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The Role of Polyunsaturated Fatty Acids and Moringa Oleifera Leaf in Primary Osteoporosis Induced by Insomnia: Pathophysiological Mechanisms and Agricultural Implications

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Moringa oleifera leaves are rich in polyunsaturated fatty acids (PUFAs), which may help geriatric bone health in a balanced diet. These leaves are anti-inflammatory and calcium-enhancing due to their magnesium, vitamin C, vitamin A, and calcium content. Omega-6 polyunsaturated fatty acids may exceed osteoporosis risk. Moringa may improve sleep quality for osteoporosis patients using omega-6 fatty acid-reducing medication. This study examines whether polyunsaturated fatty acid consumption in elderly Chinese adults increases the risk of primary osteoporosis and sleep problems. Insomnia is linked to primary osteoporosis in this population. In the cross-sectional investigation, 400 people over 60 participated. Sleep duration, polyunsaturated fatty acid consumption, and bone mineral density were measured using standardised questionnaires. Evidence from logistic regression analysis links PUFA intake to a higher risk of early-onset osteoporosis (odds ratio = 2.796; $p < 0.05$). Conversely, increased PUFA intake and shorter sleep duration reduced osteoporosis risk (odds ratio = 0.406, $p = 0.05$). Omega-3 polyunsaturated fatty acids may reduce sleep deprivation's negative effects, according to research. These findings add to the evidence that polyunsaturated fatty acids (PUFAs) benefit bone health. However, high polyunsaturated fatty acid intake may raise osteoporosis risk. Adding Moringa oleifera leaves and PUFAs to the diet may help older persons maintain bone density. Moringa may mitigate omega-6 polyunsaturated fatty acid effects by boosting calcium and reducing inflammation. Moringa leaves are rich in calcium, magnesium, vitamins A and C. Along with complete treatment, lowering omega-6 fatty acid consumption may help osteoporosis patients with sleeplessness. Moringa has anti-inflammatory benefits, however some people react negatively. These findings suggest that public health campaigns should promote healthy eating in older persons. Including polyunsaturated fats with Moringa oleifera leaves in diets may be beneficial. Educational efforts should emphasise the benefits of moringa in an omega-3 fatty acid-rich diet for sleep, bone health, and polyunsaturated fatty acid reduction.

Keywords: Polyunsaturated Fatty Acids (PUFA), Insomnia, Osteoporosis, Bone Mineral Density, Sleep Disturbances, Aging Population, China, Moringa Oleifera Leaf.

Introduction

There is considerable interest in Moringa oleifera leaf extracts for treating age-related bone problems like osteoporosis. Moringa oleifera, the "Miracle Tree," is rich in magnesium, calcium, and vitamin C. These bioactive chemicals are antioxidants and anti-inflammatory. Das (2024) and Zhang & Wu (2024) found that moringa supplements ameliorate osteoporosis symptoms including inflammation and bone density. Several studies suggest that moringa leaves may slow or reverse bone loss and promote bone growth. These benefits are due to the plant's oxidative stress reduction and calcium absorption. Omega-3 PUFAs may reduce inflammation and strengthen bones, making them a viable treatment for osteoporosis (Chen et al., 2024; Wang et al., 2022). Degenerative skeletal condition osteoporosis reduces bone mineral density (BMD) and increases bone fragility. This condition is a global health issue, especially for the elderly. The illness increases fracture risk and lowers quality of life. Elderly ladies and men are vulnerable. Dietary variables, particularly polyunsaturated fatty acids (PUFAs), and sleep disorders such insomnia have been linked to bone health (Calder, 2006; Wang et al., 2022). Although osteoporosis is an increasing concern, biological and lifestyle factors affect its progression.

A common sleep problem, insomnia, causes trouble sleeping or staying asleep. This causes short sleep and low quality. Multiple studies have connected chronic sleep disturbances to metabolic changes, higher cortisol levels, and decreased growth hormone synthesis, which significantly impact bone mineral metabolism (Swanson, 2022). Sleep deprivation increases osteoporosis risk by causing bone resorption (Petrov et al., 2024). Older persons are more at risk because hormonal changes increase bone loss (Tang et al., 2021). Recent research suggests that essential fatty acids, especially long-chain polyunsaturated omega-3 and omega-6 fatty acids, may maintain bone health. Phospholipid-based fatty acids (PUFAs) regulate inflammation, lipid metabolism, and cell signalling. Polyunsaturated fatty acids influence osteoblastic and osteoclastic activity, improving bone density, mass, and strength (Chen et al., 2024; Tao et al., 2022). Omega-3 fatty acids may slow osteoporosis by

reducing inflammation (Das, 2024). Dietary changes like eating more omega-3 fatty acids and soy may also help prevent estrogen-related bone loss.

Sleep disruptions, polyunsaturated fatty acids, and osteoporosis risk are actively studied. Chronic insomnia affects the HPA axis and inflammatory pathways, worsening bone loss. PUFAs are anti-inflammatory, unlike saturated fatty acids, which may mitigate sleep deprivation's impact on bone density (Swanson, 2022). Elderly people are more likely to have sleep difficulties and nutritional inadequacies that increase osteoporosis risk (Feehan et al., 2023). Older people are also more likely to develop type 2 diabetes and cardiovascular disease, which share metabolic pathways with osteoporosis. The exact processes by which PUFAs affect bone health in chronic insomniacs are unknown. Environmental issues like pollution might also cause osteoporosis. Air, water, and soil pollution cause illness and early death. A steady, nutrient-rich food supply depends on soil health. Heavy metals, herbicides, plastic debris, and over fertilisation alter soil microbiology, releasing dangerous compounds into groundwater (Münzel et al., 2023). Aquatic habitats are threatened by agricultural runoff, industrial pollution, and home sewage. Polluted air contains volatile organic compounds, greenhouse gases, and particle matter, which can cause respiratory, cardiovascular, and cancer (Rather et al., 2023). With an ageing population, osteoporosis has increased in China. According to the 2004 China Osteoporosis Prevalence Study, those over 50 had a 20% higher risk of osteoporosis. Recent data from Wang et al. (2021) confirm postmenopausal women and older men's increased risk.

