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VITAMIN D DEFICIENCY AND PSYCHOLOGICAL WELL-BEING IN KERALA: A SYSTEMATIC REVIEW OF MENTAL HEALTH OUTCOMES, EMOTIONAL RESILIENCE, COGNITIVE REAPPRAISAL, NEUROTICISM, AND LOCUS OF CONTROL

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Abstract

Vitamin D deficiency has emerged as a major public health concern across the world, affecting individuals across age, gender, region, and socioeconomic status. Although vitamin D has traditionally been understood in relation to calcium absorption, bone mineralization, and skeletal health, recent research has increasingly emphasized its role in brain functioning, emotional regulation, cognitive processes, immune modulation, and psychological well-being. The presence of vitamin D receptors in several brain regions involved in mood regulation, stress response, memory, and executive functioning has encouraged growing scholarly interest in the psychological implications of vitamin D deficiency. India presents a unique public health paradox because vitamin D deficiency remains highly prevalent despite abundant sunlight exposure. Kerala, a tropical state with year-round sunlight and relatively strong health indicators, offers a particularly important context for examining this paradox. Changing lifestyles, indoor occupations, urbanization, academic pressures, reduced outdoor activity, dietary transitions, and sun-avoidance behaviors may contribute to persistent vitamin D deficiency among Kerala populations. This systematic review aims to synthesize existing literature on the association between vitamin D deficiency and psychological well-being, with specific attention to depression, anxiety, emotional resilience, cognitive reappraisal, neuroticism, and locus of control. The review adopts a systematic literature-based approach guided by PRISMA principles and draws upon studies published between 2000 and 2024. Existing evidence suggests that low vitamin D status is associated with increased depressive symptoms, anxiety, psychological distress, cognitive vulnerability, reduced emotional resilience, maladaptive emotion regulation, and poorer quality of life. However, Kerala-specific psychological research remains limited. The review highlights the need for interdisciplinary research integrating nutrition, psychology, psychiatry, and public health. Addressing vitamin D deficiency may offer a low-cost, preventive strategy for improving psychological well-being and mental health outcomes.

Keywords: Vitamin D deficiency; psychological well-being; mental health; emotional resilience; cognitive reappraisal; neuroticism; locus of control; depression; anxiety; Kerala.

1. Introduction

Vitamin D deficiency is a worldwide and growing public health problem. In the past, vitamin D was considered mainly to be a vitamin of bone, known for its effects on calcium metabolism, bone mineralisation and the prevention of bone disorders like rickets, osteomalacia and osteoporosis. But biomedical and neuroscientific studies over the past 30 years have greatly increased the knowledge of the physiologic functions of vitamin D. Current evidence indicates that vitamin D is a neuroactive steroid hormone and plays a role in many biological processes beyond the skeleton. These encompass immune regulation, cardiovascular functioning, endocrine activity, neuroprotection, neurotransmitter synthesis and brain development. This has made vitamin D deficiency an important field of study in psychology, psychiatry, neuroscience and public health.

The main source of Vitamin D is the sun, its ultraviolet B (UVB) radiation acting on skin. Lesser amounts come from food sources such as fatty fish, egg yolk, fortified dairy products, mushrooms and nutritional products. Vitamin D deficiency is very common in both developed and developing countries despite the fact that sunlight and food sources are natural sources of vitamin D. Vitamin D deficiency has been recognized as a global public health problem by the World Health Organization and other public health agencies affecting some 1 billion people worldwide. Although it is present in every environment, deficiency continues to be a problem, and hence, there has been considerable interest among researchers trying to understand the reasons for and consequences of this problem.

New research is increasingly looking at the connection between vitamin D and mental health. This change is mainly due to findings that vitamin D receptors (VDRs) and enzymes that regulate vitamin D metabolism, are widely present in the central nervous system. These receptors are especially found in areas of the brain involved in emotional control, cognition, memory, executive functioning and stress adaptation such as the hippocampus, prefrontal cortex, hypothalamus, amygdala, and cingulate cortex. These results give strong biological reasons to look at the psychological consequences of vitamin-D deficiency.

