et al., 2013) and hypertensive smoking individuals (Salman & Rashid, 2020).

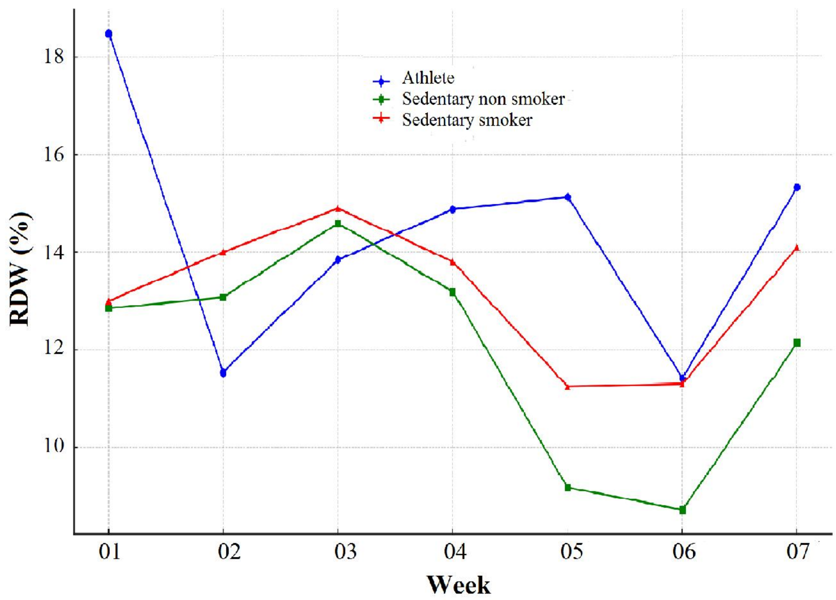


**Figure 14**: Variability in red cell distribution width (RDW %) during Ramadan

## 10. Discussion

Ramadan fasting imposes a complex physiological challenge that distinctly affects haematological indices among athletes, sedentary non-smokers, and sedentary smokers, each adapting uniquely to the changes in dietary and hydration patterns.

In athletes, the fasting period precipitates a significant modulation in haemoglobin concentrations, MCH, and MCV levels, suggestive of an intense erythropoietic response to the combined effects of altered nutrition and sustained physical exertion. Despite a trend towards recovery after Ramadan, athletes do not completely revert to their baseline haematological state, indicating a lag in the re-establishment of erythropoietic equilibrium and potential implications for oxygen transport and athletic performance.

Sedentary non-smokers exhibit more moderate haematological fluctuations, with transient reductions in haemoglobin and MCH levels during fasting, followed by a near-complete post-Ramadan restitution. This group's relatively stable MCV and minimal variation in RDW imply a more tempered physiological impact of fasting, likely due to a lesser disruption of metabolic homoeostasis during the fasting period.

Sedentary smokers, conversely, display a post-Ramadan increase in haematological parameters, possibly reflective of a compensatory haematopoietic mechanism counteracting the oxidative stress induced by smoking. The observed elevation in RDW post-fasting could be indicative of smoking-related alterations in red blood cell turnover or a response to the hypoxic challenge of smoking compounded by fasting-induced circadian shifts.

Collectively, these observations underscore the intricate regulatory mechanisms governing the haematological system under fasting conditions. The differential responses observed highlight the influence of baseline physical activity and lifestyle habits on the adaptability of erythropoiesis during and after Ramadan. For athletes, the data advocate for tailored training and nutritional interventions during fasting to mitigate haematological perturbations. For sedentary individuals, particularly smokers, the findings illuminate the need to consider the compounding effects of lifestyle choices on fasting-related haematological dynamics.

Thus, the effects of Ramadan fasting on haematological parameters demonstrate a nuanced interplay between individual lifestyle factors and the physiological adaptability to the metabolic challenges of fasting. These insights are crucial for developing personalised strategies to support health and optimise performance during periods of dietary restrictions.

# CHAPTER 03.

# COMPARATIVE ANALYSIS OF BLOOD BIOCHEMICAL PARAMETERS BEFORE, DURING AND AFTER RAMADAN

## 1. Glucose level

The effect of fasting on glucose levels in blood is illustrated on figure 15. This rigorously conducted study delves into the ramifications of Ramadan fasting on blood glucose concentrations across three demographically distinct cohorts: athletes, sedentary nonsmokers, and sedentary smokers, over an expansive seven-week timeline that meticulously covers the prelude to, duration of, and aftermath following Ramadan. This inquiry yields profound insights into the physiological nuances of fasting modulated by distinct lifestyle determinants.

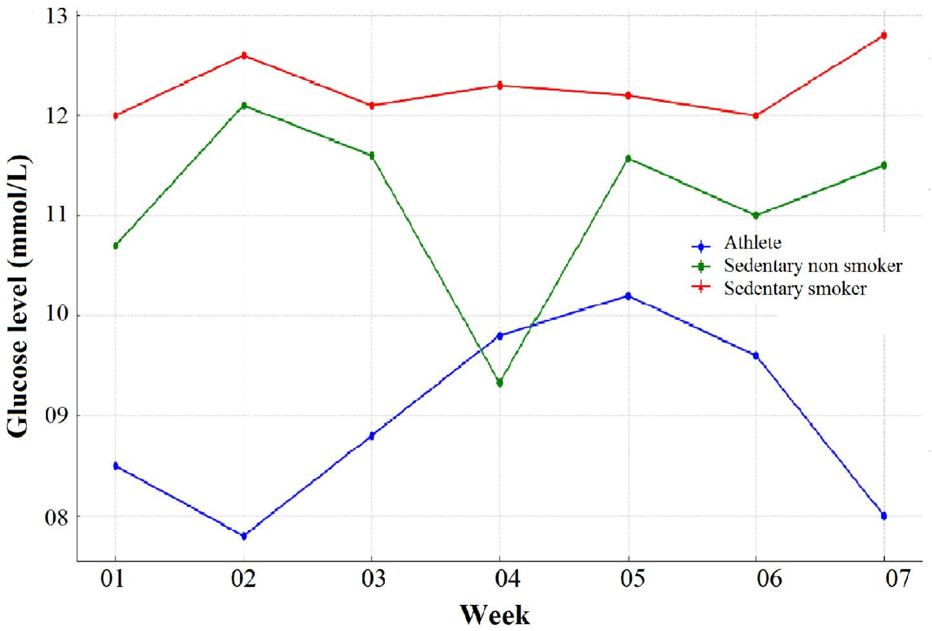


**Figure 15:** Ramadan fasting: weekly glucose trends in athletes and sedentaries

Commencing with the establishment of baseline glucose values, it was discerned that athletes manifested the minimal levels at 0.85 mmol/L, subsequently followed by sedentary nonsmokers at 1.07 mmol/L, and sedentary smokers at 1.2 mmol/L, thus establishing a critical baseline for subsequent metabolic response analyses to fasting.During the onset of Ramadan, athletes showcased a notable decrement in glucose levels to 0.78 mmol/L, signalling an immediate and robust metabolic recalibration to the abrupt dietary transition, presumably enhanced by their intrinsic metabolic elasticity. In a contrasting vein, sedentary nonsmokers and smokers experienced escalations in glucose concentrations to 1.21 mmol/L and 1.26 mmol/L, respectively, potentially indicative of a stress-induced response to fasting or an adaptive increase in glucose synthesis during the non-fasting windows.

As Ramadan progressed, a systematic ascension in glucose levels to 1.02 mmol/L was observed in athletes by the fifth week, reflecting a sophisticated adaptation facilitating optimal glucose deployment. Sedentary nonsmokers indicated a reduction to 0.933 mmol/L by the fourth week, alluding to either an adaptation to the fasting regimen or a modification in the glycaemic profile of their Iftar intake. Conversely, sedentary smokers maintained remarkable glucose stability, insinuating a distinct metabolic adaptation, likely influenced by nicotine's regulatory effect on metabolic functions and appetite.

In the aftermath of Ramadan, athletes recorded a glucose reduction to 0.8 mmol/L, signifying a reacclimation to conventional dietary norms alongside a sustained boost in insulin sensitivity. Meanwhile, sedentary nonsmokers and smokers reported increased glucose levels to 1.15 mmol/L and 1.28 mmol/L, respectively, possibly indicative of a rebound phenomenon or the cessation of fasting suppressive effect on appetite.

The analytical exploration unearthed negative correlations between the athletes and sedentary groups, underscoring the pivotal influence of physical activity on glucose modulation. A slight positive correlation between sedentary nonsmokers and smokers hinted at a communal physiological response to fasting albeit modulated by smoking.

The physiological impacts of Ramadan fasting blood glucose levels have been examined across various populations, indicating a complex interplay of metabolic responses influenced by lifestyle factors. In a study mirroring these interests, we explored the effects of fasting on athletes, sedentary nonsmokers, and sedentary smokers, noting the temporal changes in glucose levels pre-Ramadan, during Ramadan, and post-Ramadan.