Certain plants may solve health and ecological issues despite environmental concerns. Moringa oleifera, a nutritious and therapeutic plant, may be used in sustainable agriculture and ecosystem restoration. This study examines Moringa oleifera's phytochemical and bioactive qualities for health and environmental advantages. Increased consumption of processed foods high in omega-6 fatty acids and decreased intake of omega-3-rich seafood have been associated to bone health decline (Zhang & Wu, 2024). Research showing a high frequency of insomnia and poor sleep quality in older Chinese adults suggests dietary changes may affect bone density. Yan et al. (2024) say some medical problems enhance osteoporosis risk. China's ageing population is suffering from more sleep difficulties, thus this study investigates dietary solutions.

Moringa oleifera leaves, PUFAs, sleep problems, and primary osteoporosis in elderly people are the focus of this study. Since osteoporosis causes decreased bone density and an increased risk of fractures, nutrition and sleep are crucial to disease progression. Insufficient sleep hinders bone remodelling, which is needed for regeneration. This research tries to uncover dietary recommendations that may reduce geriatric osteoporosis and sleeplessness, which are common. Omega-3 polyunsaturated fatty acids are osteoprotective and anti-inflammatory, according to research. The goal of this study is to examine their impacts. Moringa oleifera leaves contain bioactive substances that may replace bone health treatments. Moringa supplementation will be compared to standard treatment in this study. Cost-effective, accessible dietary treatments like vitamin-fortified pills to help older Chinese manage sleep problems and osteoporosis are a priority. This study advocates for environmentally sustainable agriculture by highlighting the synergistic effects of Moringa oleifera leaves and omega-3 polyunsaturated fatty acids. These activities aim to improve long-term health and quality of life for elderly osteoporosis patients.

Literature Review

The Role of Polyunsaturated Fatty Acids and Moringa Oleifera leaf in Primary Osteoporosis Induced by Insomnia: Pathophysiological Mechanisms and Agricultural Implications

The Moringa oleifera plant, originally found in the tropical and equatorial regions of India, is a common sight in these areas. It has spread rapidly across various parts of the world, including Cambodia, the Philippines, and numerous African, Central American, and Caribbean nations. Moringa oleifera has long been recognized in traditional medicine for its remarkable ability to thrive in dry environments. Historical Ayurvedic texts show that this plant has been used for medicinal purposes since 150 BC, treating conditions such as skin problems, lung congestion, anaemia, and blood impurities. Known as the "Miracle Tree," moringa is celebrated not only for its adaptability and health benefits but also for its ability to address nearly 300 different medical conditions. Due to its impressive nutritional content and bioactive properties, Moringa oleifera is frequently referred to as a "superfood" in the food industry. Its PUFAs, antioxidants, vitamins, and amino acids make it an effective alternative for those suffering from primary insomnia caused by osteoporosis. Aside from its leaves, seeds, roots, bark, flowers, and fruits, Moringa oleifera likely has additional uses. Its seeds contain around 75% polyunsaturated fatty acids and are known for their anti-inflammatory, cholesterol-lowering, and bone-health-promoting properties.

Abd El-Hack et al. (2018) highlight the presence of β-carotene, provitamin A carotenoids, minerals, vitamins A and B, and various other bioactive compounds that exhibit antibacterial, anti-inflammatory, and antioxidant activities. Some of the key molecules identified include phenolics, chlorogenic acid, kaempferol, and flavonoids. Current research suggests that Moringa oleifera has potential not only in medicinal applications but also in ecological ones. It has shown promise in treating a variety of ailments, including cholera, osteoporosis, pneumonia, and cardiovascular diseases. The plant's phytochemicals, such as eugenol, tannins, and saponins, help reduce inflammation and oxidative stress, enhancing its ability to treat osteoporosis related to sleep disturbances. Beyond health benefits, moringa has significant potential for environmental applications, including soil restoration and water purification. Companies that prioritize sustainable farming practices can benefit greatly from exploring ways to combat desertification and enhance soil fertility. Moringa oleifera thrives on disturbed soils, making it a valuable resource. Techniques like coagulation are employed to grow seedlings and purify water.

Osteoporosis and Bone Health: Prevalence and Risk Factors

Osteoporosis is a global health concern, particularly affecting the elderly and women after menopause. This condition is marked by reduced bone mineral density, alterations in the structure of trabecular and cortical bone, and increased bone fragility, which raises the likelihood of fractures (Sabri et al., 2023). Osteoporosis is often asymptomatic, meaning that fractures may occur before the condition is diagnosed. Fragility fractures, especially hip fractures, are strongly linked to higher mortality rates and significant morbidity in older adults. Therefore, early detection and preventive measures are crucial (Sabri et al., 2023). Osteoporosis is prevalent on all five continents, but its occurrence varies across regions due to factors such as genetics, environmental influences, and access to healthcare. Liu et al. (2014) found that in China, 36% of women and 13% of men aged 50 and older are affected by osteoporosis, with urban populations showing higher rates. A study conducted by Wang et al. (2021), known as the China Osteoporosis Prevalence Study, suggests that this increase in prevalence is linked to an aging population, dietary changes, reduced physical activity, and insufficient vitamin D due to limited sun exposure in cities (Zhang & Wu, 2024). Moreover, rapid urbanization, reduced intake of local omega-3 fatty acid sources, and lifestyle changes may worsen the impact of osteoporosis (Wang et al., 2022).