Studies have shown that vitamin D is involved in various neurobiological processes that are important in psychological functioning. These encompass the synthesis of serotonin, regulation of dopamine, neuroplasticity, neuronal differentiation, connectivity of synapses, inflammatory regulation and functioning of the hypothalamic-pituitary-adrenal (HPA) axis. Dysfunctions in these mechanisms have been linked to many psychiatric and psychological illnesses such as depression, anxiety disorders, stress related disorders, cognitive impairment and neurodegenerative diseases. Therefore, vitamin D deficiency has become a risk factor of interest to see if it can be modified to impact mental health outcomes.

The rising rates of psychological disorders in the worldwide are also an additional point to the importance of this area of study. Depression and anxiety disorders are among the major causes of disability and impaired quality of life and are estimated to impact hundreds of millions of people worldwide. Beyond clinical psychiatric disorders, more attention has been given to other aspects of psychological functioning, such as resilience, emotional regulation, coping effectiveness, personality traits, and subjective well-being. It is important to understand the biological factors responsible for these contributions to develop integrated strategies for mental health promotion and disease prevention.

Vitamin D deficiency has been seen in various parts of the world including Europe, North America, Asia, Africa, Australia and the Middle East. Even countries with lots of sunshine all year round have high prevalence rates. This paradox serves as a reminder to the intricate interplay of environmental, behavioural, cultural and biological factors affecting vitamin D status. Factors such as urbanization, sedentary lifestyles, indoor jobs, air pollution, using sunscreen, wearing clothes, and fewer activities in the sun have all been recognized as affecting the vitamin D status of modern populations.

India is a unique and important scenario for vitamin D research. Although this often occurs in tropical countries where there is significant exposure to sunlight, vitamin D deficiency prevalence rates between 50% and 90% have been reported in various age groups and populations. Studies carried out in children, adolescents, adults, pregnant women and elderly people show that deficiency is a problem in the country. There are a number of factors that lead to this phenomenon. There is a high level of urbanization, which has led to more people working inside and less outside activity. Limited sun exposure due to educational and occupational requirements. Besides, the consumption of vitamin D rich foods remains relatively low and the fortification of foods is not as much as it is in many western countries. The darker the skin pigmentation, the less efficient the synthesis of vitamin D in the skin and the longer exposure to sunlight is needed to produce an adequate amount of vitamin D.

In India, Kerala is a unique region for studying vitamin D deficiency and mental health. Kerala has better health outcomes, literacy rates and social development than many other states in India. This can be due to the fact that the state has a tropical climate offering ample sunshine all year round, which in theory should enable adequate vitamin D synthesis by residents. However, vitamin D deficiency remains a high occurrence in

various sections of the population in Kerala as shown in empirical studies. This has been dubbed as the "Kerala Paradox."

There are a number of explanations that have been offered to explain the Kerala Paradox. The growing urbanisation has led to a change in the traditional lifestyle which was based on outdoor occupation to the new lifestyle where there is a lot of work being done indoors. The increased and intensified educational demands, the technological dependency, the screen-based recreation and the sedentary lifestyle have also decreased the opportunities for sun exposure. Also, dietary changes can play a role in reducing vitamin D levels. In addition, cultural and cosmetic practices that promote sun avoidance and heat exposure concerns can also reduce the amount of effective UVB exposure, even in favorable climates.

This is significant because Kerala is experiencing a shift in the mental health landscape and vitamin D deficiency remains an issue. As in many other parts of the world that are witnessing fast-paced social and economic change, Kerala has seen a rise in stress, stress-related disorders, anxiety, depression, lifestyle diseases and psychosocial issues. These trends are due to many interacting factors, but nutrition is an important and relatively under studied area of research. Knowing if vitamin D deficiency is a factor in psychological vulnerability can offer important clues to prevention mental health and public health interventions.

