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Blue Zone Dietary Patterns, Telomere Length Maintenance, and Longevity: A Critical Review

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Abstract

Blue Zones are regions known for exceptional longevity and lower reported incidences of some chronic diseases, potentially linked to their unique dietary patterns. This review critically examines the nutritional practices of five Blue Zones—Okinawa, Sardinia, Nicoya, Ikaria, and Loma Linda—focusing on their contributions to health, longevity, and telomere length maintenance, a marker of cellular ageing. Blue Zone diets are predominantly plant-based, emphasising whole grains, legumes, fruits, and vegetables, with moderate consumption of meat and milk products. Fermented foods, rich in probiotics, are commonly consumed and play a role in reducing inflammation and supporting gut health. The Okinawan practice of "hara hachi bu" (eating until 80% full) exemplifies the role of caloric restriction in reducing oxidative stress and slowing ageing, particularly in this specific population. This review aims to evaluate the effect of Blue Zone dietary patterns on chronic disease prevention and cellular ageing mechanisms. A systematic review of peer-reviewed studies published between 2000 and 2024 was conducted using PubMed, Scopus, web of Science, and Google Scholar databases, and sixteen studies were critically analysed for dietary practices. Findings indicate that these diets are linked to improved health outcomes, including markers of reduced risk for cardiovascular disease, cancer, and diabetes, in studies conducted in Blue Zone populations. These diets promote cellular health through anti-inflammatory and antioxidant-rich foods, which help preserve telomere length, a critical factor in delaying the ageing process. While the findings suggest that Blue Zone dietary practices are associated

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with longevity and some chronic disease prevention, these observations are largely population-specific and influenced by regional cultural and environmental factors. Incorporating these principles into public health policies could enhance health outcomes and extend lifespan across diverse populations.

Introduction

Blue Zones (BZ) refers to regions around the world where people exhibit exceptional longevity and experience notably low rates of chronic diseases compared to other areas. This phenomenon has garnered significant attention due to these regions' remarkable health and lifespan outcomes. The five well-known BZ include Okinawa in Japan, Sardinia in Italy, Nicoya in Costa Rica, Ikaria in Greece, and Loma Linda in California, USA.[1] These areas share common dietary patterns that are thought to contribute to their inhabitants' extraordinary health and longevity. The term "Blue Zone" was introduced by demographer Michel Poulain and physician Gianni Pes while studying and confirming the longevity of centenarians in Sardinia.[2] This study aims to critically examine the existing research on the nutritional practices prevalent in BZ, focusing on their potential health benefits and the underlying mechanisms driving these benefits. By exploring these dietary patterns, the review seeks to provide valuable insights that can inform public health interventions and strategies to improve health outcomes and extend lifespan across diverse populations.[3-6]

The modern diet, characterised by the high consumption of junk food, fast food, and packaged food, has become a significant concern due to its impact on health. These dietary patterns, often high in refined sugars, unhealthy fats, and artificial additives, have been linked to the rising prevalence of obesity, a major risk factor for numerous chronic diseases. Research indicates that such diets contribute to excessive caloric intake, poor nutritional quality, and adverse metabolic effects, which collectively promote obesity and its related complications.[7,8]

The detrimental effects of a diet high in processed foods extend beyond weight gain. Emerging evidence suggests that these dietary patterns are associated with accelerated telomere shortening, a biomarker of cellular ageing.[9] Telomeres, the protective caps at the ends of chromosomes, shorten as cells divide, and their accelerated loss has been linked to increased risk of age-related diseases and reduced lifespan.[10] Studies have shown that diets high in processed and high-glycemic-index foods are correlated with shorter telomeres, highlighting a potential mechanism by which poor dietary choices may contribute to ageing and chronic health conditions.[11,12]

In contrast, diets rich in natural and raw foods, such as fruits, vegetables, whole grains, and lean proteins, have been associated with better health outcomes and longer telomere length.[13] These foods are typically high in essential nutrients, *Antioxidants*, and anti-inflammatory compounds, which help protect against oxidative stress and inflammation—key factors that influence telomere integrity. Research supports that adherence to nutrient-dense, plant-based diets is linked to improved health metrics, reduced risk of chronic diseases, and potentially slower cellular ageing.[14]

Telomere length maintenance is increasingly recognised as a key biological ageing and longevity biomarker.[15] Telomeres, the protective caps at the ends of chromosomes, shorten progressively with each cell division, leading to cellular senescence or apoptosis when they become critically short.[16] This shortening process is accelerated by oxidative stress and chronic inflammation, which contribute to age-related diseases such as cardiovascular disease, diabetes, and cancer.[17] Therefore, the ability to preserve telomere length is associated with healthier ageing and longer life spans. Research has shown that certain lifestyle factors, including diet, can slow telomere attrition and even promote telomere repair, thus delaying the onset of age-related cellular damage.[18]

Diet plays a crucial role in modulating telomere length through its impact on oxidative stress and inflammation. The "Blue Zone" diets—found in regions like Sardinia, Okinawa, and Loma Linda—

are predominantly plant-based, rich in *Antioxidants*, fibre, and anti-inflammatory compounds, all of which help protect against oxidative damage and inflammation.[14] Antioxidant-rich foods, such as fruits, vegetables, whole grains, and legumes, neutralise free radicals that cause oxidative stress, thereby reducing the rate of telomere shortening.[19] Consumption of animal organs, fish, and animal-derived products is moderate to high in certain blue zone areas like Okinawa and Sardinia.[20] Ample amounts of healthy fats found in Blue Zone diets, especially in fish and nuts, have been linked to lower inflammation and slower telomere attrition.[21] These dietary practices contribute to lower incidences of chronic diseases and promote longevity by maintaining cellular health.[22] While Blue Zone dietary patterns provide valuable insights into health and longevity, their effectiveness must be understood within the cultural and environmental contexts of these unique populations.

The study of the relationship between diet, telomere length, and longevity is critical for public health, as it provides insight into how lifestyle interventions can mitigate age-related diseases and promote longer healthier lives.

Aim

The study aims to explore how these diets contribute to longevity at the cellular level, with a particular focus on telomere length maintenance and the prevention of age-related diseases, to provide insights for potential public health applications in diverse populations.

Objectives

This study aims to critically examine the dietary patterns of Blue Zone populations—specifically in Okinawa, Sardinia, Nicoya, Ikaria, and Loma Linda—and evaluate their impact on health outcomes, including the reduction of chronic diseases, inflammation, and oxidative stress.