The decline in estrogen production after menopause is a major factor in the development of osteoporosis, especially among postmenopausal women. Estrogen plays a vital role in bone health by inhibiting bone breakdown and encouraging bone formation (Vilaca, Eastell, & Schini, 2022). A decrease in estrogen accelerates bone turnover, increasing bone resorption and raising fracture risk. Although osteoporosis is commonly thought to affect women more than men, aging men are also at risk. As testosterone levels decrease with age, men experience bone loss as well (Diab & Watts, 2021). However, osteoporosis in men is often underdiagnosed and undertreated, despite its significant impact on health (Vilaca et al., 2022). In addition to hormonal changes, various factors contribute to osteoporosis, including lack of physical activity, smoking, alcohol use, poor diet, and genetic factors (Fang et al., 2023). Nutrition plays a critical role in bone health, with calcium and vitamin D being essential for bone formation. However, recent studies emphasize the importance of polyunsaturated fatty acids (PUFAs) in regulating bone metabolism and promoting bone health (Chen et al., 2024; Tao et al., 2022).

Insomnia and its Impact on Bone Health

Sleep disorders include insomnia, which causes trouble falling or staying asleep, can lead to metabolic, cardiovascular, and musculoskeletal issues (Swanson, 2022). Recent research have examined how sleep disruptions and chronic insomnia affect bone health and integrity (Swanson, 2021). Sleep disruptions can impair hormone balance and bone metabolism Petrov et al. (2024). Over time, sleep deprivation raises cortisol, which promotes osteoclasts, which break down bone tissue and resorb bone (Swanson, 2022). The condition is accompanied by a decrease in growth hormone, which is essential for bone formation and maintenanc e (Ochs-Balcom et al., 2020). Insufficient sleep stimulates the HPA stress response, which produces cortisol, which slows bone regeneration (Swanson, 2022). Bone resorption and formation imbalances lower BMD and increase fracture risk over time. This study tests the hypothesis: Bone health and sleep disorders are linked. A cross-sectional study by Ochs-Balcom et al. (2020) found that women who slept less than six hours per night had reduced BMD and an increased risk of fractures. Tang et al. (2021) linked sleep disruptions to lower BMD in adults, particularly older women. Disrupted sleep may cause bone loss, especially in postmenopausal women at risk for osteoporosis due to hormonal changes. Petrov et al. (2024) found that actigraphy-measured sleep parameters were substantially linked with bone turnover and BMD, confirming that inadequate sleep can harm younger bone health. Chronic sleeplessness causes hormonal disruption and inflammation that accelerates bone density loss. Sleep deprivation increases IL-6, a pro-inflammatory cytokine that activates osteoclasts and accelerates bone loss (Fang et al., 2023). This inflammation may worsen in insomniacs, increasing osteoporosis risk. Thus, modifying sleep habits, especially in older persons, can minimise bone loss and osteoporosis risk.

PUFAs and Bone Health

Essential nutrients including omega-3 and omega-6 polyunsaturated fatty acids regulate inflammation, lipid metabolism, and cellular signalling (Chen et al., 2024). Omega-3s, notably EPA and DHA, decrease inflammation and bone loss by affecting osteoporosis-related inflammatory markers (Alva, Pinto, & Gowda, 2024). Omega-6 fatty acids are important, but excessive ingestion might cause inflammatory reactions that aggravate bone loss, especially when their ratio exceeds omega-3s (Das, 2000). Recent research has shown that increasing omega-3 PUFA intake improves BMD and reduces osteoporosis risk. A meta-analysis by Gao et al. (2023) found that omega-3 PUFA supplementation in adults improved bone metabolism and BMD, lowering bone resorption and promoting bone formation.

Fang et al. (2023) used 2011–2018 NHANES data to assess dietary fatty acid intake and BMD in 25–59-year-olds. Omega-3 fatty acid-rich diets increased BMD compared to omega-6 fatty acid diets. This study emphasizes the importance of maintaining a balanced omega-3 to omega-6 ratio for optimal bone health and osteoporosis prevention. Feehan et al. (2023) conducted cross-sectional research to explore how estrogen deficiency impacts bone loss in postmenopausal women, revealing a positive correlation between omega-3 PUFA levels and BMD, while inflammatory markers showed an inverse relationship with PUFA levels. Studies suggest that omega-3 PUFAs may help improve bone health in postmenopausal women and decrease the risk of osteoporosis. Bone health is regulated by hormones such as Parathyroid Hormone (PTH) and insulin-like growth factor 1 (IGF-1), with research by Chen et al. (2024)

indicating that these hormones may influence PUFA levels and bone metabolism. IGF-1, in particular, promotes new bone formation and mineralization. A recent study by Wang, Fang, & Xie (2024) found that omega-3 fatty acids could increase BMD by stimulating IGF-1 signalling pathways, further supporting the role of omega-3s in bone health.

Interaction between Insomnia, PUFAs, and Bone Health

Research has explored the effects of sleep deprivation and PUFAs on bone health, but it remains unclear whether these factors contribute to osteoporosis independently or interactively. Sleep deprivation has been associated with a reduction in growth hormone levels, an increase in cortisol (the stress hormone), and heightened inflammation. These changes can disrupt bone metabolism by enhancing osteoclast activity and reducing BMD, as noted by Swanson (2021). On the other hand, PUFAs, particularly omega-3 fatty acids, have been shown to possess anti-inflammatory properties that support bone health (Chen et al., 2024). By reducing osteoclast activity and stimulating osteoblast function—through their inverse relationship—omega-3 fatty acids promote bone formation. With this understanding in mind, it becomes important to investigate whether PUFAs can prevent bone loss in individuals suffering from chronic insomnia.