In modern psychological studies, apart from psychiatric conditions like depression and anxiety, there is growing focus on positive psychological functioning and coping. Characteristics like emotional resilience, cognitive reappraisal, neuroticism, and locus of control are now known to be important markers of psychological well-being. Emotional resilience is the capacity of a person to adjust well to difficult circumstances and to bounce back from stressful events. Cognitive reappraisal is the reinterpretation of emotionally challenging situations to decrease distress and to promote adaptive coping. Neuroticism is a personality trait that is marked by emotional instability, negative affectivity and stress sensitivity. The locus of control is beliefs about how much control people perceive they have over their lives.

These constructs are especially pertinent for the ways they shape a person's reactions to stress, emotional regulation, sense of the world, and mental health. New research indicates that psychological processes can be affected by biological factors like nutrition. Vitamin D's function in the regulation of neurotransmitters, the neuroplasticity process, and stress response systems offers a rational foundation for studying the link between Vitamin D and resilience, emotion regulation, personality functioning, and perceived control.

Although attention is growing on vitamin D and mental health, there are several key areas that need to be addressed in literature. The current literature on emotion regulation emphasizes mainly on depression and anxiety, and there has been limited research on more general psychological traits, including resilience, cognitive reappraisal, neuroticism, and locus of control. Moreover, despite the epidemiological and sociocultural characteristics of Kerala, investigations are limited to Kerala. There are a number of studies available, but the majority focus on physical health effects of vitamin D deficiency, and have overlooked the potential psychological effects.

In view of these gaps, a thorough review of the current evidence is timely and needed. This review aims to provide a more comprehensive understanding of the nutritional and psychological health by synthesising the existing literature on vitamin D deficiency and psychological health. Special emphasis is laid on mental health outcomes, emotional resilience, cognitive reappraisal, neuroticism, and locus of control in the general context of Kerala's vitamin D paradox. The results can be used as a basis for future studies, clinical care, public health policies, and mental health prevention activities that can help improve the well-being of diverse populations.

2. Methodology

2.1 Research Design

A systematic literature review design was used for the present study to explore the relationship between vitamin D deficiency and psychological well-being, specifically mental health outcomes, emotional resilience, cognitive reappraisal, neuroticism, and locus of control. Systematic review methodology was chosen because it allows for thorough identification, appraisal, and synthesis of available data and helps to reduce researcher bias and improve transparency. Systematic reviews, in contrast to traditional narrative reviews, are structured and replicable process of literature selection and analysis to make conclusions more reliable and valid.

This review targeted empirical, theoretical and review studies that explored the psychological issues of vitamin D deficiency in various populations. Studies on the neurobiological mechanisms, emotional functioning, personality characteristics, coping processes, and mental health outcomes were of special

interest. Also, literature pertaining to vitamin D deficiency prevalence and determinants in the Indian and the Kerala context were explored to gain context.

2.2 PRISMA Framework

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines were followed when conducting the review. PRISMA sets internationally accepted standards for the systematic review process and encourages transparency in the selection of studies, screening, eligibility assessment, and inclusion process.

The PRISMA process had four big steps:

Identification

A systematic search of relevant literature was conducted by searching major electronic databases and academic search engines. Other records were acquired by hand-searching reference lists and related publications.

Screening

Records were retrieved and screened by titles and abstracts to identify those relevant to the purposes of the review. Screening was carried out after removing duplicate records.

Eligibility

Full-text articles were evaluated based on inclusion and exclusion criteria. Only those studies that met the inclusion criteria were selected for detailed review and analysis.

Inclusion

Eligible studies were included in the final synthesis and grouped by the thematic areas pertinent to the goals of the review.

In future updates of this review, a PRISMA flow diagram might be created to illustrate the process of study selection.

2.3 Data Sources

Multiple electronic databases were used to complete a comprehensive search of the literature to ensure that extensive research was conducted and covered. The following databases were used:

- PubMed
- Scopus
- Web of Science
- PsycINFO
- ScienceDirect
- SpringerLink
- Google Scholar

These databases were chosen because they contain peer-reviewed literature from various fields, such as psychology, psychiatry, neuroscience, nutrition, public health, and behavioral medicine.

2.4 Search Strategy

The literature search was performed using combinations of key words and Boolean operators. The most important concepts discussed in the review were used to identify keywords.