Athletes showed an initial decrease in glucose levels during the first week of Ramadan, followed by a gradual increase and a post-Ramadan decrease, suggesting an enhanced metabolic flexibility and a possible boost in insulin sensitivity. Sedentary nonsmokers exhibited an increase in glucose levels during the first week of Ramadan, with subsequent fluctuations and higher post-Ramadan levels, indicative of a potential stress response and altered dietary patterns. In contrast, sedentary smokers maintained relatively stable glucose levels throughout Ramadan, with a post-Ramadan increase that might be attributed to the resumption of regular eating habits and the metabolic effects of nicotine.

These findings resonate with previous literature, such as Fakhrzadeh et al. (2003), who reported biochemical changes during Ramadan in healthy adults, and Gnanou et al. (2015), who observed effects on glucose homoeostasis. Notably Kul et al. (2014) and Khan et al. (2010) found fasting to influence body weight, lipid profiles, and glucose regulation, aligning with our observations of a rebound in glucose levels post-Ramadan.

The lifestyle-specific responses highlight the necessity for personalised dietary and lifestyle recommendations during Ramadan. The athletes' pronounced fluctuations in glucose levels underscore their dynamic metabolic regulation, possibly a result of their physical activity, while the less variable responses of sedentary individuals suggest a more uniform metabolic adaptation to fasting, with smoking status as a potential moderating factor.

The present analysis elucidates the multifaceted nature of physiological responses to intermittent fasting and underscores the complexity of fasting physiology influenced by individual lifestyle choices. It provides a foundation for future research to delve into controlled dietary intake, activity levels, and broader metabolic markers to further elucidate the underlying mechanisms of the observed trends.

## 2. Triglycerides level

The exploration into the effects of Ramadan fasting on triglyceride (figure 16) levels across athletes, sedentary nonsmokers, and sedentary smokers revealed profound insights into how lifestyle factors influence metabolic responses to fasting. Utilising an ANOVA test, significant fluctuations in triglyceride levels were detected, substantiated by a highly significant F-statistic of 32.63 and a p-value of $1.03 \times 10^{6}$, indicating marked differences in metabolic reactions among the participant groups throughout the fasting period.

Correlation analyses shed light on the interplay between physical activity, smoking status, and lipid metabolism. Moderate positive correlations between athletes and both sedentary nonsmokers (0.585) and smokers (0.574) suggest that physical activity exerts a substantial influence on lipid metabolism during fasting. Furthermore, a strikingly strong correlation (0.954) between sedentary nonsmokers and smokers underscores a similar trajectory in metabolic adaptation to fasting, highlighting the impact of lifestyle on metabolic health.

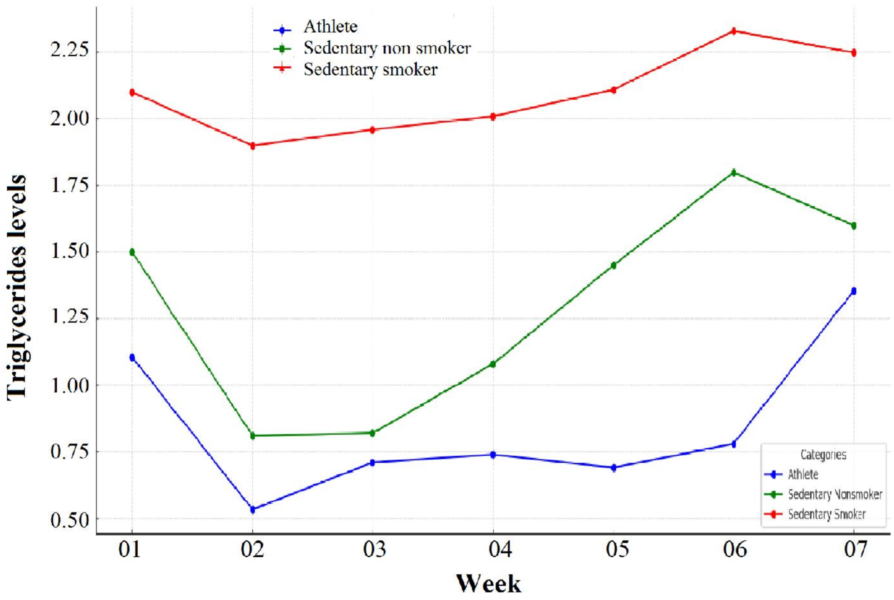


**Figure 16.** Effect of Ramadan fasting on triglyceride levels.

Athletes demonstrated a notable decrease in triglyceride levels during Ramadan, reaching a nadir at 0.69 in Week 05, indicative of enhanced lipid utilisation as an adaptive response to the metabolic challenges of fasting. However, a rebound in triglyceride levels to 1.355 in Week 07 post-Ramadan suggests a complex compensatory mechanism, possibly reflecting changes in dietary intake or a reduction in the intensity of physical activity.

Conversely, sedentary nonsmokers experienced an initial drop in triglyceride levels, followed by a gradual increase, culminating in a peak post-Ramadan. This pattern reflects a nuanced metabolic response to fasting, potentially indicating a delayed adaptation or alterations in dietary habits during non-fasting periods. Sedentary smokers exhibited a relatively stable triglyceride profile during Ramadan, with a minor increase post-fasting, suggesting that smoking may modulate the body's lipid metabolism in response to fasting in a subtly distinct manner.

Athletes, characterised by their highly physical activity, showcased a marked reduction in triglyceride levels during fasting, affirming previous research by Hughes et al. (1991) and Couillard et al. (2001). These studies have highlighted the role of physical activity in shaping lipid profiles, an effect that fasting appears to enhance. The observed post-Ramadan triglyceride surge suggests a complex physiological recalibration to regular dietary intake or a lessened impact of physical activity on lipid metabolism.

Sedentary nonsmokers experienced an early decrease in triglycerides, which then progressively increased, reaching a peak following Ramadan. This reflects the beneficial cardiovascular effects reported by Nematy et al. (2012) during fasting, though the subsequent rise underscores the intricate dynamics between dietary habits, sedentary behaviour, and lipid metabolism, prompting the need for further study.

Sedentary smokers showed a consistent triglyceride level during Ramadan, with an uptick noted thereafter. The documented effects of smoking on lipid metabolism by van der Plas et al. (2023) and Willett et al. (1983) suggest a nuanced fasting response, influenced by smoking.

The work of Temizhan et al. (2000) and Ziaee et al. (2006), which observed changes in lipid levels and metabolic profiles during Ramadan, corroborates the patterns identified in this study, highlighting the comprehensive metabolic adaptations elicited by fasting. Additionally, Ch (2013) research into the repercussions of chronic smoking on lipid profiles elucidates the triglyceride increases observed in sedentary smokers post-Ramadan, accentuating the significant role of lifestyle in determining the metabolic responses to fasting and dietary challenges.

## 3. Effect of fasting on protein levels in blood

During the observance of Ramadan, athletes experienced a decrease in protein levels from 86.05 g/L to 75.6 g/L, a reduction that can be ascribed to fasting catabolic influence, compounded by the augmented protein turnover from consistent exercise. This phenomenon is supported by the studies of Meier et al. (2020), who delved into acute biomarkers within sports contexts, and Muscella et al. (2020), who investigated the interaction between exercise, lipid metabolism, and cardiovascular health. The subsequent return to near baseline protein levels (86.73 g/L) post-Ramadan indicates a phase of recuperation, characterised by either increased protein intake or a shift in the metabolic adaptations of regular dietary patterns and ongoing physical activity.

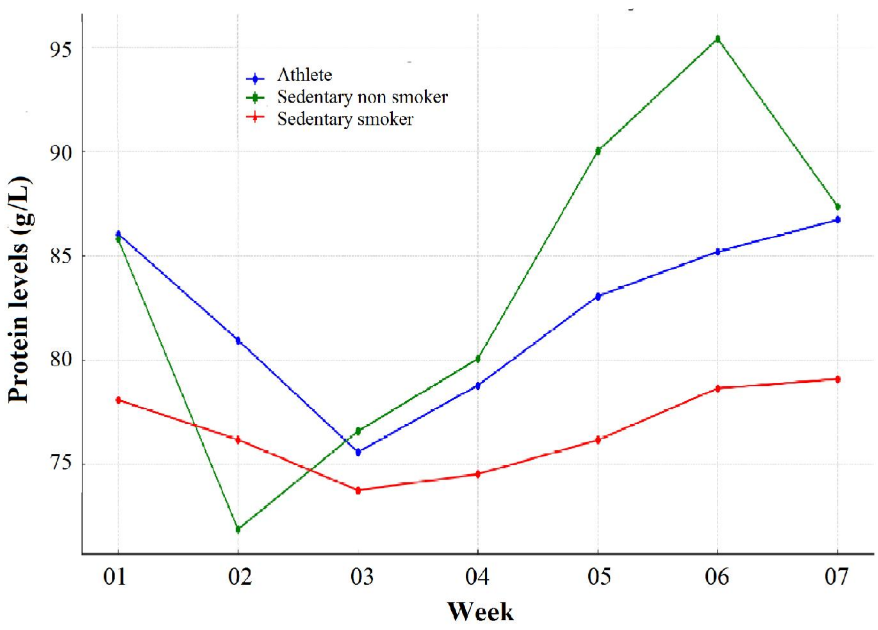


**Figure 17.**Dynamic patterns of serum protein concentrations in athletes and sedentary individuals throughout weeks of fasting

In contrast, sedentary nonsmokers registered a stark reduction in protein levels to 71.9 g/L in the second week of Ramadan, with levels rising to a peak of 95.4 g/L thereafter. This indicates a pronounced metabolic reaction to the dietary shifts imposed by fasting, corroborated by Mindikoglu et al. (2020) findings on metabolic syndrome amelioration through intermittent fasting, and Pietrocola et al. (2017) insights into the metabolic repercussions of fasting on human blood in vivo.