Environmental Challenges and the Role of Plants

Environmental pollution adversely affects various aspects of the natural world, including water, land, and air quality, and human health is just one of the many areas impacted. Münzel et al. (2023) identify a range of pollutants, such as pesticides, heavy metals, plastic waste, and excessive fertilizers that degrade soil quality. These contaminants lead to decreased soil productivity and contaminate groundwater as beneficial bacteria are eliminated. Water pollution, caused by human waste, agricultural runoff, and industrial discharge, severely impacts aquatic ecosystems and the biodiversity within them. Rather et al. (2023) highlight that the rise in greenhouse gases and particulate matter emissions accelerates climate change and poses significant risks to respiratory and cardiovascular health. A sustainable, long-term solution to pollution and environmental degradation involves planting trees and vegetation. These plants help purify water and soil by filtering out harmful substances. Khandare & Govindwar (2015) suggest that green infrastructure, such as tree-planting initiatives, can contribute to better air quality, as plants produce oxygen and absorb harmful gases. Numerous studies have also indicated that the plant Moringa oleifera has the potential to improve both human health and the environment by reducing pollution levels.

Research Gap

While there is ample evidence showing that insomnia and PUFAs independently affect bone density in individuals with primary osteoporosis, limited research has examined their combined impact. Several studies have established insomnia as a significant risk factor for bone loss due to its effect on hormones, particularly raising cortisol levels and lowering Growth Hormone (GH) levels, both of which are critical for bone remodelling (Ochs-Balcom et al., 2020; Swanson, 2021). Additionally, research has shown that omega-3 PUFAs promote bone health by stimulating osteoblast production, inhibiting osteoclast-induced bone resorption, and reducing inflammation (Alva et al., 2024; Chen et al., 2024). However, there is a lack of studies investigating the interaction between insomnia and PUFA intake in relation to osteoporosis. While PUFAs are known to reduce inflammation and enhance bone quality, their potential to counteract the negative effects of chronic insomnia on bone health remains unclear (Fang et al., 2023; Feehan et al., 2023).

Furthermore, the precise molecular mechanisms through which PUFAs influence bone health in the context of sleep disorders like insomnia are not well understood. Research by Das (2024) and Swanson (2022) aims to explore how omega-3 fatty acids may reverse bone loss associated with insomnia, potentially through their anti-inflammatory and cortisol-lowering effects. There is also a gap in population-specific studies, particularly in regions such as China, where aging populations are facing rising rates of both sleep disorders and osteoporosis (Wang et al., 2021). Most of the available studies have been conducted on Western populations, highlighting the need for research focused on how lifestyle factors such as sleep quality and diet influence bone health in Asian populations, where sleep patterns and dietary habits may differ significantly (Yan et al., 2024; Zhang & Wu, 2024).

Although some studies have shown a relationship between sleep quality and BMD, there is a lack of longitudinal research to examine the long-term effects of insomnia, PUFA intake, and bone health over time (Liang et al., 2023). Most current studies are cross-sectional, limiting the ability to determine the causal relationship between sleep disturbances, dietary factors, and the progression of osteoporosis (Tao et al., 2022). Despite the established effects of insomnia and PUFA intake on bone density, research exploring their combined impact on osteoporosis is still lacking. Sleep deprivation is known to disrupt hormonal balance, increasing the risk of bone loss, as chronic insomnia is linked to low Growth Hormone (GH) levels and elevated cortisol levels, which inhibit bone remodelling and accelerate bone resorption (Ochs-Balcom et al., 2020; Swanson, 2021). Meanwhile, omega-3 PUFAs have been shown to reduce inflammation, activate osteoblasts, and protect against osteoclast-induced bone resorption, all of which benefit bone health (Alva et al., 2024; Chen et al., 2024).

However, there is currently no data on how PUFA supplementation may interact with insomnia to prevent bone loss. The Moringa oleifera plant, known for its rich bioactive compounds and high concentration of PUFAs, may offer a promising solution for mitigating insomnia-related anxiety and bone loss. The omega-3 fatty acids found in Moringa oleifera seeds have anti-inflammatory, cortisol-lowering, and BMD boosting effects. Additionally, the combination of flavonoids and phenolic acids in Moringa oleifera may provide the dual benefits of reducing oxidative stress and increasing bone density. Despite these promising effects, the molecular pathways through which Moringa oleifera influences bone health in relation to insomnia are still largely unknown.

Theoretical/Empirical Justification for the Variables

Sabri et al. (2023) note that BMD decreases with age, making the elderly more susceptible to fractures and other bone fragilities. Osteoporosis is more likely in postmenopausal women due to a significant drop in oestrogen levels (Vilaca et al., 2022). Sleep difficulties, especially insomnia, are becoming more widespread in the elderly, which may worsen hormone imbalances and circadian rhythms, which hasten bone loss (Swanson, 2021). In osteoporosis research, women, especially postmenopausal women, are more likely to develop the condition due to a rapid reduction in oestrogen, which maintains bone density (Vilaca et al., 2022). Although less common, osteoporosis in males is still a concern as they age and testosterone levels drop, affecting bone health (Diab & Watts, 2021). Targeted interventions for men and women require gender understanding (Wang et al., 2021). Due to hormonal modulation, insomnia increases osteoporosis risk. Insomnia increases cortisol and decreases growth hormone, which cause bone resorption (Swanson, 2022). Research on insomnia is crucial for understanding the link between sleep quality and bone health, as sleep disorders impair bone remodelling (Ochs-Balcom et al., 2020). BMD and T-score are essential osteoporosis diagnosis criteria. T-scores below -2.5 suggest osteoporosis (Sabri et al., 2023). Osteoporosis research and disease prediction depend on regular BMD testing to evaluate lifestyle and dietary changes (Wang et al., 2022). PUFAs, especially omega-3s, reduce inflammation, promote bone growth, and inhibit osteoclast activity to prevent bone resorption (Chen et al., 2024; Tao et al., 2022). Dong et al. (2014) found that greater PUFA levels inhibit bone turnover and boost BMD. Preventing osteoporosis may require studying the effects of PUFA-rich diets on insomnia-induced bone loss.