Key words used were:

- “Vitamin D deficiency”
- “Vitamin D and sleep”
- “Vitamin D and depression”
- “Vitamin D and depression”
- “Psychological well-being”
- “Emotional resilience”
- “Cognitive reappraisal”
- “Emotion regulation”
- “Neuroticism”

- "Locus of control"
- "Psychological functioning"
- "Kerala"
- "India"

Boolean operators like AND and OR had been applied to increase the precision and comprehensiveness of the search. Some of the search combinations used were:
- Vitamin D deficiency" AND "psychological wellbeing"
- "Vitamin D" AND "mental health"
- "Vitamin D deficiency" AND "psychological well-being" AND "children"
- "Vitamin D" AND "depression" OR "anxiety" and NOT "vitamin D deficiency"
- "Vitamin D deficiency" AND "Kerala Government"

Studies published between January 2000 and December 2024 were searched for.

2.5 Inclusion Criteria

To be included in the review, studies had to be:
- Published between 2000 and 2024.
- Presented in peer reviewed academic journals.
- Written in the English language.
- Included human participants.
- Reviewed vitamin D levels, deficiency, insufficiency, or supplementation.
- Studied psychological, psychiatric, emotional, cognitive or behavioral outcomes.
- Discussed issues related to mental health, resilience, cognition, personality, coping or psychological functioning.
- Featured observation, experiment, longitudinal, cross-sectional, systematic review, or meta-analytic designs.

2.6 Exclusion Criteria

Studies were excluded if they:
- Were conference abstracts that were not available as full text.
- Were dissertations or non-peer-reviewed sources.
- Only concerned with physical health issues, but with no psychological relevance.
- Involved animal models that were not necessarily relevant to psychological functioning in humans.
- Were duplicate publications.
- Lacked adequate methodological information.
- Were not available in English.

2.7 Data Extraction Procedure

A structured review framework was used to extract relevant information from each study included. Extracted information included:
- Author(s)
- Year of publication
- Country of study
- Research design
- Sample characteristics
- Measures of vitamin D status
- Psychological variables examined
- Key findings
- Conclusions

Data extraction enabled the systematic comparison between studies and thematised synthesis of the data.

2.8 Data Analysis and Synthesis

The selected studies were integrated using a narrative synthesis. Narrative synthesis was deemed suitable due to the variations in study design, participant characteristics, measurement strategies, and psychological outcomes across the literature.

Studies were grouped into thematic areas according to the objectives of the review:

A link between vitamin D and emotional or mental health has been identified.

A lack of vitamin D has been linked to depression.
Vitamin D can impact anxiety.
The emotional support provided by vitamin D.
Vitamin D and cognitive reappraisal;
Vitamin D and neuroticism
Vitamin D and locus of control
Neurobiological mechanisms
Kerala-specific evidence
Because of the thematic analysis, it was possible to see if there were patterns, consistencies, or contradictions in the research, or any research gaps. Results were then analyzed in the context of wider psychological, neurobiological and public health concepts.

2.9 Quality Considerations
A formal quantitative meta-analysis was not used in this review, but an effort was made to include only high-quality, peer-reviewed research that appeared in reputable journals. Systematic reviews and meta-analysis, longitudinal studies, RCTs and large scale observational studies were preferred when available.

2.10 Ethical Considerations
The study did not include direct human subjects, clinical interventions or primary data collection as it was a literature review. Therefore institutional ethical approval was not necessary. However, the ethical principle of academic honesty, transparency, accurate reporting and appropriate mentioning of the original sources was strictly adhered to throughout the review process.

The review aimed to objectivity present the findings and identify limitations and uncertainties in the current literature.