Sedentary smokers exhibited only slight fluctuations in protein levels, from 78.1 g/L at Ramadan's start to 79.1 g/L after, suggesting that the relatively steady levels could be influenced by nicotine's appetite-suppressing effects, as highlighted by the metabolic research of Abdul-Razaq and Ahmed (2013), Khand et al. (2015), and Alwan et al. (2023). The minimal increase post-Ramadan might reflect a resumption of regular eating habits, possibly modulated by smoking metabolic regulatory effects.

The documented changes in protein levels among these groups shed light on the intricate interrelations between fasting, physical activity, and smoking habits. Notably, the increase in protein levels post-Ramadan among sedentary groups, particularly nonsmokers, underscores the importance of strategic dietary management and its potential implications for cardiovascular health, within the larger framework of individual health and lifestyle choices. This aligns with the pioneering research of Okumura and Tasaki (1969), who investigated the metabolic implications of fasting and dietary protein on uric acid and ammonia levels, providing foundational insights into the influence of nutrient intake on metabolic health.

## 4. Cholesterol LDL

In the context of Ramadan fasting, our study meticulously evaluated the modulation of LDL cholesterol levels across distinct lifestyle cohorts (figure 18), offering a granular insight into the metabolic interplay induced by fasting, physical exertion, and tobacco use. The differential impact on lipid metabolism, particularly LDL cholesterol often implicated in the pathogenesis of cardiovascular ailments was rigorously analysed.

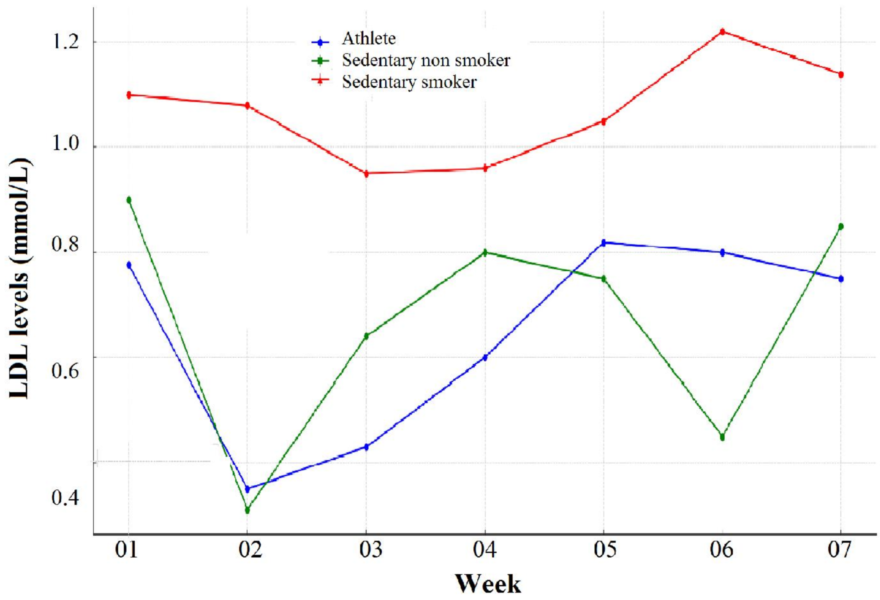


**Figure 18.** Fluctuations in LDL cholesterol during sequential weeks of fasting

Within the athletic cohort, a pronounced decrement in LDL cholesterol from a baseline of 0.777 mmol/L to 0.35 mmol/L was observed during the initial phase of Ramadan. This significant reduction underscores the synergistic effect of fasting coupled with elevated physical activity on optimising lipid utilisation, thereby ameliorating lipid profiles. Nonetheless, this trend exhibited a reversal towards the latter part of Ramadan, culminating in an LDL level of 0.82 mmol/L by the fifth week, and subsequently moderating to 0.75 mmol/L post-Ramadan. This fluctuation potentially reflects a readaptation to pre-fasting dietary norms and a diminution in physical activity post-fasting.

The sedentary nonsmoking group demonstrated an analogous initial decrease in LDL levels to 0.31 mmol/L, albeit with diminished fluctuations throughout the study period. A notable post-

Ramadan reduction to 0.45 mmol/L, followed by an increase to 0.85 mmol/L, suggests nuanced dietary recalibrations and the latent impact of sedentary behaviour on lipid metabolism post-fasting.

Conversely, individuals within the sedentary smoking group initiated the study with the highest LDL levels at 1.1 mmol/L, experiencing a modest decline during Ramadan. This cohort's LDL levels showcased a relative stability, with a subsequent post-Ramadan escalation to 1.22 mmol/L, elucidating the intricate modulation of fasting-induced lipid metabolism by smoking. This stability and subsequent rise underscore the potential antagonistic effects of tobacco use on the fasting-mediated lipid profile enhancements.

Employing an ANOVA test, we ascertained a statistically significant disparity among the groups (p-value = 0.00035), affirming the critical role of lifestyle determinants—specifically, physical activity and smoking habits—in influencing LDL cholesterol levels during and subsequent to Ramadan fasting.

The discerned positive correlation between athletes and sedentary smokers (0.536) intimates a shared physiological mechanism modulating LDL metabolism in response to fasting, despite divergent smoking statuses. In contrast, the negative correlation between sedentary nonsmokers and smokers (-0.233) delineates the divergent impacts of tobacco use on LDL cholesterol levels during the fasting period.

This investigation elucidates the multifaceted effects of Ramadan fasting on LDL cholesterol, highlighting the modulation exerted by physical activity levels and smoking habits. The outcomes underscore the imperative for bespoke dietary and lifestyle interventions aimed at optimising cardiovascular health during fasting, emphasising the significance of individual lifestyle factors in mediating the metabolic benefits and potential risks associated with fasting.

In the discussion of our findings, it's imperative to place the observed modulation of LDL cholesterol levels during Ramadan within the broader scholarly context. The significant influence of lifestyle factors in lipid metabolism, as evidenced in our study, resonates with findings from Athyros et al. (2013), who elucidated the impact of tobacco smoking and cessation of plasma lipoproteins and associated cardiovascular risk factors, highlighting the adverse effects of smoking on lipid profiles. This insight is particularly relevant in understanding the relatively stable LDL levels during Ramadan among our cohort of sedentary smokers.

Moreover, the work of Devaranavadagi et al. (2012) on the influence of cigarette smoking on blood lipids corroborates our observations, shedding light on the complex relationship between smoking habits and lipid levels, which may elucidate the stable LDL levels observed in our smoking participants during Ramadan. Furthermore, the findings of Savendahl and Underwood (1999), demonstrating that fasting elevates serum total cholesterol and LDL cholesterol in healthy individuals, lend support to the post-Ramadan LDL profiles observed across our study cohorts.

Kersten (2023) investigation into fasting impact on adipose tissue metabolism provides a valuable framework for interpreting our findings, suggesting broad metabolic adaptations that extend beyond the lipid profile changes observed during Ramadan. This aligns with the transient improvements in LDL cholesterol levels potentially attributed to enhanced lipid utilisation for energy during fasting periods. The study of Liu et al. (2023) examining the effects of fasted aerobic exercise on overweight and obese young adult males, along with Swift et al. (2023) research on the influence of exercise training level on arterial stiffness post-weight loss offers a complimentary view on the beneficial effects of physical activity on lipid metabolism and cardiovascular health markers, pertinent to our athletes' cohort. Lastly, the research by Oh and Lee (2023) on the effects of varying intensities of aerobic exercise combined with resistance training on lipid profiles in middle-aged women with obesity underscores the complexity of exercise's impact on metabolic outcomes, reinforcing the need for personalised approaches to maximise health benefits during fasting periods.

## 5. HDL level

In our longitudinal analysis examining the dynamics of HDL cholesterol levels during Ramadan fasting (figure 19), we observed distinct patterns across different lifestyle cohorts, including athletes, sedentary nonsmokers, and sedentary smokers. These findings contribute to the nuanced understanding of how fasting, combined with varying levels of physical activity and smoking habits, influences lipid metabolism.

Athletes experienced a marked reduction in HDL cholesterol, from an initial baseline of 0.5 mmol/L to 0.398 mmol/L in the second week of Ramadan, further decreasing to 0.3 mmol/L by the fourth week. This significant decline, potentially indicative of increased lipid utilisation for energy in response to heightened physical activity during fasting, aligns with the notion that exercise influences lipid profiles. However, the subsequent increase to 0.38

mmol/L by the fifth week, followed by a slight decrease post-Ramadan to 0.35 mmol/L, suggests a complex metabolic recalibration as individuals transition back to their regular dietary and exercise routines.