Smoking is a major risk factor for osteoporosis, affecting bone mass density, fracture risk, calcium absorption, and bone resorption (Fang et al., 2023). Smoking worsens the effects of insomnia on bone loss by disrupting sleep quality and increasing inflammation (Wang et al., 2022). Liu et al. (2016) found that alcohol consumption alters calcium homeostasis and reduces bone production, further increasing osteoporosis risk, which underscores the negative impact insomnia has on bone density (Swanson, 2022). Investigating lifestyle factors like alcohol consumption is essential for understanding their influence on bone health. Regular physical exercise, particularly weight-bearing activities, helps increase bone density and development, providing protection against osteoporosis (Feehan et al., 2023). Consistent physical activity improves sleep quality, which may mitigate the adverse effects of insomnia on bone density (Wang et al., 2022). Comorbid conditions like diabetes, cardiovascular disease, and hypertension increase osteoporosis risk by affecting bone remodelling and inflammation (Chen et al., 2024). These conditions also exacerbate insomnia, contributing to a cycle of deteriorating bone health. Understanding the role of comorbidities is crucial in studying the relationship between insomnia, PUFA intake, and osteoporosis (Feehan et al., 2023).

Research has shown that both underweight and obesity significantly impact bone mass, with Body Mass Index (BMI) serving as a critical indicator of bone health (Wang et al., 2022). Underweight individuals tend to have lower BMD, while obesity—especially central obesity—causes inflammation that leads to bone resorption (Fang et al., 2023). Both low and high BMIs have been linked to insomnia, suggesting that BMI influences sleep patterns and, consequently, bone health (Swanson, 2022). Sleep duration has a notable impact on bone mass. Reduced BMD and elevated Bone Turnover Markers (BTM) are associated with shorter sleep duration, which increases the risk of osteoporosis (Ochs-Balcom et al., 2020). Analysing sleep duration can help researchers understand how sleep deprivation influences PUFA intake and its potential in reducing bone loss. Osteoporosis prevalence differs between urban and rural populations, with factors such as access to healthcare, physical activity, and diet playing a role. Urban residents often experience higher stress levels, poor sleep, and lack of natural light, contributing to increased osteoporosis risk (Wang et al., 2021). Zhang & Wu (2024) propose that examining environmental factors in rural and urban areas can provide insights into osteoporosis development. This study focuses on the intersection of osteoporosis, insomnia, and polyunsaturated fatty acid (PUFA) intake, especially in aging populations. Moringa oleifera, a plant rich in bioactive compounds and PUFAs, offers a potential solution for improving bone health and addressing insomnia-related anxiety. With its high nutritional value, Moringa oleifera may help mitigate bone loss in rural populations in China and other aging regions. The research also explores the environmental and agricultural impacts of promoting Moringa oleifera as a sustainable crop in public health campaigns aimed at reducing osteoporosis and enhancing bone health.

Data and Methodology

Study Design

This cross-sectional observational study aimed to investigate the potential relationship between PUFAs and the development of primary sleep-related osteoporosis in an elderly Chinese population. Key parameters, including sleep quality, bone density, and fatty acid intake, were assessed through self-administered questionnaires. The goal was to explore the correlation between PUFA consumption and the onset of primary osteoporosis within the study group. The study also focused on Moringa oleifera due to its rich nutritional profile, which includes antioxidants, calcium, and anti-inflammatory compounds. Moringa's properties, particularly its ability to reduce inflammation and combat oxidative stress, are believed to be beneficial for older individuals in managing sleep issues, oxidative stress, and osteoporosis. Given its anti-inflammatory effects, moringa may play a significant role in mitigating these health concerns.

By examining the combined benefits of moringa and PUFAs, this research aims to provide valuable insights into dietary recommendations that could promote better health

outcomes for the elderly, specifically in the context of sleep-related osteoporosis.

Study Population and Sampling

The study involved 400 participants aged 60 years and older from both urban and rural areas in China. To ensure proper representation of all age groups, genders, and regions, the sample was carefully stratified. The inclusion criteria for the study were as follows:

- Participants must be 60 years or older.
- Must have consumed Moringa oleifera leaves.
- Must provide information on the frequency of Moringa oleifera leaf consumption.
- Must specify the form of Moringa oleifera consumption (fresh leaves, powdered supplements, or incorporated into meals).
- Must track the duration of Moringa oleifera usage, with a focus on consistent consumption over several months or years.
- Must have no history of secondary osteoporosis or other bone disorders not related to lifestyle factors.
- Willingness to participate and provide informed consent.

Exclusion criteria included individuals with pre-existing conditions such as rheumatoid arthritis, chronic corticosteroid use, or severe cognitive impairments, as these could potentially interfere with the study's outcomes.

Data Collection Tools

The purpose of this cross-sectional observational research was to examine the relationship between Moringa oleifera usage and the occurrence of primary sleep-related osteoporosis in a group of elderly Chinese individuals. The study was overseen by the Chinese government and aimed to explore several variables, including:

Variables

Dependent Variable: BMD was assessed using a T score to ascertain whether respondents exhibited osteoporosis at a T score of less than -2.5.

Independent Variables

Insomnia: Yes/No variable categorized or responded on the questionnaire for sleep quality.
PUFA Intake: Categorized and measured into Low, Moderate, and High.
Moringa Consumption**:** Categorized as Low, Moderate, and High, based on frequency of moringa intake.

Control Variables: Several potential confounders were included in the analysis:

Age: Coded as a continuous variable.
Gender: Coded as a binary variable (Male/Female).
BMI (Body Mass Index): Measured and included as a continuous variable.
Smoking: Coded as a binary variable (Yes/No).
Alcohol Consumption: Coded as a binary variable (Yes/No).
Physical Activity: Coded as a categorical variable (Low, Moderate, High).
Comorbidities: Coded as a binary variable (Yes/No) for conditions such as diabetes, hypertension, and cardiovascular disease.
Living Area: Coded as a binary variable (Urban/Rural).

Statistical Analysis

The collected data were analysed using STATA 22.0. The analysis involved several stages:
Descriptive Statistics: Mean, standard deviation, and frequency distributions were calculated for all variables to summarize the characteristics of the sample. These statistical measures helped in providing a clear overview of the data, allowing for a better understanding of the sample's demographics and key health factors.