Materials and Methods

This critical review explores the dietary patterns of Blue Zone populations and their potential role in telomere length maintenance, longevity and overall health. Abroad and integrative approach was used to analyze relevant literature, drawing from diverse sources to provide a well-rounded perspective.

Literature selection approach: Relevant observational and experimental studies, review articles were identified using open-access databases such as Pubmed, Scopus, Web of Science and Google Scholar. The selection was guided by key concepts related to Blue Zone dietary habits, telomere biology and aging, ensuring a diverse range of perspectives were considered.

Key Search terms used included combinations of the following: “Blue Zones,” “dietary patterns,” “longevity,” “Mediterranean diet,” “plant-based diet,” “healthy ageing,” “Okinawan diet,” “Sardinian diet,” and “chronic disease prevention.” Boolean operators such as AND, OR, and NOT were applied to refine the search and ensure relevant articles were captured.

Studies were chosen based on their relevance, scientific rigor, and contribution to the understanding of how the Blue Zone diets influence metabolic and cellular health. Both primary research and critical reviews were considered to provide a balanced interpretation.

Scopes and Focus

The review specifically examinesthe common dietary principals observed across Blue Zones, with a focus on whole foods,plant based eating and moderate consumption of animal products. The potential impact of these diets on oxidative stress, inflammation and telomere length, key markers of biological aging.How cultural, lifestyle and environmental factors interact with dietary habits to influence longevity in these populations.This review critically evaluates the strengths, limitations and inconsistencies in the existing literature,identifying gaps and potential areas for future research.Studies emphasizing mechanistic links between diet and telomere biology were given particular attention.

Inclusion and Exclusion Criteria

Inclusion Criteria

- Peer-reviewed and open-access articles.
- Studies that discuss dietary patterns within recognised Blue Zones (Okinawa, Ikaria, Sardinia, Loma Linda).
- Articles published between 2000 and 2024
- Studies are available in full-text for free
- English language studies.

Exclusion Criteria

- Non-peer-reviewed or non-open-access articles are unavailable without paywalls.
- Articles focusing primarily on non-dietary factors (e.g., exercise, social networks).
- Studies on populations outside the recognised Blue Zones.
- Articles focusing on isolated dietary components without broader health correlations were excluded to maintain focus on holistic dietary patterns.

Data Extraction

After completing the initial search, duplicate results were removed. Titles and abstracts were screened to determine relevance based on the inclusion and exclusion criteria. Full-text articles were then reviewed. Extracted data included:

- Study type (e.g., observational, longitudinal, cross-sectional).
- Geographic location and population details.
- Dietary elements and their categorisation (e.g., plant-based, meat consumption).
- Health and longevity outcomes (e.g., mortality rates, disease reduction).
- Limitations, such as small sample sizes or methodological biases.

Critical Analysis and Synthesis

The findings were synthesized thematically exploring predominantly plant based diets and their association with reduced oxidative damage and enhanced telomere stability. Minimal intake of processed foods and refined sugars, reducing metabolic stress. The role of polyphenol rich foods (e.g.legumes, nuts, olive oil, alcohol in moderation)in cellular protection and longevity. Interpaly between diet, gut microbiota and systemic inflammation, which may influence aging and telomere attrition.

Limitations of the Review

Potential limitations of the review include reliance on observational studies, exclusion of non-English studies, and challenges in accessing subscription-based databases. Efforts to address these limitations included using a comprehensive search strategy and focusing on open-access articles to enhance the study's transparency and replicability.

Results

Overview of Blue Zone Dietary Patterns

BZ include Okinawa (Japan), Sardinia (Italy), Nicoya (Costa Rica), Ikaria (Greece), and Loma Linda (California, USA). The common dietary practices in these regions are characterised by:

Predominantly Plant-Based Diets

High consumption of vegetables, legumes, fruits, and whole grains, with minimal intake of processed foods and animal products.[3-6, 23,24]

Moderate Animal Product Consumption

Small amounts of animal proteins, such as pork and chicken, and animal-derived foods, such as goat and sheep cheese, are included, contributing essential nutrients while maintaining an overall plant-forward dietary pattern[20,25]

Moderate Alcohol Consumption

Particularly red wine, consumed in moderation, often with meals.[3,23,26,27]

Caloric Restriction Practices

For example, the Okinawan practice of "hara hachi bu" (eating until 80% full).[27-29]

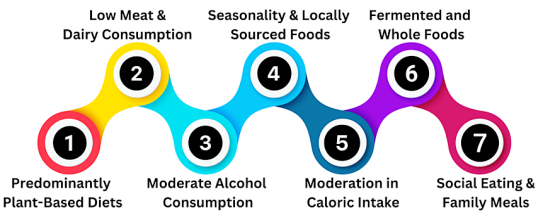

Fig 1: Common Dietary Practices in Blue Zone

Fermented Food Products

The diets in Blue Zones frequently include fermented foods, such as certain cheeses like casu axedu, a sour cheese made from goat or sheep milk, which shares similarities with yoghurt. Other fermented products include various types of curds and yoghurts. Traditional bread, like the flat, dehydrated pistoccu and sourdough bread, is also notable for its high lactobacilli content.[2] Figure 1. Shows the common dietary practices in the Blue Zones.

Table 1: Blue Zone dietary patterns and their impact on telomere length maintenance and longevity

Study	Location	Population		Duration	Intervention of study	Parameter Measured	Health Outcomes
		Age Group	Number				
Cohort study[4]	California	30 years and above	34,192	1976 to 1988	Questionnaire on diet, exercise, smoking, body weight, and hormone replacement therapy	Diet, exercise, smoking, body weight, and hormone replacement therapy	California Adventists has higher life expectency than whites california
Prosctive[5] cohort study	Greece	18 years above	22,043	44 months	10-point Medite-rranean-diet scale	Mediterranean-diet score	Lower total mortality, lower coronary heart disease mortality, lower cancer mortality
Observational study[6]	US	43–69 years	660	1976 to 1990	Various diet-quality scores (HEI, AHEI, DQI-R, RFS, aMED) were used.	Alternate Healthy Eating Index (AHEI), Dietary Approaches to Stop Hypertension (DASH), Plasma biomarker CRP, IL-6, E-selectin, sICAM-1, sVCAM-1	Higher-quality diets were linked to lower levels of inflammation and endothelial dysfunction, suggesting a reduced risk of cardiovascular disease.
Observational cohort study[28]	Okinawa, Japan	≥100 years	~900	Ongoing (since 1975)	Genetic and lifestyle analysis	Genetic markers, inflammation markers, lifestyle factors	Exceptional longevity, reduced age-related diseases, low inflammation, extended lifespan
Ecological study[3]	Sardinia, Italy.	60 years above	Male pop -ulation	Early decades	Nutritional variables,	Lifestyle and nutrition	Low LDL, high HDL, lower oxidative stress