Sedentary nonsmokers showed an initial increase in HDL levels, peaking at 0.48 mmol/L in the second week of Ramadan, before declining to 0.354 mmol/L by the fourth week and rising again to 0.41 mmol/L post-Ramadan. This fluctuation, ending with stabilisation at 0.4 mmol/L by the seventh week, might reflect the interplay between dietary changes during fasting and the rate of HDL clearance, echoing findings from Ara et al. (2016), who reported effects of Ramadan fasting on cholesterol levels in healthy adults.

Contrastingly, sedentary smokers started with lower baseline HDL levels at 0.33 mmol/L, experiencing a decrease to 0.25 mmol/L by the fourth week of Ramadan. The post-Ramadan period saw an uptick in levels, peaking at 0.33 mmol/L in the sixth week, then slightly dropping to 0.31 mmol/L. This pattern suggests that smoking modulatory effects might blunt the lipid-lowering impact of fasting, supported byHe et al. (2013), who discussed smoking implications on HDL quantity and function.

The ANOVA test underscored significant differences among the groups (p-value = 0.00123), reinforcing the impact of lifestyle choices on HDL cholesterol levels during and after Ramadan. The correlation between athletes and sedentary smokers (0.673) hints at a shared physiological response to fasting in terms of HDL metabolism, despite the differences in smoking status. However, the minimal correlation between sedentary nonsmokers and smokers (0.043) highlights the divergent effects of smoking on lipid metabolism during fasting.

These observations suggest that fasting during Ramadan exerts a significant influence on HDL cholesterol levels, modulated by an individual's activity level and smoking status. The transient decrease in HDL among athletes and subsequent post-Ramadan adjustment underscore a metabolic adaptation phase influenced by resumed dietary practices and physical activity. For sedentary individuals, HDL fluctuations may reflect alterations in dietary intake during fasting and the impact of smoking on lipid metabolism. Collectively, these insights emphasise the necessity of personalised lifestyle and dietary interventions to optimise cardiovascular health, particularly during periods of intermittent fasting, aligning with the broader research narrative on fasting metabolic impacts (Ahmed et al., 2021; D. L. Tahapary et al., 2020; Urooj et al., 2020).

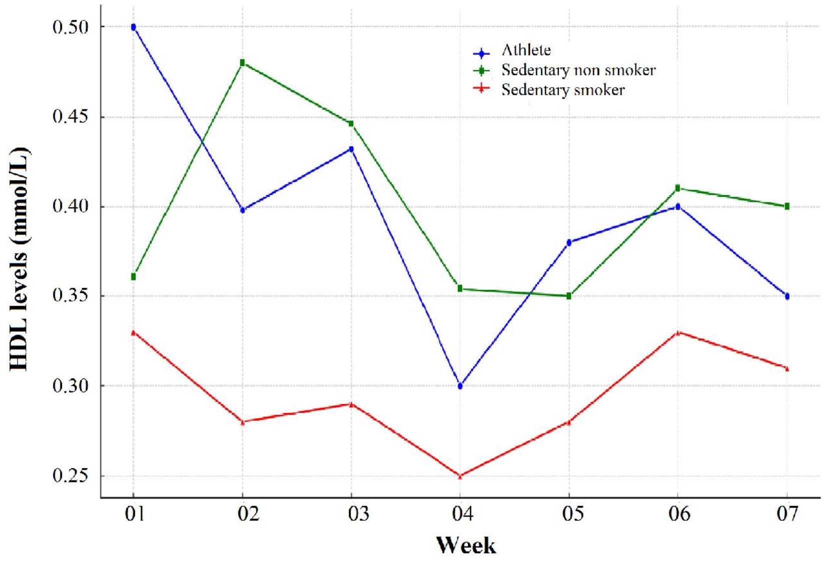


**Figure 19**. Effects of Ramadan fasting on weekly HDL cholesterol levels in active and sedentary individuals

## 6. Total Cholesterol

The comprehensive analysis of total cholesterol levels during Ramadan (figure 20), encompassing athletes, sedentary nonsmokers, and sedentary smokers, illuminates the multifaceted metabolic adjustments triggered by fasting. This study also delves into the critical influence of physical activity and smoking on these metabolic shifts.

Athletes experienced a significant modulation in total cholesterol levels, beginning with an increase from 1.301 mmol/L to 1.509 mmol/L in the second week of Ramadan, followed by a notable reduction to 1.022 mmol/L in the third week, and a subsequent rise to 1.468 mmol/L by the fifth week. This pattern likely mirrors the enhanced lipid mobilisation associated with increased physical activity during fasting, coupled with dietary adjustments. Post-Ramadan, a trend towards normalisation was observed, with levels stabilising at 1.33 mmol/L, indicative of a return to homoeostatic lipid levels, possibly influenced by resumed dietary habits and physical activity. This observation aligns with findings fromWati et al. (2024), who explored the BMI, fat percentage, and total cholesterol of athletes, suggesting that regular physical activity contributes to maintaining favourable lipid profiles.

In contrast, sedentary nonsmokers began with higher cholesterol levels at 1.95 mmol/L, which decreased to 1.87 mmol/L in the second week, and then significantly to 1.237 mmol/L by the third week. This reduction may reflect a fasting-induced decrease in lipogenesis or improved cholesterol clearance, with levels peaking at 1.5 mmol/L in the fifth week and increasing post-Ramadan to 1.65 mmol/L. This fluctuation could be attributed to dietary changes during Iftar, as suggested by Kodama et al. (2007) and Lee and Lee (2021), who highlighted the impact of aerobic exercise and dietary modifications on lipid profiles.

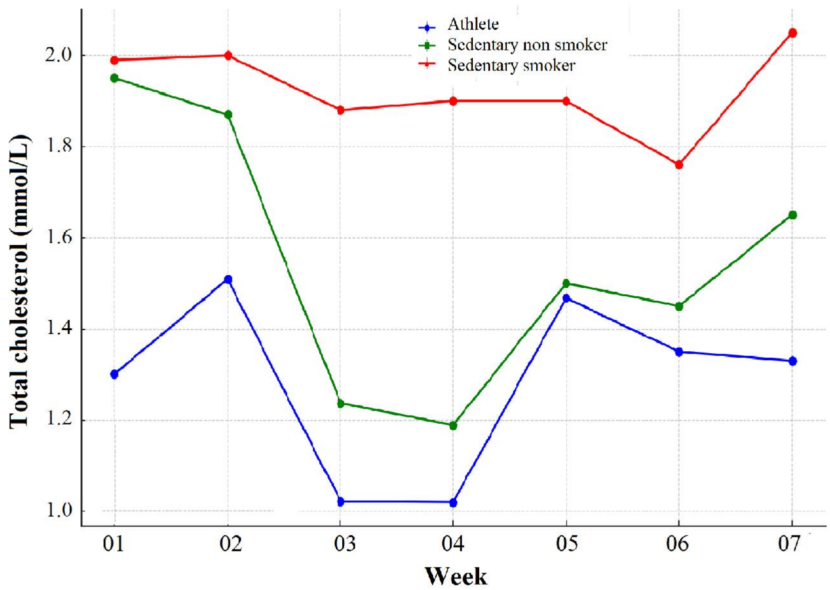


**Figure 20.** Ramadan fasting influence on total cholesterol levels in different lifestyle groups over seven weeks

Sedentary smokers displayed a modest decrease from 1.99 mmol/L to 1.88 mmol/L by the third week of Ramadan, with levels slightly increasing post-Ramadan to 2.05 mmol/L. The relatively stable cholesterol levels during Ramadan, followed by a post-Ramadan rise, may be attributed to the modulator effects of smoking on metabolism, potentially masking the lipid-lowering benefits of fasting. This is supported by research from Willett et al. (1983) and Nakamura et al. (2009), which discuss the adverse effects of smoking on lipid metabolism, particularly in the context of fasting.

Our findings suggest that fasting during Ramadan impacts total cholesterol levels differently among physically active individuals and those leading sedentary lifestyles, with smoking further influencing the metabolic response. For athletes, the overall trend indicates a beneficial effect of fasting when coupled with exercise on lipid metabolism. However, sedentary lifestyles, especially among smokers, might not experience the same degree of favourable changes. These insights underscore the necessity for personalised dietary and lifestyle interventions post-Ramadan to sustain the metabolic benefits of fasting. This approach is corroborated by the systematic reviews and meta-analyses conducted by Meng et al. (2020) and Yin et al. (2021), which emphasise the effects of intermittent fasting and energy-restricted diets on lipid profiles and the management of non-alcoholic fatty liver disease.

## 7. Effect of Ramadan fasting on Albumin level

The data collected over the course of Ramadan on albumin levels present a distinctive pattern across the three study groups, highlighting the physiological responses to a combination of fasting, physical activity, and smoking.For athletes, albumin levels began at 43.215 g/L and showed a steady increase during the fasting period, peaking at 66.186 g/L in Week 04. This substantial rise could be indicative of a stress response to increased physical exertion during fasting, potentially leading to an upregulated synthesis of albumin or decreased catabolism. The subsequent decrease to 55.132 g/L post-Ramadan suggests a reversion towards baseline levels, aligning with the body's recovery and adjustment post-fasting.