Multivariate Logistic Regression

Logistic regression was employed to model the relationship between Insomnia (independent variable) and the likelihood of osteoporosis (dependent variable), while adjusting for age, gender, BMI, physical activity, comorbidities, and PUFA intake. The model also included an interaction term between PUFA intake and Insomnia to evaluate whether higher PUFA intake could potentially mitigate the adverse effects of Insomnia on bone health.

Pathophysiological Mechanism Exploration

The potential mediating role of sleep disturbances in bone loss was investigated using regression models. These models aimed to examine how Insomnia might influence inflammatory markers associated with bone resorption, such as cortisol levels and pro-inflammatory cytokines. The relationship between Insomnia and these markers was discussed in the context of existing literature, highlighting how disruptions in sleep can contribute to increased bone resorption and, consequently, bone loss.

Ethical Considerations

Ethical approval for this study was obtained from the Institutional Review Board (IRB). All participants provided informed consent before participating in the survey. The data collection process ensured the anonymity and confidentiality of respondents, and participants were informed of their right to withdraw from the study at any point without any consequences.

Results

Descriptive Statistics

Table 1 displays the range of characteristics (categorical variables) present in the sample of Chinese seniors. The consumption patterns of Moringa oleifera leaves were highly consistent across the population, with 32.5% of respondents classified as high consumers, 33.3% as low consumers, and 34.3% as intermediate users. This distribution underscores the necessity of conducting research to investigate the potential effects of varying dosages of Moringa oleifera leaf consumption on the risk of osteoporosis and other variables associated with the disease. In the study, which examined the relationship between nutrition and lifestyle and the risk of osteoporosis, 53% of the participants were female and 47% male, ensuring that the study was representative of both sexes. Osteoporosis, a condition that impacts a substantial fraction of the population (52%), may be significantly influenced by

dietary and behavioural factors, including the ingestion of Moringa oleifera leaves and PUFAs. An elevated risk of developing health issues, such as osteoporosis, has been associated with both the consumption of alcohol (51.5%) and the usage of tobacco (51.3%). The health of bones may be influenced by the interactions between the aforementioned activities and dietary behaviours, including the ingestion of PUFAs and Moringa oleifera fruits and foliage. Physical activity levels exhibit significant variation, with low levels comprising 35.3%, moderate levels comprising 30.8%, and high levels comprising 34%. To develop effective solutions for osteoporosis prevention, it is essential to have a comprehensive understanding of the relationship between physical activity and dietary choices, including the consumption of Moringa oleifera, as physical exercise is beneficial for bone health.

It may be more challenging to draw conclusions about the relationship between osteoporosis and specific dietary and lifestyle characteristics due to the fact that nearly half of the sample (48.5%) had comorbid conditions. In addition to the physiological processes that are affected by the ingestion of Moringa oleifera leaf and other nutrients, comorbidities may also entail modifications. Even though 52.8% of the population lives in cities, 47.3% still resides in rural areas. Consistent with a balanced state, environmental and behavioural variables impact both dietary characteristics and the risk of osteoporosis. Various geographical characteristics impact the relative advantages and risks of PUFA and Moringa oleifera leaf ingestion in this context. Osteoporosis affects a large number of people, and one research indicated a link between sleeplessness (in 52.5% of the sample) and the disease. More studies are needed to confirm the association between sleeping disorders, Moringa oleifera leaf use, and the risk of osteoporosis. Poor sleep quality may impact both food choices and bone density. Low (35%), moderate (34.3%), and high (30.8%) PUFA consumption was used to categorize the population. This distribution can be used to examine how eating Moringa oleifera leaves and PUFAs correlates with other risk factors for osteoporosis, such as inadequate sleep and physical inactivity.

Table 1: Descriptive Statistics.

Variable	Categories	Frequency	Percent
Moringa Oleifera Leaf Consumption	Low	133	33.3
	Moderate	137	34.3
	High	130	32.5
Gender	Male	188	47
	Female	212	53
Having Osteoporosis	No	192	48
	Yes	208	52
Smoking Habit	No	195	48.8
	Yes	205	51.3
Alcohol Consumption	No	194	48.5
	Yes	206	51.5
Physical Activity Level	Low	141	35.3
	Moderate	123	30.8
	High	136	34
Comorbidities (Yes/No)	No	206	51.5
	Yes	194	48.5
Living Area	Rural	189	47.3
	Urban	211	52.8
Having Insomnia	No	190	47.5
	Yes	210	52.5
PUFA Intake Level	Low	140	35
	Moderate	137	34.3
	High	123	30.8

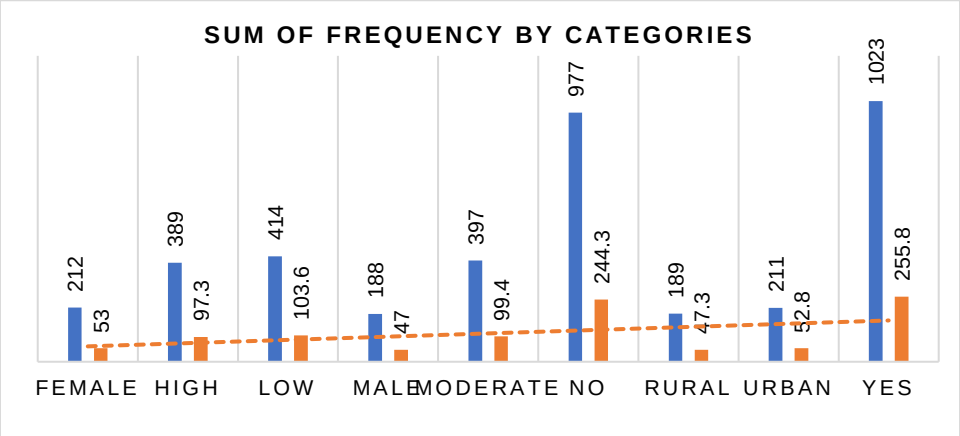

Figure 1: Descriptive Statistics.