			across 377 municipa -lities.	of the 20th century.	pastoralism, physical activity.		
Observational study[25]	Nicoya, Costa Rica	60 years above	16,300	1990 to 2011	Traditional foods like rice, beans, and animal protein; low glycemic index and high fiber content	Lifestyle factors contributing to longevity	Longer telomere lower blood pressure
Prospective cohort study[30]	North America (Adventist Health Study 2)	Younger than 25 years	73,308	2002 to 2009	Assessed via a quantitative food frequency ques-tionnaire, categorized into five dietary patterns	Food frequency questionnaire	Lower mortality
Randomized Control trial[31]	Spain	55 to 80 years	7447	4.8 years	Mediterranean diet supplemе-nted with extra-virgin olive oil or mixed nuts, compared to a control diet	Mediterranean diet supplement	Reduced -lar events infarction, stroke), Lower LDL, higher HDL, improved blood pressure
cohort study[32]	USA	50 years above	6,381	18 years	Protein intake categorized as low, moderate, or high	Protein Intake	Lower protective effects in younger adults
Population-based cohort	USA.	21 years above	4,676	1976 to 1990	Alternate Medi-terranean Diet	Telomere length	Longevity, aging, Longer

study.[13]					score from food frequency questionnaires.		telomere length
Cross-sectional observational study[33]	Loma Linda, California	23 years above	474	2009 to 2013	Semen analyses and dietary self -categorization	Sperm chare -ctoristics	Higher, sperm count, improved sperm motility
Cross-sectional observational study[34]	Evdilos and Raches, Ikaria, Greece	90 years	71	several years	Mediterranean Islands study food frequency questionnaire (MEDIS-FFQ)	MEDIS-FFQ	High social interaction, adherence to the Mediterranean diet
Evaluative study[35]	Sardinian Blue Zone and Cagliari	60 years above	95	extended period	Mental health and religiosity	Life satisfaction and optimism	Higher life satisfaction, better resilience
Observational study[1]	Sardinia, Italy	90-101 years	150	decades	Consumption frequency of common food items assessed via validated questionnaires	Health indicators in oldest-old	Improved cognitive function, lower disability
Prospective analysis[36]	Costa Rica	60 years above	909	several years	Food frequency questionnaire and Principal Component Analysis (PCA)	Leukocyte telomere length	between diet and telomere length in Costa Rican elderly
Cohort study[37]	Northern	85 years Sweden	1602 above	2000-2002 to 2015-2017	Mini Nutritional Assessment (MNA) scores and BMI classification	Nutritional patterns in centenarians	Improved nutritional status, reduced dementia

In examining the relationship between diet and longevity in Blue Zones, various studies have explored the dietary patterns of long-lived populations, with particular attention to regions like Sardinia, Okinawa, and Loma Linda. These studies highlight how specific nutritional habits, particularly plant-based and minimally processed foods, contribute to the health and longevity of these populations. In the following section, studies will be grouped and summarised based on their geographical focus, population, intervention, measured health outcomes, and observed results. Table 1. summarises the implications of the Blue Zone diet throughout the globe and its significant impact on telomere length maintenance and longevity.

Sardinia and Mediterranean Diet

Several studies have focused on Sardinia, Italy, one of the most well-known Blue Zones. A literature review published in 2022 investigated the dietary patterns of Sardinian centenarians, specifically examining the consumption of traditional plant-based foods and fermented dairy products.[38] The study found that Sardinian diets, rich in whole grains, legumes, and fermented goat or sheep milk products like casu axedu, were associated with increased longevity and lower mortality rates. The high consumption of these traditional foods was thought to improve cardiovascular health and reduce inflammation, contributing to the region's high number of centenarians. The research also suggests that Sardinia's isolated pastoral lifestyle, with low meat consumption and reliance on dairy, grains, and foraged vegetables, plays a role in the longevity of its population. In Sardinia, the diet includes significant contributions from animal-derived foods such as goat and sheep cheese, along with traditional plant-based staples like legumes and whole grains.[1] The consumption of animal foods, particularly dairy products provides a vital source of protein that helps preserve muscle mass in the elderly.[32] Additionally, moderate consumption of locally produced red wine, rich in resveratrol and proanthocyanidins, contributes to mortality due to heart diseases, promoting longevity in the region.[1]

An epidemiological study conducted by Canelada Fernández in 2021 explored the intergenerational nutritional habits of the Sardinian population and their impact on public health.[2] This study found that the traditional Sardinian diet, particularly its emphasis on whole grains, legumes, vegetables, and fermented dairy products, contributed to a lower prevalence of chronic diseases, such as cardiovascular disease and cancer. The study concluded that the Sardinian diet's focus on plant-based foods and fermented milk products played a key role in promoting longevity.

In a historical analysis conducted by Pes *et al.* in 2015, the authors reviewed dietary habits over time and their association with male longevity in Sardinia.[3] The study focused on the dietary patterns of Sardinian men, particularly in remote areas, and found that traditional foods like whole grains, legumes, and sourdough bread were strongly correlated with increased life expectancy. This study underscored the role of conventional, non-industrialized diets in promoting long life spans, especially in regions less influenced by modern dietary habits.

An epidemiological study conducted by Pes *et al.* in 2021 explored the association between dietary patterns and body weight management, focusing on the role of inflammation and oxidative stress in obesity.[20] This study found that consuming an anti-inflammatory, antioxidant-rich diet—including fruits, vegetables, whole grains, and healthy fats—can help reduce obesity-related inflammation and oxidative stress. The authors concluded that such dietary habits contribute to better weight management and overall metabolic health by mitigating the pro-inflammatory state commonly associated with obesity.

The research on Sardinia highlights the Mediterranean diet's core components—plant-based foods, olive oil, whole grains, and moderate consumption of fermented dairy. These studies suggest Sardinian longevity is closely linked to dietary habits promoting cardiovascular health and reducing inflammation.