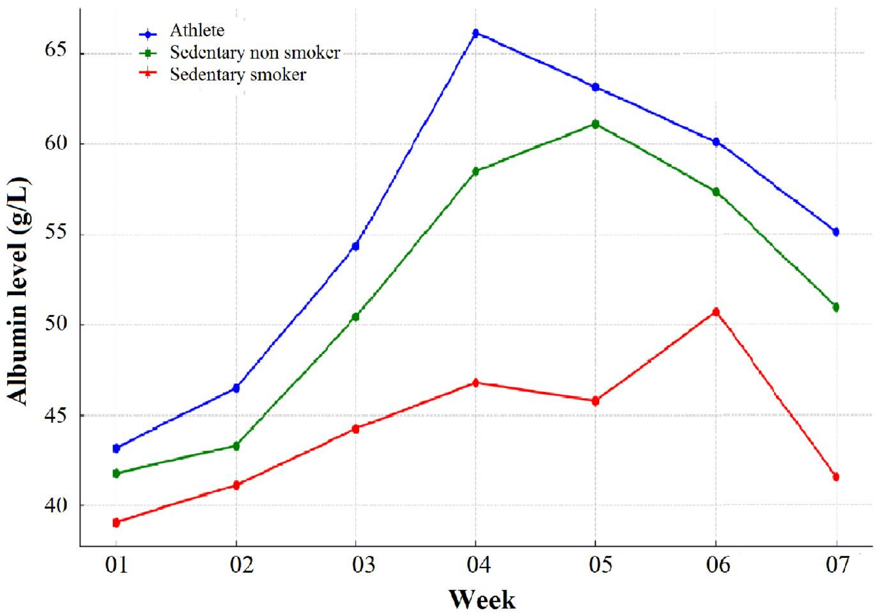


**Figure 21.** Effect of Ramadan fasting on albumin levels

Sedentary nonsmokers started at 41.809 g/L, experiencing a more gradual increase throughout Ramadan, with a peak of 61.154 g/L in Week 05. The fluctuations observed, including the decrease to 50.99 g/L by Week 07, might be reflective of less pronounced metabolic stress and a slower pace of dietary and physiological adjustment to the fasting state and post-fasting period.Sedentary smokers showed an initial increase from 39.08 g/L to 46.81 g/L by Week 04, followed by a slight decrease and then a post-Ramadan increase, ending with a level of 41.6 g/L. The relatively stable profile during Ramadan, with a modest increase thereafter, may be attributed to the complex effects of smoking on albumin metabolism, potentially influencing the synthesis and degradation of albumin during and after fasting.

The ANOVA analysis would likely reveal statistically significant differences between the groups, indicative of the various impacts that lifestyle factors have on albumin levels during and after Ramadan fasting.

In the broader context of existing literature, these findings are consistent with research that has investigated the effects of fasting on biochemical parameters. Sanchetee et al. (2020) noted that Jain fasting influenced anthropometric and clinical parameters, which could parallel the effects of Ramadan fasting on albumin levels. Similarly, Urooj et al. (2020) reported changes in biochemical profiles during Ramadan, providing a comparative backdrop for our observations. Furthermore, Caldo-Silva et al. (2021) explored the effects of exercise on albumin and inflammatory markers, which may shed light on the increased albumin levels observed in our athletic cohort during fasting. The literature on smoking impact on serum albumin, such as studies by Podzolkov et al. (2020) and Elisia et al. (2020), may explain the subtler changes in the albumin levels of the sedentary smokers in our study.

Our data demonstrate that Ramadan fasting exerts distinct effects on albumin levels, influenced by an individual's level of physical activity and smoking habits. For athletes, increased albumin levels during fasting may signify a combination of heightened metabolic activity and the body's adaptive response to increased physical demands. For sedentary individuals, the observed fluctuations suggest that fasting impact on albumin levels is less pronounced and potentially moderated by lifestyle factors such as smoking. These insights underscore the need for a nuanced approach to dietary and lifestyle modifications during fasting to optimise protein metabolism and overall health.

## 8. Urea Levels and the Impact of Ramadan Fasting

The interplay between fasting during Ramadan and lifestyle choices is starkly evident in the urea levels observed across our study cohorts. In athletes, the initial urea concentration of 0.375 g/L dropped to 0.241 g/L by the second week, perhaps a reflection of the body's heightened state of protein turnover during increased physical activity, as well as the fasting state. This is in line with findings by Olisah and Nicholate (2021), who noted changes in serum electrolytes and urea due to exercise, and by Stankevych et al. (2021), who recognised the need to monitor blood urea in athletes to optimise training and recovery. The rebound to 0.302 g/L in Week 04 and the subsequent decrease to 0.343 g/L post-Ramadan suggest a return to a more typical metabolic state as dietary habits normalise and training intensities adjust.

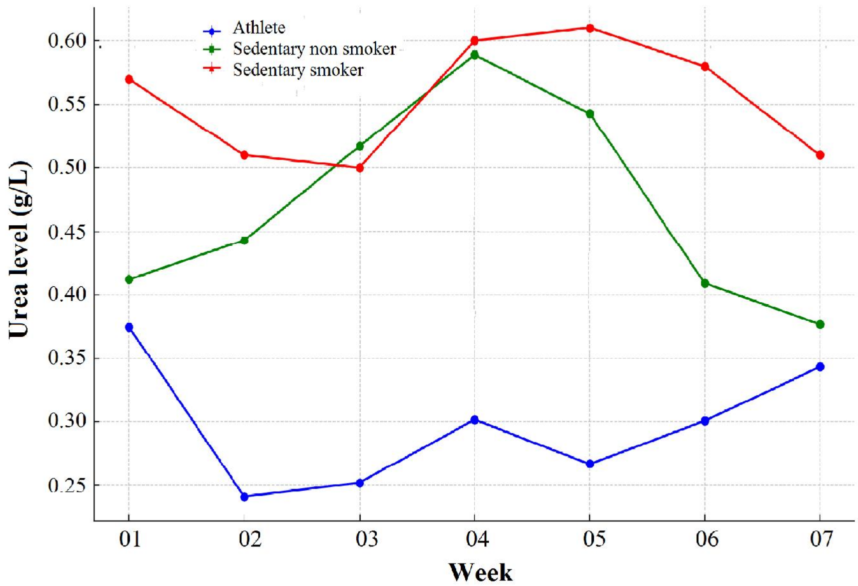


**Figure 22**. Effect of Ramadan fasting on urea levels

Sedentary nonsmokers present a different pattern, with their urea levels rising from 0.412 g/L to 0.589 g/L in Week 04 of Ramadan, possibly indicating a less efficient metabolic response to fasting compared to their athletic counterparts. The post-Ramadan decrease to 0.377 g/L could reflect a re-establishment of metabolic balance. These findings echo the broader effects of fasting on biochemical parameters as described by Wang and Wu (2022), and resonate with the work of Mohamed et al. (2023), which examined how intermittent fasting influences renal and liver markers.

The sedentary smokers' urea levels, starting at a higher baseline of 0.57 g/L, decreased slightly during Ramadan and returned to 0.51 g/L post-Ramadan. This group's results may be interpreted within the context of the complex effects of smoking on metabolism, as outlined in the studies by Hafez et al. (2020), and Bandiera et al. (2021). The modest changes could be due to the modulator influence of smoking on renal function and protein breakdown, which may mask the metabolic impacts of fasting observed in nonsmokers.

Overall, the trends in urea levels throughout the fasting period reveal that the physiological impact of Ramadan is distinctly modulated by lifestyle choices, with physical activity and smoking status serving as key determinants of metabolic adaptation. For athletes, the fasting period appears to enhance metabolic efficiency, while sedentary individuals, particularly smokers, exhibit a less pronounced response. The post-Ramadan period, with its potential for dietary relapse, underscores the importance of vigilant resumption of regular eating patterns to maintain the beneficial effects observed during fasting. Our analysis contributes to the growing evidence supporting the significance of personalised nutrition and lifestyle adjustments during and after fasting to optimise health outcomes.

## 9. Uricacid / L Creatinine

The longitudinal assessment of uric acid to creatinine ratios (figure 23) across different cohorts during the Ramadan period reveals significant metabolic adjustments reflective of fasting, physical activity, and smoking habits.

Athletes exhibited an acute increase in uric acid concentrations, with values rising from 44,704 mg/L to a peak of 86,613 mg/L by the second week of Ramadan, before gradually declining to 46,061 mg/L post-Ramadan. This fluctuation might reflect a heightened turnover of purines due to increased exercise-related catabolism, potentially augmented by the fasting state. The post-Ramadan decrease suggests a renormalisation of metabolic processes, possibly indicative of renal adaptation to altered dietary and physical activity patterns, a phenomenon consistent with the renal functional adaptations to physical training as suggested by Defi et al. (2023) and Olisah and Nicholate (2021).