Multivariate Analysis: PUFA, Insomnia, and Osteoporosis

Primary osteoporosis and agitation are strongly correlated, according to the research. The risk ratio for primary osteoporosis was 1.28 in individuals who reported difficulty sleeping compared to those who reported no such problem. However, this finding did not reach the significance threshold ($p>0.05$). Primary osteoporosis was shown to be strongly correlated ($p < 0.05$) with increased consumption of PUFA, according to the study. The odds ratio for primary osteoporosis was 2.797, indicating that individuals who ingested a substantial quantity of polyunsaturated fatty acids were nearly 2.8 times more likely to develop the disease than those who consumed very little. The occurrence of primary osteoporosis in individuals with insomnia was reduced by a statistically significant interaction between high PUFA intake and insomnia (odds ratio = 0.406; $p < 0.05$). According to preliminary research, the Moringa oleifera leaf, which is nutrient-dense, may facilitate the consumption of a greater quantity of PUFAs. Consequently, there is a possibility that individuals may experience fewer symptoms of insomnia and be less likely to develop primary osteoporosis. This suggests a moderating effect, where PUFA potentially mitigates the negative impact of insomnia on osteoporosis risk (see Table 2).

Table 2: Multivariate Analysis.

Variables in the Equation	B	S.E.	Wald	df	p-Value	Odds Ratios	95% C.I. for Odds Ratios	
							Lower	Upper
Interaction: Insomnia * High Intake of Moringa Oleifera Leaf	-0.721	0.428	2.846	1	0.092	0.486	0.207	1.141
Having Insomnia (RC: No Insomnia)	0.248	0.245	1.021	1	0.312	1.281	0.793	2.07
High Intake of Polyunsaturated Fatty Acid (PUFA) (RC: Low Intake)	1.028	0.342	9.02	1	0.003	2.797	1.429	5.472
Having Insomnia * High Intake of PUFA	-0.902	0.457	3.902	1	0.048	0.406	0.166	0.993
High Moringa Oleifera Leaf Intake (RC: Low Intake)	0.815	0.335	5.916	1	0.015	2.259	1.17	4.361
Age	-0.017	0.012	2.098	1	0.147	0.983	0.961	1.006
Female Gender (RC: Male)	-0.009	0.209	0.002	1	0.966	0.991	0.659	1.492
Smoking (RC: Not Smoking)	0.125	0.208	0.36	1	0.548	1.133	0.754	1.704
Consuming Alcohol (RC: Not Consuming)	-0.081	0.207	0.153	1	0.696	0.922	0.614	1.384
Physical Activity Level (RC: Low)			1.658	2	0.436			
- Moderate	0.321	0.257	1.555	1	0.212	1.378	0.833	2.281
- High	0.223	0.251	0.789	1	0.374	1.249	0.764	2.042
Comorbidities (RC: No)	0.104	0.207	0.254	1	0.614	1.11	0.74	1.666
BMI	-0.018	0.021	0.723	1	0.395	0.983	0.943	1.023
Living in an Urban Area (RC: Rural)	0.359	0.207	2.998	1	0.083	1.432	0.954	2.151
Sleep Duration (hours)	0.099	0.073	1.835	1	0.176	1.104	0.957	1.275
Constant	0.551	1.149	0.229	1	0.632	1.734		

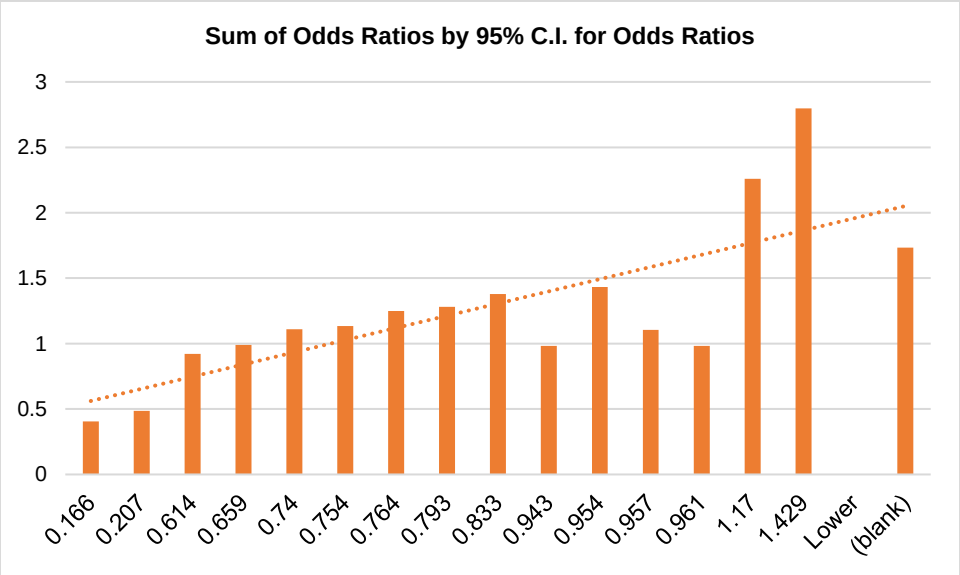

Figure 2: Multivariate Analysis.