Okinawa and Caloric Restriction

The Okinawa region of Japan is another Blue Zone known for its high concentration of centenarians. Willcox *et al.* conducted a study in 2006 focusing on caloric restriction and its impact on longevity in Okinawan populations.[28] The study highlighted that the traditional Okinawan diet is low in calories and rich in nutrient-dense vegetables, tofu, and sweet potatoes. These foods provide essential nutrients

while maintaining a low caloric intake, which has been shown to reduce inflammation and oxidative stress, key factors in promoting long-term health.

Another study by Willcox *et al.* in 2006 delved into the genetic and dietary factors contributing to longevity in Okinawa.[39] The study noted that the combination of a traditional, low-calorie diet and a strong genetic predisposition for longevity resulted in a reduced risk of age-related diseases, such as cardiovascular disease, cancer, and neurodegenerative disorders. The research also emphasised that the Okinawan diet, high in vegetables, seaweed, and legumes, has anti-inflammatory properties that contribute to long life expectancy. The Okinawan diet emphasises nutrient density and caloric restriction through sweet potatoes, seaweed, and tofu. Although intelligent use of all edible parts of pork and freshwater fish provides essential nutrients like collagen and elastin that support cell health, wound healing, and cognitive function. Additionally, traditional methods like fat removal (Akatsuki) and low salt consumption contribute to better heart health, complementing the mineral-rich local water in promoting longevity.[1]

A review article published in 2014 by Willcox *et al.* compares primarily older Okinawan populations with younger generations post-WWII.[40] This research examines the impact of the traditional Okinawan diet on longevity and age-related chronic diseases, particularly cardiovascular disease, cancer, and diabetes. Key elements of the diet include high consumption of vegetables, legumes, fish, and medicinal plants, paired with low saturated fat intake. These dietary features, shared with Mediterranean and DASH diets, contribute to reduced inflammation, oxidative stress, and improved cardiovascular health. The study highlights that Okinawan elders experience lower rates of chronic diseases compared to younger Okinawans and Westernized populations, largely due to the diet's low caloric density and high phytonutrient content, which support healthier ageing. However, post-war dietary shifts, particularly among younger Okinawans, have resulted in increased calorie intake and rising obesity, prompting public health concerns. Despite this, Okinawan elders maintain healthier risk profiles, underscoring the benefits of traditional dietary patterns. The study concludes that while the Okinawan diet remains one of the healthiest, there is an urgent need for public health efforts to encourage younger generations to return to traditional eating habits to combat rising chronic disease risks.

Loma Linda and Plant-Based Diets

The Loma Linda region of California, home to a large population of Seventh-day Adventists, is another Blue Zone where plant-based diets have been linked to increased longevity. A cohort study by Fraser and Shavlik in 2001 examined the dietary habits of Seventh-day Adventists, focusing on their predominantly vegetarian diet.[4] The research reveals that individuals following a vegetarian diet have significantly lower mortality rates and a reduced risk of cardiovascular diseases, with specific measures indicating lower incidence rates of conditions such as hypertension and diabetes. Additionally, the study highlights a decreased occurrence of certain cancers among this population, showcasing improved overall health outcomes compared to the general population.

The Loma Linda population, which emphasises plant-based eating and avoiding processed foods, demonstrated longer life expectancy and better overall health outcomes. A prospective cohort study by Orlich *et al.* in 2013 analysed the impact of vegetarian diets on mortality and disease incidence in the Adventist Health Study 2.[30] The study showed that vegetarian diets, particularly those rich in fruits, vegetables, whole grains, and legumes, were associated with reduced mortality rates and a lower incidence of diabetes and cardiovascular diseases. The research found that individuals adhering to vegetarian diets exhibited significantly lower mortality rates across various causes, including cardiovascular disease and certain cancers. Specifically, the study measured key health outcomes such as all-cause mortality, cardiovascular events, and cancer incidence, demonstrating that vegetarians had a notable reduction in risk compared to non-vegetarians. The findings highlighted the role of nutrient-rich plant foods, which contribute to lower body mass index (BMI), improved lipid profiles, and better overall metabolic.

A cross-sectional observational study published in the International Journal of Environmental Research and Public Health in 2016 examines the connection between food intake, diet, and sperm characteristics in populations within a blue zone, specifically focusing on regions known for high longevity.[33] It underscores

the importance of a plant-based diet, rich in fruits, vegetables, whole grains, and legumes, in promoting optimal reproductive health. The study finds that adherence to such dietary patterns is positively correlated with improved sperm quality, including higher sperm concentration and motility, which are crucial for fertility. The research also highlights the potential adverse effects of a diet high in processed foods on sperm parameters, suggesting that these dietary habits may contribute to declining male reproductive health. The authors advocate for dietary interventions emphasising whole, plant-based foods to enhance reproductive health and longevity in populations. They call for increased awareness and public health initiatives that promote these dietary patterns as vital for supporting reproductive health and addressing the rising concerns around male infertility in contemporary society.

The studies conducted in Loma Linda consistently show that a plant-based diet, rich in whole foods and low in processed ingredients, is associated with increased life expectancy and improved health outcomes. These findings support the notion that dietary habits play a crucial role in promoting longevity in Blue Zone populations.

Nicoya (Costa Rica)

The study is a prospective analysis conducted in Costa Rica in 2021, focusing on the elderly population (aged 60+ years) within the Costa Rican.[36] It measured leukocyte telomere length (LTL) as a marker of biological ageing, using food frequency questionnaires to assess dietary patterns. Results indicated that a traditional Costa Rican diet, characterised by rice and beans, positively correlates with longer telomere length. Specifically, increased consumption of grains was also associated with longer LTL, suggesting dietary factors may contribute to the region's extended longevity. The researchers measured various dietary intake variables, including adherence to the Mediterranean diet, overall diet quality, and specific nutrient intake. The results indicated that higher adherence to the Mediterranean diet was significantly associated with longer LTL, suggesting that healthier dietary patterns may play a role in promoting cellular longevity. Furthermore, certain nutrients such as omega-3 fatty acids and *Antioxidants* were positively correlated with LTL, reinforcing the potential benefits of a nutritious diet on cellular health and ageing outcomes.