**Week**

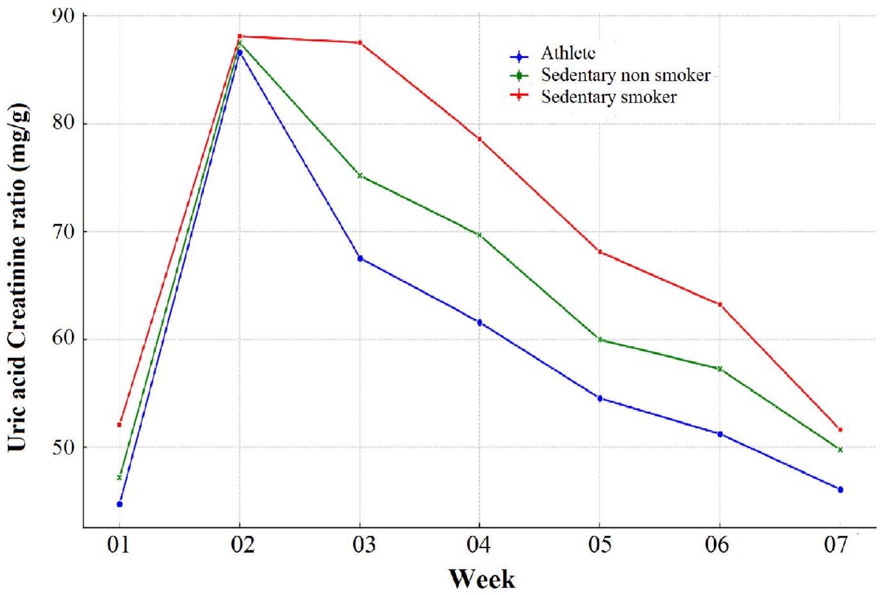


**Figure 23.** Effect of Ramadan fasting on Uric acid to creatinine ratio

Sedentary nonsmokers presented with an increase in uric acid levels to 87,488 mg/L during Ramadan, with subsequent normalisation to 49,756 mg/L after the fasting period. This trend may be attributable to dietary changes during Ramadan, affecting protein intake and purine metabolism, leading to increased uric acid production and altered clearance rates. These observations parallel findings from studies on the impact of fasting on liver and kidney profiles, such as those by Ashfaq et al. (2023) and Bener et al. (2021), which noted changes in biochemical profiles during Ramadan fasting.

Sedentary smokers, starting at a higher baseline of 52,06 mg/L, demonstrated a less marked increase in uric acid levels during Ramadan, followed by a post-Ramadan decrease to 51,6 mg/L. The smoking habit may have a modulatory effect on uric acid metabolism and renal clearance, potentially masking some of the metabolic impacts of fasting. The interplay between smoking and renal function has been previously explored in studies like those by Bandiera et al. (2021), which could explain the observed patterns in our data.

The post-Ramadan period appears to be characterised by a trend towards metabolic homoeostasis across all groups, suggesting a potential corrective response of the kidneys to the fasting-induced metabolic demand. The reduction in urea levels post-Ramadan aligns with the body's reversion to a balanced metabolic state, underscoring the influence of diet and lifestyle on renal health, as demonstrated by the synergistic effect of micronutrients in supporting organ function noted by Deshmukh and Manjalkar (2021).

The data indicate that Ramadan fasting significantly affects metabolic markers related to renal function, with physical activity and smoking status serving as key modulators. These insights support the need for a nuanced approach to dietary and lifestyle interventions during and after fasting to maintain optimal renal function and metabolic balance.

## 10. Effect of Ramadan fasting on Calcium levels

The dataset reflecting serum calcium levels during Ramadan offers valuable insights when considered alongside existing scientific literature.Athletes in our study exhibited an increase in serum calcium from 88,044 mg/L to a peak of 91,612 mg/L during Ramadan, which subsequently decreased to 89,9 mg/L post-Ramadan. This trajectory suggests an adaptive mechanism to the increased demands of exercise and fasting, with calcium potentially being mobilised to support muscular and skeletal function. These findings resonate with the study by Guillemant et al. (2004), which observed acute calcium elevation in response to endurance exercise, and Barry et al. (2011), who discussed calcium's role in mitigating exercise-induced disruptions in homoeostasis.

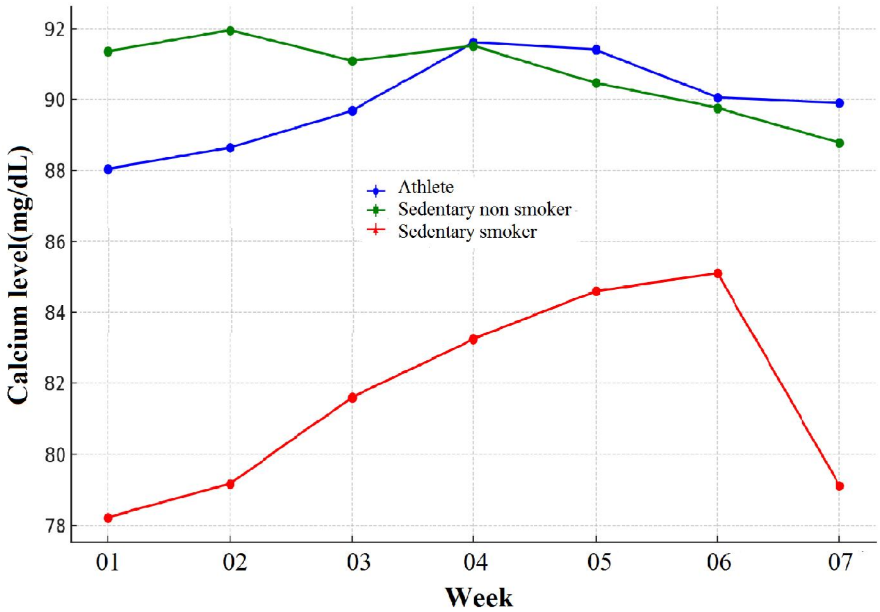


**Figure 24.** Calcium-level evolution on Ramadan

Sedentary nonsmokers showed a plateau in calcium levels during Ramadan, with a slight decrease post-fasting. This pattern aligns with studies such as those by Lausson et al. (1985) and Al-Kotobe et al. (2006), which noted fasting-related alterations in calcium regulation.For sedentary smokers, a consistent rise in calcium levels was observed during Ramadan, which then declined after the fasting period, possibly reflecting the complex interplay between tobacco's effects on bone metabolism and the compensatory responses elicited by fasting. This is in concordance with Li et al. (2020) and Krall and Dawson-Hughes (2020), who noted the detrimental impact of smoking on bone mineral density and the potential mediating role of tobacco-related cadmium exposure.

These observations suggest that fasting can affect calcium metabolism differently depending on lifestyle choices. For athletes, the changes might be a reflection of physiological adaptation to maintain bone health under increased physical demands, while for sedentary individuals, particularly smokers, the response may be moderated by the effects of smoking on calcium balance. Ciosek et al. (2021) highlights the influence of various elements on bone tissue, which could explain the post-Ramadan decrease as a return to baseline calcium levels and dietary patterns. Furthermore, the post-Ramadan period across all cohorts could signal a reversion to pre-fasting metabolic conditions, with the body recalibrating its mineral balance. This concept is supported by Mehrabani et al. (2020), who noted the metabolic effects of fasting on cellular processes. Our findings underscore the complex relationship between fasting, exercise, and lifestyle factors such as smoking on mineral metabolism. These results support the need for personalised nutritional advice during and after fasting to optimise mineral balance and bone health, particularly in populations with varying levels of physical activity and tobacco exposure.

## 11. Discussion

The investigation into the metabolic effects of Ramadan fasting across different cohorts - athletes, sedentary nonsmokers, and sedentary smokers - highlights the profound impact of lifestyle factors on physiological adaptations to fasting. The differential responses observed in glucose, triglycerides, blood protein, LDL, HDL, total cholesterol, albumin, urea, uric acid to creatinine ratios, and calcium levels offer a nuanced view of the metabolic complexities associated with fasting, physical activity, and smoking.

The enhanced metabolic flexibility noted in the athlete cohort underscores the beneficial role of regular physical activity in modulating fasting-induced metabolic changes. This is in line with previous research that emphasises the positive impact of exercise on lipid metabolism and overall metabolic health (Couillard et al., 2001; Hughes et al., 1991). The findings suggest that athletes may experience amplified metabolic benefits from Ramadan fasting, attributed to their superior metabolic adaptability.

Conversely, the sedentary cohorts, particularly smokers, exhibit distinct metabolic profiles, indicating that smoking may attenuate the metabolic benefits of fasting. This observation is supported by studies highlighting the complex interactions between smoking, fasting, and metabolic health (van der Plas et al., 2023; Willett et al., 1983). The data suggest that smoking may interfere with the fasting-induced metabolic adaptations, potentially negating some of the health benefits associated with Ramadan fasting.

The interplay between fasting and physical activity emerges as a key determinant of the metabolic outcomes of fasting. The transient improvements in lipid profiles and protein metabolism observed in athletes during Ramadan points to the critical role of exercise in enhancing the body's response to fasting. This aligns with recent literature that documents the positive effects of physical activity on cardiovascular health markers and lipid metabolism during fasting periods (Liu et al., 2023; Swift et al., 2023).

Moreover, the study sheds light on the complex relationship between smoking and metabolic health during fasting. The relatively stable metabolic markers in sedentary smokers throughout Ramadan suggest that nicotine may modulate the body's metabolic response to fasting in a unique manner. This underscores the need for targeted health interventions for smokers during fasting to mitigate the potential adverse effects of smoking on fasting-induced metabolic benefits.