4. Literature Review
4.1 Vitamin D and psychological well-being
Psychological well-being is a multi-dimensional phenomenon that involves positive emotional functioning, satisfaction with life, self-acceptance, autonomy, mastery of the environment, personal growth and positive interpersonal relationships. Modern theories of psychology do not just focus on the absence of mental disorder, but also on optimal functioning of the mind and adaptive response to life difficulties.
There is growing evidence that nutrition is an important determinant of psychological health. Of these, vitamin D has been in the headlines for being widely deficient, and for its widespread role in neurologic function. A new understanding of vitamin D as a nutrient now has a new definition as a neuroactive steroid with significant implications for psychological functioning, due to the presence of vitamin D receptors throughout the central nervous system.
Low vitamin D has been shown to be associated with psychological well-being in a number of population-based studies. People with vitamin D deficiency often complain of decreased happiness, decreased life satisfaction, decreased emotional stability and decreased quality of life. On the other hand, sufficient vitamin D has been linked to improved mood, increased vitality, improved cognitive functioning, and improved psychological adjustment.
There are several potential pathways by which vitamin D affects people's psychological health. These are the control of neurotransmitters like serotonin and dopamine, modulation of inflammatory reactions, neuroplasticity, and normal functioning of stress-response systems. Thus, deficiency might contribute to psychological vulnerability and decrease positive psychological functioning.
There is an increasing number of publications suggesting the status of vitamin D as an important biological factor influencing overall psychological well-being. While the causal pathways are still under investigation, there's evidence upon evidence that keeping vitamin D levels up can help with emotional and psychological well-being.

4.2 Vitamin D and Depression
Depression is one of the most well studied psychological consequences of vitamin D deficiency. Depression is a global disease impacting over 280 million people, and known to be a major contributor to disability and diminished quality of life. The potential role of vitamin D deficiency in the pathogenesis, persistence, and/or worsening of depressive symptoms has been explored in recent studies.
Many observational studies have reported large associations between low 25(OH)D levels and depressive symptoms. People with low vitamin D levels have reported a higher prevalence of sadness and hopelessness,

fatigue, decreased motivation and decreased interest in daily activities than those with sufficient vitamin D levels.
In a systematic review and meta-analysis, Anglin et al. (2013) found that vitamin D deficiency was associated with a significantly higher risk for depression among adults. Likewise, Parker et al. (2017) found that there was significant evidence that vitamin D and depressive disorders are linked, but that more research is needed to confirm the causality of this relationship.
A number of biological explanations have been suggested for this connection. One of the most frequently cited is related to the synthesis of serotonin. Vitamin D controls genes that produce serotonin, and lower vitamin D levels may lead to lower amounts of serotonin. Serotonin is essential for maintaining healthy mood and if it's lacking, this could make someone more vulnerable to symptoms of depression.
Another important pathway is inflammation. Depression is now thought to be an inflammatory illness with an increase in cytokines and immune activation. Vitamin D also has anti-inflammatory effects and could help to regulate immune function. Therefore, deficiency may play a role in the inflammatory processes in depression.
Neuroplasticity also seems to be at play. Depression has been associated with decreased neurogenesis and dysfunction of neurons. There is evidence that Vitamin D is responsible for neuronal growth and synaptic plasticity and that deficiency could impact brain systems regulating mood.
Results from intervention studies that tested vitamin D supplementation have been mixed. Some studies have found that supplementation results in a reduction of depressive symptoms in deficient patients, but others have found only a slight effect. However, the vast majority of literature is in favor of vitamin D status as a significant factor in the overall biopsychosocial context of depression.

4.3 Vitamin D and Depression
Another large area of research related to low vitamin D is anxiety disorders. Anxiety is defined as over-worry, overarousal, fear responses, and cognitive apprehension. It is one of the most common types of mental illness in the world.
In recent years, there have been studies that have found inverse relationships between vitamin D levels and anxiety symptoms in a variety of populations. Lower levels of Vitamin D have been associated with higher levels of anxiety, increased stress sensitivity and emotional distress amongst adolescents, adults, pregnant women and older adults.
One possible explanation is a dysfunction of the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis controls physiological reactions to stress and is thought to be involved in anxiety disorders. Vitamin D has an impact on the functioning of the HPA axis and has a role in adaptive stress regulation. So, deficiency can lead to heightened stress reactions and anxiety symptoms.
Another plausible explanation is through the action of neurotransmitter systems. Vitamin D is beneficial for controlling serotonin and dopamine, which play a role in emotional balance and anxiety management. These systems may be impaired by decreased vitamin D availability and lead to increased anxiety.
The association is further supported by inflammatory pathways. High inflammatory markers have been seen in patients with anxiety disorders, and Vitamin D has anti-inflammatory activity that can decrease immune activation. Deficiency can thus be a factor in physiological conditions associated with anxiety.
While there is support for an association between vitamin D deficiency and anxiety, more longitudinal and experimental research is needed to elucidate the cause and effect relationship and the possible mechanisms.