An observational study conducted in 2013 by L Rosero-Bixby in Costa Rica, known for its high male longevity, involving a survival follow-up of 16,300 elderly Costa Ricans and found that Nicoyan males have a significantly lower death rate ratio (DRR) of 0.80, independent of socioeconomic status.[25] Nicoyan males have a 2.2-year greater life expectancy and a seven times higher probability of reaching 100 years compared to Japanese males. Key health outcomes include lower cardiovascular mortality, favourable biomarkers, leaner body composition, fewer disabilities, and markers of slower ageing like longer telomeres and higher dehydroepiandrosterone sulfate (DHEAS) levels.

The Nicoya diet is known for its emphasis on traditional foods such as rice, beans, and animal proteins. It features a low glycaemic index and high fibre content, both of which promote cardiovascular health. Observations indicate that centenarians on this diet consumed dairy products one to three times a day and ate meat three to five times a week, with 25% consuming it daily. Among the different types of meat, pork was the most frequently consumed, though it was eaten in moderate quantities.[41] Nicoyans also use basic preventive healthcare services and have lower usage of medications for blood pressure and lipids despite clinical risk. The study suggests that environmental factors, such as the local diet and lifestyle, play a significant role in this longevity advantage, as the benefits diminish when Nicoyans migrate away from the region.

Ikaria (Greece)

Trichopoulou *et al.* conducted a population-based prospective study on the Greek population, focusing on adherence to the Mediterranean diet and its impact on survival rates.[5] The study found that individuals who closely followed the Mediterranean diet, which is rich in olive oil, fruits, vegetables, whole grains, and legumes, had significantly lower mortality rates, particularly from cardiovascular disease and cancer. It has been observed that Ikarians consume a moderate amount of goat meat, milk, and cheese rather than fish, which is different from the Mediterranean diet.[1] These studies align with findings from the Sardinian population, further supporting the link between Mediterranean dietary patterns and longevity.

A cross-sectional observational study conducted in 2021 by Romain Legrand on the lifestyle of people living on Ikaria Island and longevity.[34] The study found that adherence to the Mediterranean diet was associated with reduced coronary heart disease risk, independent of traditional cardiovascular factors, particularly in men. The population had few cardiovascular risk factors, such as low rates of diabetes, dyslipidaemia, and smoking, along with moderate to high physical activity. Despite a high prevalence of hypertension, it was generally controlled, and over half of the participants were overweight or obese. The Mediterranean diet's protective effects against cardiovascular disease have been documented since the 1950s, highlighting its emphasis on vegetables, olive oil, moderate fish and dairy intake, and low red meat consumption.

Mediterranean Diet and Longevity

The Mediterranean Diet balances animal-based proteins like fish, white meat, and eggs with predominantly plant-based foods, emphasizing vegetables, fruits, legumes, and cereals at every meal. While it limits red and processed meats, it promotes seafood and lean proteins, prioritizing heart health and overall longevity.[42]

A systematic review conducted by Rafie *et al.* explored the relationship between various dietary patterns and telomere length, a biomarker of ageing.[10] The review found that diets high in fruits, vegetables, nuts, and seeds were consistently associated with longer telomeres, indicating a slower rate of biological ageing. The authors concluded that plant-based diets, which are common in Blue Zone populations, play a critical role in promoting longevity by preserving telomere length and reducing the risk of age-related diseases.

Another systematic review conducted by Galiè *et al.* in 2020 expanded on these findings by reviewing observational cohort studies and randomised clinical trials to assess the impact of nutrition on telomere health.[11] The Mediterranean diet (MedDiet) emerged as a significant dietary pattern linked to cardiovascular disease risk and longevity, with key components such as vegetables, fruits, nuts, and olive oil rich in *Antioxidants* and anti-inflammatory agents. However, studies show mixed results regarding the relationship between adherence to the MedDiet and TL, with some indicating longer TL associated with higher adherence while others found no significant correlations. Additionally, a few studies investigated the Dietary Inflammatory Index (DII), finding a high DII score linked to shorter TL, although results varied across different populations. Other dietary patterns like the Healthy Eating Index (HEI) and the Dietary Approaches to Stop Hypertension (DASH) also demonstrated positive associations with TL, while certain diets like the Baltic Sea Diet showed no significant impact. Notably, the only randomised controlled trial (RCT) assessed within the review did not find beneficial effects of the MedDiet on TL after five years, emphasising the need for further prospective studies to establish causal relationships.

In contrast to a priori food patterns, a posteriori dietary patterns derived from data analyses take into account broader dietary aspects. Research showed that specific nutrient intake influenced TL, although results remained inconsistent. For instance, higher intakes of omega-3 fatty acids (FAs) correlated with reduced telomere shortening, whereas trans-fatty acids had adverse effects. Vitamins and minerals also played varying roles, with some studies indicating potential links between vitamin D and TL, while others showed no associations. Furthermore, oxidative stress and chronic inflammation emerged as critical factors influencing TL, as diets that promote antioxidant defences could mitigate telomere attrition. This highlights the importance of understanding dietary impacts on telomere maintenance through potential mechanisms such as oxidative stress reduction and inflammation modulation, which may ultimately influence biological ageing. Overall, while existing studies suggest potential connections between dietary patterns and TL, more rigorous prospective and RCTs are necessary to clarify these relationships and their implications for health. These results suggest that dietary patterns common in Blue Zones contribute to cellular health and longevity by protecting against oxidative stress and inflammation.

In 2024, Li *et al.* conducted a cross-sectional study using data from the UK Biobank to examine the association between ultra-processed food consumption and leukocyte telomere length.[9] The study found that higher consumption of ultra-processed foods was linked to shorter telomeres, indicating accelerated biological ageing. This finding

contrasts with the dietary patterns observed in Blue Zones, where processed foods are largely absent, further supporting the role of whole, minimally processed foods in promoting longevity.

A study, "Is diet the key to longevity? A narrative review of the dietary patterns of the Blue Zones," published in 2023, examines the relationship between longevity and the unique nutritional patterns found in Blue Zones. It highlights how diets rich in plant-based foods, minimally processed foods, and moderate alcohol consumption contribute to the exceptional health and longevity observed in these regions.[43] A book published in 2023, Current Perspectives on Centenarians: Introduction to Lifespan and Health Span, focuses on the dietary habits of centenarians, particularly those in Blue Zones.[37] It includes a systematic review and meta-analysis, emphasising how these traditional dietary patterns, which are low in meat and high in whole foods, are strongly associated with lower risks of chronic diseases and extended lifespans. Together, these studies underscore the significant role that diet plays in promoting longevity and preventing age-related diseases.