# GENERAL DISCUSSION

## General discussion

Ramadan fasting, an annual observance for Muslims, involves abstaining from all food and drink from dawn to sunset. This practice provides a unique natural experiment to study the effects of intermittent fasting on the human body, particularly focusing on body mass, BMI, and body fat. Given the global observance of Ramadan, research spanning diverse populations offers insights into how this form of fasting might influence health outcomes.

Studies (Nobari et al., 2022; Duncan et al., 2023; Khaled Trabelsi et al., 2024) have shown variable effects of Ramadan fasting on body mass and BMI, largely dependent on individual lifestyles, dietary habits during non-fasting hours, and physical activity. For example, Sembiring et al. (2021) observed a decrease in BMI among Type 2 Diabetes Mellitus patients during Ramadan, suggesting that fasting could contribute to better management of diabetes through weight control. Similarly, Aydın et al. (2019) through a meta-analysis, underscored the positive effect of Ramadan fasting on glycaemic control and BMI reduction in Type II diabetic patients, highlighting its potential as a complementary strategy in diabetes management.

Conversely, research by Al-Barha & Aljaloud (2019) on healthy men demonstrated that Ramadan fasting could also influence body composition and potentially improve parameters related to metabolic syndrome. These studies suggest a broad applicability of fasting benefits across different populations.

A key area of interest is the effect of Ramadan fasting on body fat percentage. Syam et al. (2016) provided evidence that Ramadan fasting could reduce body fat without significantly impacting protein mass, indicating a preservation of lean mass during fasting. This finding is critical for understanding the health benefits of fasting beyond simple weight loss. Fernando et al. (2019) supported this in their systematic review, noting weight loss and decreased body fat among healthy adults following Ramadan fasting.

The decrease in body fat percentage during Ramadan has been further supported by studies such as those conducted by Memari et al. (2011), focusing on female athletes, and Aliasghari et al. (2017), who investigated patients with Non-Alcoholic Fatty Liver Disease (NAFLD), suggesting that the benefits of fasting on body composition may extend across different levels of physical activity and health status.

The physiological mechanisms underlying these changes include alterations in eating patterns, hormone levels, and metabolic responses. Ramadan fasting induces a state of negative energy balance, leading to fat mobilisation for energy production. Furthermore, fasting may improve metabolic flexibility, enhancing the body's ability to switch between fuel sources efficiently.

The observed reductions in body mass, BMI, and especially body fat percentage could have significant health implications, including reduced risk of cardiovascular diseases, improved insulin sensitivity, and better management of metabolic syndrome components. Studies like those by Sezen et al. (2016) and Ramadan (2002) provide valuable insights into the potential cardiovascular and performance-related benefits of Ramadan fasting.

Collectively, the referenced studies illustrate a complex but generally positive picture of Ramadan fasting impact on body mass, BMI, and body fat percentage. These effects are manifested through various mechanisms, leading to potential health benefits. However, individual outcomes can vary based on numerous factors, including pre-existing health conditions, lifestyle, and adherence to fasting. Continued research is necessary to fully understand the long-term implications of Ramadan fasting on body composition and to identify strategies to maximise its health benefits. This body of evidence underscores the potential of intermittent fasting, as practised during Ramadan, to serve as a tool for improving health outcomes related to body composition.

Athletes managed to maintain their body mass and BMI during Ramadan, quickly reverting to pre-fasting levels post-Ramadan, indicating their adaptability to fasting. Conversely, sedentary smokers showed a slight increase in body mass during fasting and a more significant post-Ramadan increase, likely due to nicotine's appetite-suppressing effects and altered eating habits. Sedentary non-smokers experienced increases in BMI both during and after Ramadan, pointing to the impact of fasting on regular eating patterns and the importance of dietary vigilance to avoid weight gain. Thus, analyses revealed that athletes maintained lower levels compared to increases observed in both groups of sedentary individuals, highlighting the role of physical activity, diet, and smoking in body composition changes during fasting. These findings suggest the need for tailored dietary and lifestyle recommendations to address the potential negative effects on body composition, especially for sedentary and smoking populations. This study sheds light on the complex relationship between fasting, lifestyle, and body composition, offering insights for developing effective health strategies during fasting periods.

Ramadan fasting influences haematological (Nobari et al., 2022; Chaatani & Khan, 2023; Khaled Trabelsi et al., 2024) parameters, such as haemoglobin levels, haematocrit values, white blood cells (WBC) counts, red blood cell (RBC) parameters, and platelet counts. Studies by Ünalacak et al. (2011) and Farshidfar et al. (2006) investigated the impact of Ramadan fasting on haemoglobin and haematocrit levels among healthy and obese individuals. These studies concluded that Ramadan fasting does not significantly affect these parameters (Chaatani & Khan, 2023; Hafidh et al., 2023; Trabelsi et al., 2023) indicating that the body can maintain normal red blood cell concentration and function during fasting periods. This finding suggests that, despite the altered eating and drinking patterns, the physiological mechanisms responsible for regulating red blood cell volume and concentration remain effectively unchanged during Ramadan.

The research conducted by Osamah Awad Ahmed (2019) and Nasiri et al. (2016) focused on the changes in white blood cell count during Ramadan. Both studies observed a slight reduction in WBC count, which could reflect a beneficial anti-inflammatory response or an adaptation of immune function. Importantly, these changes remained within normal physiological limits, suggesting that Ramadan fasting does not adversely affect immune system functionality in healthy individuals.

Investigations into red blood cell parameters by Ünalacak et al. (2011) and Nasiri et al. (2016) revealed stability in RBC counts, mean corpuscular volume (MCV), and mean corpuscular haemoglobin concentration (MCHC) throughout Ramadan. This stability underscores the body's capability to effectively manage red blood cell production and turnover, even under the conditions of fasting, ensuring that oxygen transport and tissue oxygenation are not compromised.

Sarraf-Zadegan et al. (2000) examined the effects of Ramadan fasting on platelet count and coagulation factors, finding no significant changes. This outcome is crucial for assessing the risk of thrombosis or bleeding disorders during fasting, indicating that fasting during Ramadan does not adversely affect the body's haemostatic function.

The collective findings from these studies suggest that Ramadan fasting has minimal adverse effects on haematological parameters among healthy individuals, with observed changes generally remaining within normal ranges. This indicates that fasting during Ramadan is safe for healthy individuals and does not compromise haematological health. However, it's important for individuals with pre-existing health conditions or those who experience adverse effects during fasting to consult with healthcare professionals.

The impact of Ramadan fasting blood glucose levels has been studied with varying results, reflecting the complexity of glucose regulation and the influence of fasting. Harbuwono et al. (2020) found that Ramadan fasting led to significant fluctuations in glucose variability among type 2 diabetes mellitus (T2DM) patients on oral antidiabetic agents, underscoring the necessity for these patients to closely monitor and possibly adjust their medication regimens during Ramadan. This observation is crucial for diabetic patients considering fasting, as it highlights the potential risks associated with unmonitored fasting. Conversely, Tahapary et al. (2020) conducted a meta-analysis that suggested Ramadan fasting could improve the metabolic profile in T2DM patients, indicating that, under proper medical supervision, fasting could be beneficial for some diabetic patients.

Numerous studies have reported beneficial changes in lipid profiles during Ramadan fasting. Akhtar et al. (2022) observed significant reductions in total cholesterol and LDL cholesterol levels, suggesting a positive impact of fasting on cardiovascular risk factors. These findings align with those of Ahmed et al. (2022), who reported improvements in lipid profiles and other cardiovascular risk factors in patients with stable coronary artery disease. Such improvements could be attributed to changes in diet and eating patterns during Ramadan, emphasising the potential of lifestyle modifications in managing and preventing cardiovascular diseases.

The effects of Ramadan fasting extend beyond glucose and lipid metabolism. Kul et al. (2014) conducted a meta-analysis that examined body weight, blood lipids, and fasting blood glucose in a healthy population, finding no significant detrimental effects, which suggests that Ramadan fasting can be safely practised by healthy individuals without adverse effects on these parameters. Momen et al. (2007) explored changes in diabetic patients, indicating the need for individualised management plans during Ramadan to accommodate the altered metabolic demands of fasting. These changes in cholesterol levels are influenced by the quantity and quality of food consumed during non-fasting hours, as well as potential increases in physical activity levels among individuals observing Ramadan. Dietary practices during Ramadan, including the consumption of nutrient rich, less processed foods at Suhoor (pre-dawn meal) and Iftar (meal to break the fast), might play a crucial role in modulating blood cholesterol levels. Moreover, the prolonged fasting intervals could enhance lipid metabolism, leading to improved regulation of cholesterol synthesis and clearance.

Al-Jafar et al. (2021) investigated the impact on blood pressure, discovering that Ramadan fasting could lead to reductions in both systolic and diastolic blood pressure. This finding has important implications for cardiovascular health, suggesting that fasting may help in managing hypertension. Khan et al. (2020) further support this by showing that fasting can have positive effects on glucose levels, serum lipid profile, and blood pressure in a young, healthy population, indicating the broad applicability of these health benefits.