4.4 Vitamin D and Emotional Resilience
Emotional resilience is the ability to adjust effectively to difficult circumstances, bounce back from stressful events and function psychologically well in the face of difficult times. Resilience has become more widely understood as a resilience factor in psychological illnesses and a key element of mental health.
Currently, direct research into the links between vitamin D and resilience is still quite small, but there are emerging findings that indicate potential relationships between vitamin D and adaptive psychological outcomes. Vitamin D might affect a range of cognitive, emotional and neurobiological processes that underlie resilience.
Many people say that they feel more energetic, mood stabilised, cognitively functioning better and coping better when their vitamin D is sufficient, than when the level is low. All of these are hallmarks of mental toughness.
An explanation for this relationship is neuroplasticity. Resilience is adaptive changes in neural systems that help with recovering from stress and adversity. Vitamin D is involved in neuronal growth, plasticity, and neuroprotection, thus playing a role in the biology of resilience.

Another key mechanism is stress regulation. This is because chronic stress can interfere with emotional regulation, inflammation and psychological adaptation. The effect of vitamin D on inflammatory processes and functioning of HPA axis may play a protective role in the effects of stress.
It has also been suggested that vitamin D can have indirect effects on resilience by its actions in depression and anxiety. Given that depressive and anxiety symptoms compromise resilience, there may be a contribution of vitamin D to improve emotional adaptation and recovery capacities.

There is still not much literature on vitamin D and its relationship to emotional resilience and adaptive psychological functioning, but the evidence that exists points to the possibility that vitamin D status may be quite important to emotional resilience and adaptive psychological functioning.

4.5 Vitamin D and cognitive reappraisal
Cognitive reappraisal is a highly researched emotion regulation strategy in modern psychology. It's changing the way you think about a situation to change how you feel about it. People who are effective at cognitive reappraisal tend to be more able to deal with stress, control negative emotions, and stay in a state of psychological health. Cognitive re-appraisal is an adaptive coping style that has been robustly associated with reduced emotional distress, depression and anxiety across a range of studies.
The empirical study of the link between vitamin D and cognitive reappraisal has been somewhat under-explored. However, growing evidence indicates that vitamin D could impact cognitive functioning that is associated with good emotion regulation. Executive functioning aspects, attention regulation, working memory, cognitive flexibility and emotional control are needed for cognitive reappraisal. Vitamin D receptors are found in large numbers in the prefrontal cortex and associated neural networks, which mediate most of these functions.
Vitamin D deficiency has been shown to impair cognitive function, such as concentration, memory, information processing and executive control. These deficits could make it harder for an individual to rethink stressful experiences in ways that are adaptive. A deficiency can be accompanied by mental fatigue, lack of cognitive flexibility and struggles to deal with emotional situations.
Vitamin D has been found to have a role in neuronal differentiation, synaptic plasticity and neurotransmitter regulation through neuroscientific research. These mechanisms can be helpful support processes in cognition and can indirectly affect the success of cognitive reappraisal strategies. Deficiency can thus play a role in the development of maladaptive emotional reactions, as it reduces cognitive resources that are used for adaptive emotion regulation.
While the direct evidence is still limited, there are some findings suggesting a potential link between cognitive reappraisal processes and vitamin D status. The role of vitamin D in the improvement of cognitive flexibility and adaptive emotion regulation may be explored in future research with vitamin D deficient people.