Key Research Findings

The Blue Zone diets are characterised by their emphasis on whole, plant-based foods, which have been consistently associated with lower risks of chronic diseases, such as heart disease, cancer, and diabetes. These diets typically include a high intake of fruits, vegetables, legumes, whole grains, and healthy fats, such as olive oil.[3-6,23] The Okinawan diet, for example, is particularly rich in *Antioxidants* and anti-inflammatory compounds derived from foods like sweet potatoes, leafy greens, and tofu. This nutrient-dense diet is linked to lower incidences of age-related diseases, including cardiovascular conditions and certain types of cancer, contributing to the exceptional longevity observed in Okinawan populations.[28,29] These findings suggest that the combination of high-quality, plant-based nutrition and the avoidance of processed foods plays a key role in promoting healthy ageing.

The Loma Linda study, which focused on Seventh-day Adventists who predominantly follow a vegetarian diet, illustrates the powerful impact of plant-based eating on reducing the rates of chronic diseases.[4,30] Research shows that those adhering to a vegetarian diet in Loma Linda have significantly lower rates of cardiovascular disease, hypertension, and cancer compared to the general population.[44-46] The Sardinian diet similarly highlights the health benefits of traditional, plant-based foods. Sardinians consume large amounts of beans, whole grains, and vegetables, while their moderate consumption of wine, rich in polyphenols, has been shown to reduce inflammation and improve heart health.[3,26] Together, these studies provide compelling evidence that plant-based diets, supported by healthy lifestyle practices, play a crucial role in the prevention of chronic diseases in Blue Zone populations.[47,48]

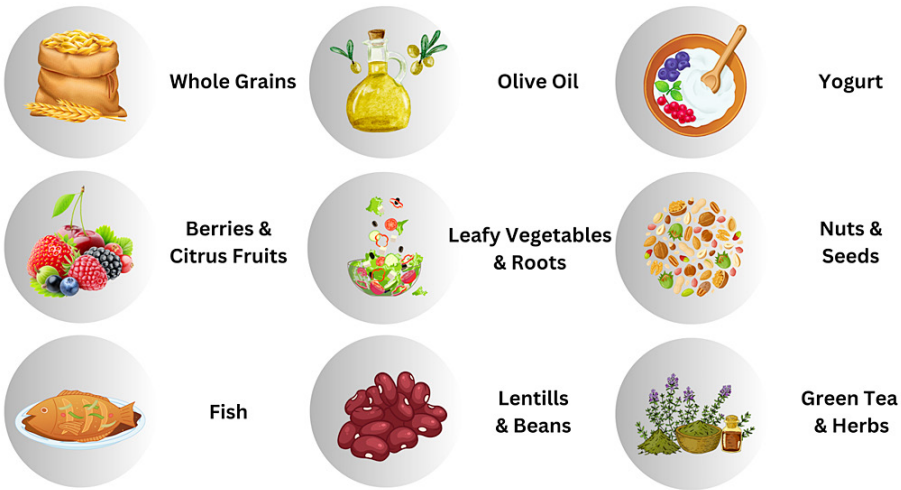

Fig 2: Major Dietary Components of Blue Zone

Caloric restriction is another key factor contributing to longevity in Blue Zones, particularly in Okinawa. The practice of "hara hachi bu", where individuals eat until they are 80% full, results in lower overall caloric intake without malnutrition. This approach is believed to enhance longevity by reducing oxidative stress, improving metabolic health, and promoting cellular repair mechanisms.[28,29] The nutrient-dense, low-calorie diet of the Okinawans, which is rich in vitamins, minerals, and *Antioxidants*, supports healthier ageing by preventing the development of chronic conditions such as diabetes and cardiovascular disease.[49,50]

The Mediterranean diet, commonly followed in Blue Zones like Sardinia and Ikaria, is widely regarded as one of the healthiest dietary patterns in the world. This diet is characterised by high consumption of olive oil, whole grains, fruits, vegetables, legumes, and moderate amounts of fish and red wine. Studies have shown that adherence to the Mediterranean diet is associated with increased longevity, lower rates of heart disease, and reduced inflammation.[5] Research by Trichopoulou *et al.* (2003) confirmed that individuals adhering to the Mediterranean diet in Greece experienced significantly lower mortality rates, particularly from cardiovascular diseases.[31,42,51] This evidence further supports the idea that nutrient-rich, minimally processed, and anti-inflammatory foods are central to promoting longevity and reducing the risk of age-related diseases in Blue Zone populations.

Comparative Analysis and Critical Evaluation

Consistency Across Regions

The dietary patterns across Blue Zones (BZ) consistently emphasise plant-based foods, low meat consumption, and moderate alcohol intake, reflecting the shared focus on longevity through nutrition. Research by Fraser and Shavlik (2001) on Loma Linda's Seventh-day Adventists found that predominantly plant-based diets, coupled with low consumption of animal products, contribute to lower mortality rates and longer life expectancy. Similarly, in Greece, Trichopoulou *et al.* (2003) demonstrated that adherence to the Mediterranean diet—a diet rich in olive oil, whole grains, fruits, and vegetables—was significantly associated with reduced mortality, particularly from cardiovascular disease.[5] The study by Fung *et al.* (2005) further supports this by showing that high-quality diets, such as those in Blue Zones, reduce markers of inflamed and endothelial dysfunction, both of which are linked to ageing and chronic disease.[6] This consistency in dietary practices across diverse regions strengthens the argument that such diets provide universal health benefits, irrespective of cultural or geographical context.

Holistic Lifestyle Approach

Diet is just one component of the holistic lifestyle that characterises Blue Zone populations. In addition to nutrition, factors like regular physical activity, social connections, and stress management play a critical role in promoting longevity. For instance, Fraser and Shavlik (2001) noted that in Loma Linda, lifestyle choices, such as avoiding smoking and alcohol combined with a plant-based diet, contributed to a longer lifespan.[4] In Sardinia and Ikaria, physical activity is embedded in daily routines through manual labour and walking, which complements their nutrient-dense diets. The cultural practice of moderate alcohol consumption, particularly red wine in Mediterranean regions, also reflects a balance that supports longevity.[23] The comprehensive approach observed in these regions underscores that di*et al*one is not sufficient; it must be integrated with other health-promoting habits, such as active social networks and purpose-driven living, as seen in Okinawa's "ikigai" concept.[24]

Cultural and Environmental Contexts

The health benefits of Blue Zone diets are heavily influenced by the cultural and environmental contexts of these regions. For instance, the strong sense of community and tradition in Sardinia and Ikaria reinforces the consumption of locally sourced, seasonal foods. This cultural connection to food, combined with environmentally sustainable practices, fosters both physical and mental well-being.[3] However, the unique environmental factors of Blue Zones, such as isolation in Sardinia or the availability of fresh, local produce in Ikaria, may limit the generalizability of these dietary practices. In modern, urbanised settings, it may be challenging to adopt the same level of dietary purity and connection to food sources.[2] Therefore, while the core principles of plant-based, whole-food diets are transferable, adapting these practices to different cultural and environmental contexts requires further study.