Age did not have a statistically significant association with primary osteoporosis (odds ratio = 0.983; $p > 0.05$), indicating a minimal effect of age on reducing the likelihood of primary osteoporosis, but this was not significant. There was no significant gender difference in the likelihood of developing primary osteoporosis. Smoking (odds ratio = 1.133, $p = 0.548$) and consuming alcohol (odds ratio = 0.922, $p = 0.696$) did not have statistically significant associations with primary osteoporosis. Both moderate and high physical activity levels did not show statistically significant associations with primary osteoporosis compared to low activity levels. Comorbidities were not significantly associated with primary osteoporosis. BMI did not significantly affect the likelihood of developing primary osteoporosis. Living in urban areas (compared to rural areas) indicated a marginally significant association ($p = 0.083$) with an increased risk of primary osteoporosis, with an odds ratio of 1.432. Sleep duration was not significantly associated with primary osteoporosis. The consumption of Moringa oleifera leaves is associated with a statistically significant reduction in the risk of osteoporosis ($p < 0.05$). The odds ratio of individuals who consume Moringa oleifera leaf is nearly two-to-one (2.259), suggesting that their likelihood of reducing their risk of osteoporosis is significantly increased. The protective tendency ($p = 0.092$) observed in the interaction between insomnia and Moringa oleifera leaf ingestion implies that the leaf may have a moderating effect on the incidence of osteoporosis in individuals who suffer from insomnia. The results, which demonstrate the efficacy of Moringa oleifera leaves and PUFA in the treatment of primary osteoporosis brought on by insomnia, have significant implications for agriculture and nutrition.

Discussion

The healthiest and most densely packed bones could be yours when you commit to a diet full of nutrients, particularly focusing on the complex relationship between PUFAs and insomnia. Omega-3 fatty acids play a role in maintaining bone density, but excess omega-6 polyunsaturated fat might have negative consequences. High consumption of omega-6 fatty acids has been linked to an increased risk of developing primary osteoporosis, as it may lead to inflammation that affects calcium absorption and vitamin D metabolism, both critical for bone health (Calder, 2006; Das, 2000; Simopoulos, 2002). This inflammation may also lead to increased osteoclast activity, further affecting bone density and resorption (Alva et al., 2024; Tao et al., 2022). Studies have shown that excessive omega-6 fatty acids, particularly when unbalanced by omega-3s, may exacerbate the inflammatory processes that contribute to osteoporosis. According to Das (2000), a higher omega-6 to omega-3 ratio has been associated with an increased risk of osteoporosis and reduced bone mass density. This highlights the importance of controlling dietary fat intake and maintaining a balanced intake of omega-3 and omega-6 fatty acids. An imbalance in these fatty acids can also reduce the body's ability to absorb calcium, a crucial element for healthy bone growth (Liang et al., 2023; Wang et al., 2022). Research has shown that higher levels of omega-6 are associated with greater bone resorption and lower bone mineral density, suggesting that excessive omega-6 fatty acid consumption may directly impact bone health.

Additionally, low levels of polyunsaturated fatty acids can contribute to fatigue, a known correlate of insomnia and lower bone mineral density (Ochs-Balcom et al., 2020; Swanson, 2022). Anxiety and fatigue, both potential side effects of high omega-6 PUFA intake, may further exacerbate sleep disturbances (Chen et al., 2024). Our findings contradict those of Petrov et al. (2024), who found that individuals with insomnia showed lower rates of bone turnover. However, this research suggests that the combined effects of insufficient sleep and high omega-6 PUFA intake may contribute to bone damage. Omega-3 fatty acids, found in fish oil, have been shown to significantly promote bone health by reducing inflammation and increasing calcium absorption, as noted by Chen et al. (2024). While a diet rich in omega-6 fatty acids may increase the likelihood of developing osteoporosis, a diet high in omega-3 fatty acids may reduce its severity. Studies on bone metabolism have shown improved bone health in individuals taking omega-3 PUFA supplements (Gao et al., 2023). However, excessive omega-6 consumption may counteract these benefits (Yan et al., 2024). A substantial body of evidence suggests that those with diets high in omega-6 fatty acids face a higher risk of primary osteoporosis, likely due to the inflammatory effects of omega-6 that disrupt calcium homeostasis and promote bone resorption. These changes might also contribute to sleep disorders such as insomnia, further complicating the condition. In conclusion, both omega-3 and omega-6 fatty acids play essential roles in bone health. Consuming them in appropriate quantities may help prevent osteoporosis and support bone strength. However, the benefits of omega-3s can be compromised by an excessive intake of omega-6 fatty acids, suggesting the importance of maintaining a balanced diet to support both bone health and overall well-being.

Conclusion and Policy Recommendations

Insufficient sleep, as shown in this study, contributes to the body's production of PUFAs, which may increase the likelihood of developing primary osteoporosis. While omega-3 fatty acids have been shown to mitigate the negative effects of sleep deprivation on bone density, the overall association between PUFA consumption and osteoporosis risk remains a concern. Research has consistently demonstrated that both short-term and long-term insomnia can elevate the risk of osteoporosis. Increasing omega-3 fatty acid intake may help counteract this effect due to its anti-inflammatory properties and role in calcium metabolism, which are essential for maintaining bone density. A study conducted in Malaysia found no significant associations between osteoporosis risk factors—such as exercise, smoking, or alcohol consumption—when controlling for demographic and fixed factors. This suggests that dietary interventions, particularly increasing omega-3 PUFA intake, may be a more effective approach to improving bone health and

reducing sleep disturbances in the elderly. According to the findings of this study, individuals who regularly consume high amounts of omega-3 fatty acids are significantly less likely to experience sleep-related bone loss.

As a result of these findings, specific recommendations can be made to support bone health. Public health organizations and government agencies should promote the benefits of an omega-3-rich diet, particularly for aging populations who are at a higher risk of developing osteoporosis. Raising awareness about the protective effects of omega-3 fatty acids against PUFA-induced sleep disruptions may also contribute to better overall health outcomes. Ensuring that both urban and rural populations adhere to recommended dietary guidelines could be facilitated through collaboration between healthcare professionals, including doctors and nutritionists. Overconsumption of omega-6 fatty acids, which have inflammatory properties, may further increase the risk of osteoporosis. On the other hand, omega-3 PUFAs have shown potential in alleviating insomnia due to their therapeutic benefits. Maintaining healthy bones requires a balanced diet that prioritizes omega-3 intake while keeping omega-6 levels in check. The primary goal should be to encourage a well-rounded dietary approach that supports bone health through optimal polyunsaturated fatty acid consumption.

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