4.6 Vitamin D and neuroticism
Neuroticism is a one of the five broad factors of personality, in the Five Factor Model of personality. Emotional instability, stress sensitivity, self consciousness, mood changes, anxiety and irritability are the features. Those with a high neuroticism score are more prone towards negative emotions and are more vulnerable to psychological disorders.
The study of the link between vitamin D deficiency and personality traits has been limited. But various studies indicate that lack of vitamin D can be linked to qualities typical of highly neurotic people. These include heightened emotional sensitivity, a negative outlook and susceptibility to stress-related disorders, fatigue and irritability.
One theory is the effects of vitamin D on neurotransmitter systems. Vitamin D plays a role in the production and regulation of serotonin, and disturbances in its production has been related to neurotic behaviour. A reduction in serotonin activity may lead to an increase in emotional sensitivity and negative affectivity, which is of relevance to neuroticism.
The relationship may be due to inflammatory mechanisms as well. There is a correlation between chronic inflammation and instable mood and emotional vulnerability. Vitamin D has anti-inflammatory effects to help regulate immune function. Deficiency could thus increase inflammatory activity and lead to emotional instability.
Neuroticism has also been found to correlate highly with depression, anxiety and perceived stress. Vitamin D deficiency is an independent risk factor for these psychological disorders and neuroticism could act as a mediator or moderator between vitamin D status and mental health.

Findings to date are preliminary, but suggest a relationship between vitamin D status and emotional stability and vulnerability to psychological distress related to personality. Further studies are needed to elucidate the relationships, and their clinical significance.

4.7 Vitamin D and Locus of Control

Locus of control is a psychological concept created by Rotter (1966) to identify what people believe about how much their lives are influenced by their own activities, in opposition to their view of how much their lives are influenced by the environment. People with an internal locus of control feel that they can control outcomes, that they are active agents that can control the outcome of their lives through their efforts and decisions. Instead, external locus of control people believe that things that happen are due to luck, destiny, chance or external forces.

Locus of control is highly linked with psychological wellbeing, coping, motivation and resilience. People who have an internal locus of control tend to have greater self-efficacy, adaptive coping and emotional well-being.

There is limited research conducted on vitamin D deficiency and locus of control. However, there are a number of theoretical avenues for how vitamin D status could be related to perceptions of personal control. Symptoms of deficiency include lack of energy, fatigue, loss of motivation, depressive symptoms and cognitive impairment. These experiences can lead to a sense of lack of control and helplessness in everyday life.

On the other hand, vitamin D sufficiency could help maintain physical vitality, cognition, and psychological confidence which, in turn, can help improve perceptions of personal agency and self-efficacy. Enhanced emotional functioning can contribute to coping strategies that are more adaptive and the augmentation of internal control beliefs.

Locus of control can also have an impact on health-related behaviors pertaining to vitamin D (from a health psychology perspective). People with an internal locus of control might be more likely to follow preventive health guidelines, such as eating healthy foods, getting enough sun, and taking supplements.

At present, there is only limited empirical evidence, but locus of control is an important psychological construct that could explain individual differences in response to vitamin D deficiency and the psychological impact.

4.8 Neurobiological mechanisms underlying the relationship between vitamin D and psychological functioning.

To interpret the current evidence, the biological mechanisms underlying the association between vitamin D deficiency and psychological outcomes must be understood. There are several neurobiological pathways that have been suggested to explain observed associations.

Serotonin Regulation

Vitamin D "affects genes that regulate and produce serotonin. Serotonin is a very important chemical messenger in the brain involved in mood and emotional regulation, social interaction and stress coping. The decrease of vitamin D may affect the way serotonin works and make one more susceptible to depression and anxiety.

Dopamine Functioning

Vitamin D is also known to affect pathways in the brain that control motivation, rewards, attention and emotional regulation. Disturbances in dopamine activity could lead to the fatigue, lack of motivation and cognitive issues that are commonly seen in vitamin D deficient people.

Neuroplasticity and Neurogenesis

Vitamin D is known to induce differentiation, growth and plasticity of neurons. These processes are critical for learning, memory, emotional adaptation and resilience. Deficiency can affect neuroplasticity and mental functioning.

Neuroprotection

Vitamin D helps guard neurons against oxidative stress and cell damage. Neuroprotective effects, which underlie proper cognitive and emotional development throughout life.