Need for Longitudinal and Interventional Studies

Most research on Blue Zones is based on observational studies, which, while insightful, do not establish definitive causal relationships between dietary patterns and health outcomes. Longitudinal and interventional studies are needed to validate these findings across diverse populations and to assess the long-term impact of adopting Blue Zone dietary habits. For example, the work of Mattison *et al.* (2012) on caloric restriction in rhesus monkeys showed promising results in improving health and longevity, suggesting that similar approaches in human populations could yield comparable outcomes.[50] Fontana and Partridge (2015) also emphasise the importance of caloric restriction as a tool to extend lifespan and reduce the risk of age-related diseases.[29] Future studies should focus on interventions where non-Blue Zone populations adopt these dietary principles, tracking health outcomes over time to establish clearer causal links between diet, cellular health, and longevity.

Overview of Healthy Lifestyle Practices Observed in Blue Zone

When analysing Blue Zone dietary patterns and longevity, it's important to account for confounding factors like physical activity, stress levels, spirituality, and sense of purpose. These factors, along with diet, collectively contribute to the extended lifespans observed in Blue Zone populations.

Physical Activity

In Blue Zones, regular physical activity is not typically structured exercise but is incorporated into daily routines, such as gardening, walking, and manual labour. This continuous, moderate activity contributes significantly to health and longevity, keeping individuals physically active well into old age.[52,53]

Stress Management

Blue Zone inhabitants tend to practice stress-reducing rituals, such as taking breaks for naps, engaging in prayer, or practising mindfulness. Chronic stress can lead to inflammation, which is a known risk factor for age-related diseases.[54]

Sense of Purpose

A strong sense of purpose, or "ikigai" in Japan, is a common trait among Blue Zone residents. This is associated with longer lifespans and better mental health. Having a clear purpose in life can motivate people to stay active, socially connected, and engaged.[55]

Spirituality and Social Engagement

Engagement in spirituality or religion also plays a role in longevity. In many Blue Zones, strong social ties, family bonds, and spiritual beliefs support emotional and mental well-being, contributing to a lower incidence of mental health issues like depression.[55]

While adopting other longevity-promoting habits, such as regular physical activity or stress management, may offer some protection against age-related diseases, a poor diet can still undermine these benefits. For example, individuals who are physically active but consume a diet high in saturated fats or refined carbohydrates may still experience adverse cardiovascular outcomes.[53] Thus, diet remains a critical, non-negotiable component of a longevity-enhancing lifestyle.

Discussion

The discussion of this review highlights several critical findings regarding the dietary patterns prevalent in Blue Zones—Sardinia, Okinawa, Loma Linda, Nicoya, and Ikaria—and their connection to health outcomes and longevity. Across these regions, a plant-based diet is the cornerstone of healthy ageing, featuring a strong emphasis on whole grains, legumes, fruits, vegetables and a moderate amount of fish and milk products. These foods are abundant in essential nutrients such as fibre, *Antioxidants*, Omega-3, and anti-inflammatory compounds, which are linked to significant health benefits, including reduced inflammation, improved gut health, and enhanced cardiovascular function.

Dietary Components and Health Outcomes

In Blue Zones, the consumption of fermented foods such as yoghurt, sour cheese, and fermented soy products is widespread. These foods are rich in probiotics, which promote gut health by maintaining a balanced microbiome. This gut-brain connection is critical in reducing systemic inflammation, a known contributor to ageing and chronic diseases. The intake of olive oil, which is high in monounsaturated fats and *Antioxidants*, has been shown to improve cardiovascular health by lowering bad cholesterol and protecting cells from oxidative damage. Additionally, regular consumption of legumes and

vegetables supplies vital nutrients and compounds that lower the risk of heart diseases and cancers, which are leading causes of death in industrialised nations.

One of the distinct features across Blue Zone diets is the limited consumption of animal products, typically in small portions, often fermented dairy or fish. This contrasts with many modern diets, where high red meat consumption is associated with an increased risk of heart disease and cancer. The lower intake of saturated fats and cholesterol in Blue Zone diets likely contributes to improved cardiovascular health and lower inflammation markers in these populations.

Caloric Moderation and Longevity

Another key dietary pattern seen in Okinawa is caloric restriction, where individuals consume fewer calories than typical Western diets while maintaining nutrient density. This practice has been extensively studied in both human populations and animal models, with results indicating that caloric restriction delays the onset of age-related diseases, reduces oxidative stress, and supports cellular repair mechanisms. Notably, a low-calorie diet in Okinawa has been linked to lower levels of oxidative stress, which helps preserve the length of telomeres—the protective caps on chromosomes that are associated with cellular ageing.

Telomere Length and Longevity

Emerging evidence from studies on telomere length provides a compelling biological explanation for the longevity observed in Blue Zones. Telomeres naturally shorten as we age, and shorter telomeres are linked to increased risk for chronic diseases such as heart disease, cancer, and diabetes. However, dietary patterns rich in *Antioxidants*, fibre, and anti-inflammatory foods, common in Blue Zones, appear to slow the rate of telomere shortening. For instance, diets high in *Antioxidants*, such as those found in fruits, vegetables, and olive oil, neutralise free radicals that cause oxidative stress, protecting DNA from damage. Furthermore, the low levels of inflammation observed in these populations, driven by plant-based and anti-inflammatory diets, are key to preserving telomere integrity and promoting cellular longevity. The evidence highlights that adherence to plant-based, antioxidant-rich diets prevalent in Blue Zones is associated with preserved telomere length, a critical biomarker of cellular ageing.