# CONCLUSION AND PERSPECTIVES

# Conclusion and perspectives

The month of Ramadan, observed by millions of Muslims worldwide, presents a unique period of fasting from dawn until sunset. This religious observance, beyond its spiritual significance, offers a valuable context for examining the physiological and metabolic impacts of intermittent fasting on human health. The research conducted during Ramadan 2023 has provided insightful revelations into how such fasting practices influence metabolic health across different population groups: athletes, sedentary smokers, and sedentary non-smokers. This study, through a meticulous methodology encompassing anthropometric measurements, haematological and biochemical analyses, and a comprehensive statistical framework, has dissected the multifaceted effects of Ramadan fasting on these distinct groups, offering a nuanced understanding that could inform personalised dietary and lifestyle interventions during fasting periods.

The study's findings underscore the profound influence of lifestyle factors, particularly physical activity and smoking, on the body's response to Ramadan fasting. Athletes demonstrated remarkable metabolic flexibility during Ramadan, as evidenced by improved lipid profiles and body composition adjustments that suggest enhancing metabolic health. This group's ability to maintain, and in some cases improve, their metabolic health indicators during fasting underscores the potential of regular physical activity to amplify the health benefits of intermittent fasting regimes.

Conversely, the sedentary lifestyle groups, particularly smokers, presented a contrasting scenario. The attenuated benefits of fasting observed among sedentary smokers highlight the adverse effects of smoking on metabolic health and its potential to undermine the positive adaptations to fasting. This finding signals a pressing need for targeted health interventions aimed at mitigating the detrimental impacts of smoking, especially during fasting periods.

The sedentary non-smokers, while not experiencing the metabolic benefits to the extent observed in athletes, still showcased changes that warrant attention. The variations in body mass, BMI, and biochemical parameters among this group point to the complex interplay between dietary intake, physical activity, and metabolic health during fasting. These insights collectively emphasise the necessity for personalised approaches to fasting that consider an individual's lifestyle habits, including their physical activity levels and smoking status.

The implications of these findings extend into the realms of public health and sports science, advocating for the integration of lifestyle considerations into fasting guidance. For public health practitioners, the study underscores the importance of promoting physical activity and addressing smoking habits as part of comprehensive health strategies during Ramadan. Tailoring public health messages to encourage active lifestyles and provide support for smoking cessation could significantly enhance the health outcomes of fasting individuals.

In sports science, the research highlights the potential of utilising fasting as a tool for optimising athletes' metabolic health and performance. The positive adaptations observed in athletes during Ramadanranging from body composition adjustments to improved lipid profilessuggest that carefully managed fasting, coupled with targeted training programs, could offer competitive advantages.

This study opens several avenues for future research aimed at unravelling the intricate dynamics between fasting, physical activity, and metabolic health. Longitudinal studies exploring the long-term effects of Ramadan fasting, with a focus on the sustainability of metabolic health improvements and performance outcomes in athletes, could provide deeper insights into the potential of fasting as a strategic element in sports training regimes.

Additionally, further research is needed to explore the psychosocial aspects of fasting, such as motivation, mental well-being, and the impact of social support systems on fasting experiences. Understanding these dimensions could enhance the effectiveness of dietary and lifestyle interventions by addressing the holistic well-being of fasting individuals.

Moreover, investigating the differential impacts of fasting on various demographic groups, including women, the elderly, and individuals with pre-existing health conditions, could offer valuable insights into the broader applicability of fasting as a health intervention. This line of inquiry could contribute to the development of inclusive fasting guidelines that cater to the diverse needs of the global Muslim population.

In summary, this research has illuminated the nuanced effects of Ramadan fasting on metabolic health, revealing the significant influence of physical activity and smoking on the body's adaptation to fasting. The study advocates for personalised dietary and lifestyle interventions during Ramadan, highlighting the importance of considering individual lifestyle factors. By paving the way for future research into the long-term effects of fasting and the interplay between fasting, physical activity, and lifestyle choices, this work contributes valuable knowledge to the fields of sports science, public health, and nutritional science. Ultimately, the findings underscore the potential of Ramadan fasting, when appropriately managed, to serve as a beneficial practice for enhancing metabolic health and well-being across diverse populations.

Through a detailed analysis of the effects of Ramadan fasting on different population groups, this research not only contributes to the scientific understanding of intermittent fasting but also provides practical insights for optimising health outcomes during Ramadan. As we continue to explore the complex interplay between diet, lifestyle, and health, the findings from this study offer a foundation for developing more effective, personalised approaches to fasting and health management, reflecting the intricate mosaic of human health and behaviour.

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**الملخص**: يسعى هذا البحث إلى سد الفجوة من خلال التقييم الدقيق لآثار صيام رمضان على مختلف معايير القياسات البشرية، وأمراض الدم، والدم عبر مجموعات مختلفة. وتظهر النتائج استجابات فسيولوجية متنوعة للصيام بناءً على نمط الحياة وعادات التدخين، مما يسلط الضوء على أهمية النصائح الصحية المخصصة خلال شهر رمضان. وأظهرت الدراسة انخفاض مستويات الهيموجلوبين لدى الرياضيين خلال شهر رمضان، مما يشير إلى تأثير كبير للصيام على نقل الأكسجين. وشهد المدخنون المستقرون زيادة تشير إلى استجابة تعويضية للصيام والتدخين. تسلط هذه الاختلافات الضوء على التأثيرات المعقدة للصيام والنشاط البدني والتدخين على معايير أمراض الدم. كشف التحليل الكيميائي الحيوي عن تغيرات واضحة في مستويات الدهون وأنزيمات الكبد. تسلط النتائج الضوء على المرونة الأيضية والقدرة على التحمل استجابة للصيام، مع آثار كبيرة على التوصيات الغذائية ونمط الحياة خلال شهر رمضان. يسلط هذا البحث الضوء على التأثير المتعدد الأوجه لصيام رمضان على الصحة البدنية والتمثيل الغذائي عبر أنماط الحياة المختلفة. ويكشف أن الصيام يؤدي إلى تغيرات فسيولوجية كبيرة، خاصة لدى الرياضيين، مما يشير إلى أهمية الدعم الغذائي المناسب. بالنسبة للأفراد المستقرين، تشير النتائج إلى أن تأثيرات الصيام يتم تعديلها من خلال عادات التدخين، مما يسلط الضوء على الحاجة إلى مبادئ توجيهية محددة للمدخنين.

**الكلمات المفتاحية**: صيام رمضان، الرياضيون، التدخين، الصحة الأيضية، القياسات البشرية، أمراض الدم

**Abstract**: This research seeks to fill the gap by rigorously evaluating the effects of Ramadan fasting on various anthropometric, haematological, and blood parameters across distinct groups. The results shows varied physiological responses to fasting based on lifestyle and smoking habits, highlighting the importance of tailored health advisories during Ramadan. The study showed haemoglobin levels in athletes decreased during Ramadan, indicating a significant impact of fasting on oxygen transport. Sedentary smokers saw an increase suggesting a compensatory response to fasting and smoking. These variations highlight the complex effects of fasting, physical activity, and smoking on haematological parameters. The biochemical analysis revealed distinct changes in lipid profiles and liver enzymes. The results highlight the metabolic flexibility and resilience in response to fasting, with significant implications for dietary and lifestyle recommendations during Ramdan. This research underscores the multifaceted impact of Ramadan fasting on physical and metabolic health across different lifestyles. It reveals that fasting induces significant physiological changes, particularly in athletes, suggesting the importance of tailored nutritional support. For sedentary individuals, the findings suggest that fasting effects are modulated by smoking habits, highlighting the need for specific guidelines for smokers.

**Keywords**: Ramadan fasting, Athletes, Smoking, Metabolic health, Anthropometry, Haematology

**Résumé** : Cette recherche vise à combler cette lacune en évaluant rigoureusement les effets du jeûne du Ramadan sur divers paramètres anthropométriques, hématologiques et sanguins dans des groupes distincts. Les résultats montrent des réponses physiologiques variées au jeûne en fonction du mode de vie et des habitudes tabagiques, soulignant l'importance de conseils de santé adaptés pendant le Ramadan. L'étude a montré que les niveaux d'hémoglobine chez les athlètes diminuaient pendant le Ramadan, ce qui indique un impact significatif du jeûne sur le transport de l'oxygène. Les fumeurs sédentaires ont constaté une augmentation suggérant une réponse compensatoire au jeûne et au tabagisme. Ces variations mettent en évidence les effets complexes du jeûne, de l'activité physique et du tabagisme sur les paramètres hématologiques. L'analyse biochimique a révélé des changements distincts dans les profils lipidiques et les enzymes hépatiques. Les résultats mettent en évidence la flexibilité et la résilience métaboliques en réponse au jeûne, avec des implications significatives sur les recommandations alimentaires et de style de vie pendant le Ramadan. Cette recherche souligne l'impact multiforme du jeûne du Ramadan sur la santé physique et métabolique dans différents modes de vie. Elle révèle que le jeûne induit des changements physiologiques importants, notamment chez les sportifs, suggérant l'importance d'un soutien nutritionnel adapté. Pour les individus sédentaires, les résultats suggèrent que les effets du jeûne sont modulés par les habitudes tabagiques, soulignant la nécessité de lignes directrices spécifiques pour les fumeurs.

**Mots-clés** : Jeûne du Ramadan, Athlètes, Tabagisme, Santé métabolique, Anthropométrie, Hématologie