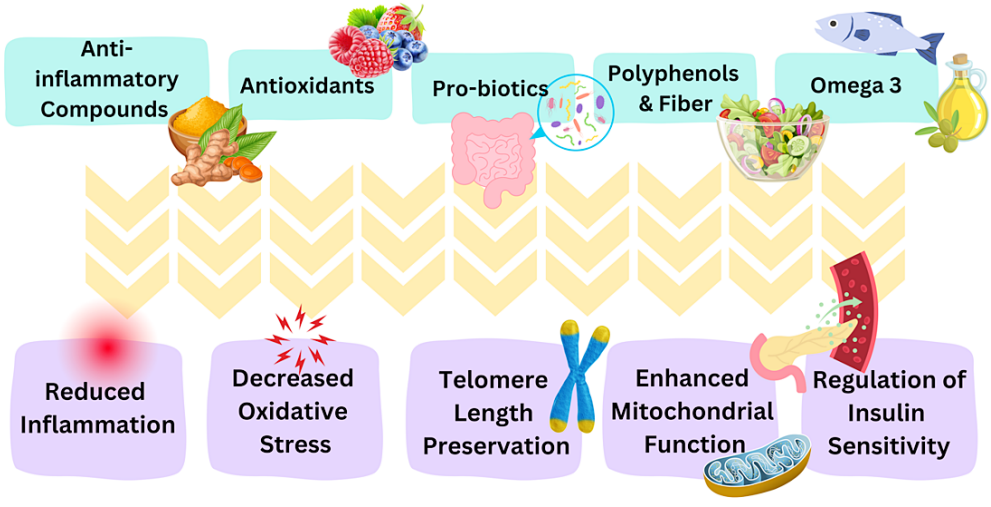

Fig 3: Impact of Blue Zone Dietary Components on the Human Health

The Role of Traditional Diets

A critical point in the review is the shift in dietary habits among younger generations in Okinawa, where increased consumption of calorie-dense and processed foods is associated with rising obesity and chronic disease. This highlights the importance of maintaining traditional dietary practices, as ultra-processed foods are linked to increased

inflammation, oxidative stress, and accelerated telomere shortening. Conversely, populations that adhere to traditional diets, such as those in Nicoya and Mediterranean regions, continue to demonstrate longer telomere length, slower biological ageing, and lower mortality rates.

Blue Zone Dietary Patterns and Epigenetic Effects

Emerging research suggests these diets may also positively affect telomere length, a biomarker of cellular ageing. For instance, adherence to Mediterranean-like diets, similar to BZ's, has been linked to longer telomeres.[56] This connection is hypothesised to be due to such diets' high antioxidant and anti-inflammatory properties, which protect against oxidative stress and inflammation, key factors in telomere shortening.[57] Additionally, the moderate protein intake typical of these diets may enhance cellular maintenance and repair mechanisms, further supporting telomere integrity.[32] Research indicates that dietary factors can influence epigenetic mechanisms, which in turn affect gene expression and health outcomes. These findings underscore the potential of BZ dietary patterns in promoting healthy ageing and longevity at the cellular level.

Public Health Policy Implications

Integrating BZ dietary patterns into public health policies could improve longevity and health outcomes through epigenetic effects. Public health initiatives that promote plant-based diets, moderate alcohol consumption, and caloric restriction can be designed to reflect the principles observed in BZ. Such policies may include educational campaigns, dietary guidelines, and subsidies for healthy foods, aiming to shift the population's dietary habits toward those found in BZ.[3,23] By adopting BZ dietary patterns, populations may experience positive epigenetic modifications that contribute to reduced chronic disease prevalence and increased longevity.[5,28,29] This approach underscores the importance of not only individual dietary choices but also systemic changes facilitated by supportive public health policies.[3,5,29] To further enhance the practical application of Blue Zone dietary patterns, future research should explore strategies for adapting these practices to diverse populations, considering socio-economic, cultural, and environmental factors. Additionally, addressing the challenges of implementing these dietary changes globally, such as accessibility and cultural acceptance, is essential for maximizing their impact on public health.

Limitations

Despite the valuable insights provided by this review, several limitations should be noted. The majority of the studies on Blue Zone populations are observational, making it difficult to establish causal relationships between diet and longevity. Additionally, the cultural and environmental contexts of these regions play a significant role in their health outcomes, which may limit the generalizability of the findings to other populations. Further, the reliance on self-reported dietary data in many studies introduces the potential for bias, as individuals may inaccurately report their food intake. Lastly, while telomere length is an important biomarker of ageing, it is only one of many factors that influence longevity, and more research is needed to understand how diet interacts with other lifestyle factors, such as physical activity and social engagement in Blue Zone populations. Future studies should aim to include more longitudinal and interventional research to validate the long-term effects of these dietary patterns across diverse populations.

Conclusion

The dietary patterns observed in Blue Zones, including those of Okinawa, Sardinia, Loma Linda, Nicoya, and Ikaria, provide a compelling model for promoting longevity and reducing the risk of chronic diseases. These predominantly plant-based diets feature whole grains, legumes, vegetables, and fruits, with moderate consumption of animal-derived products. The presence of fermented foods, healthy fats, and a focus on caloric restriction, especially in Okinawa, is associated with reduced inflammation, improved cardiovascular health, and slower biological ageing. These dietary elements have been shown to positively influence telomere length, which serves as a biomarker of cellular ageing. Longer telomeres are correlated with a decreased risk of age-related diseases and an extended lifespan, indicating that diet plays a crucial role in maintaining cellular health. The research reviewed also highlights the importance of preserving traditional dietary habits, as shifts toward processed, calorie-dense foods in younger generations may lead to increased

rates of obesity and chronic disease. Overall, the findings suggest that adopting Blue Zone dietary practices could contribute to longer, healthier lives by mitigating oxidative stress and inflammation, key factors in telomere shortening and ageing in studied populations, though the observed benefits may not be universally applicable. This study uniquely contributes to the literature by bridging the gap between Blue Zone dietary patterns and their molecular impacts on ageing, providing a model for integrating cultural dietary practices into global health interventions. However, Future research should explore how elements of Blue Zone dietary patterns can be adapted to diverse populations while considering genetic, cultural, and environmental factors.

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Author Contributions
- **Dr. Priyanka Mohol:** Conceptualization, Methodology, Formal analysis, visualisation and validation, writing – original draft preparation, writing – review and editing.
- **Anindita Ghosh:** Conceptualization, methodology, visualisation and validation, resources, supervision, writing – original draft preparation, writing – review and editing.
- **Shilpa Kulkarni Devanhalli:** Visualization and validation, supervision, writing, review, and editing.

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