Inflammatory Regulation

Inflammation has become an important factor in many psychiatric illnesses. Vitamin D regulates pro-inflammatory cytokines and regulates immune responses. Deficiency may be a factor in depression, anxiety, and cognitive dysfunction as chronic low-grade inflammation.

Hypothalamic-Pituitary-Adrenal Axis Regulation

Physiological response to stress is controlled by the HPA axis. Vitamin D affects HPA activity and adaptive stress responses. A dysfunction of this system has been found to be associated with depression, anxiety disorders and chronic stress conditions.

Together these mechanisms offer solid evidence of the biological significance of the vitamin D/psychological functioning and mental health hypothesis.

4.9 Kerala-Specific Evidence and the Kerala Paradox

Kerala is a special setting to discuss vitamin D deficiency due to its epidemiology. Although there is an ample amount of sunlight available all the year, studies have consistently reported high prevalence of vitamin D deficiency among Kerala population. This phenomenon has been dubbed as the "Kerala Paradox."

There are a number of reasons for this paradox. With the fast-paced urbanization, the lifestyle is drastically changed with reduced outdoor activity and increased sedentary lifestyle, which includes more indoor work. There are other factors that restrict exposure to sunlight, such as educational requirements and the extensive use of digital technologies, especially among young people.

Other reasons for low levels of vitamin D are dietary. The consumption of fish is still common in Kerala, but the dietary changes and nutritional transitions might lead to a decline in vitamin D consumption. Further, sun-avoidance behavior is promoted by cultural preferences for lighter skin tone, which further decreases effective UVB exposure.

Kerala has seen an increasing prevalence of psychological stress and anxiety disorders, depression and lifestyle related illnesses at the same time. Social changes, occupational pressures, academic competition, and changing family structures all help to create more mental health issues.

While these are the general trends, there is a lack of research literature that directly examines the link between vitamin D deficiency and psychological well-being within Kerala. There is a lack of studies on psychological functioning and the majority of the studies available are on prevalence, metabolic disorders, osteoporosis and physical health outcomes. Thus, there is still a significant lack of knowledge about the role vitamin D plays on emotional resilience, cognitive reappraisal, neuroticism and locus of control among the Kerala population.

As noted in the present review, the need for interdisciplinary research, spanning psychology, psychiatry, nutrition, endocrinology, and public health is therefore emphasized. These studies can help to understand the psychological effects of vitamin D deficiency and could be used to develop strategies for addressing the problem in different regions of the world.

5. Discussion

This systematic review aimed at exploring the association between vitamin D deficiency and psychological outcomes including mental health outcomes, emotional resilience, cognitive reappraisal, neuroticism and locus of control. The review also aimed to investigate these associations in the context of Kerala, where vitamin D deficiency is still common even though the state receives ample sunlight. The results taken together indicate that vitamin D deficiency may be linked to a wide spectrum of psychological effects and may be an important but overlooked factor in mental health and emotional functioning.

The one thing that has been found consistently in the literature is the relationship of vitamin D deficiency to depression. In a variety of ethnic groups and study designs, lower vitamin D levels tended to be linked to higher depressive symptoms, decreased mood stability, and diminished psychological functioning. The general results of the meta-analysis suggest that there is a significant relationship, although the strength of this effect differs from study to study. The uniformity of the results lends credence to the notion that vitamin D status might affect mood regulation through biological mechanisms such as serotonin synthesis, inflammatory regulation, and neuroplasticity. But the causal relationship of this is still under discussion. Vitamin D deficiency can be associated with depressive symptoms, but depression can also decrease outdoor activities and exposure to sunlight, which will lead to a lower vitamin D level. Likely, therefore, the relationship will be bidirectional and complex, with a number of biological, psychological and environmental factors playing a role.

The review also found that there was a significant amount of evidence of the association between vitamin D deficiency and anxiety and stress-related symptoms. Lower levels of vitamin D tended to be associated with higher psychological distress, stress sensitivity, and anxiety. The results are similar to those studies that

stressed the importance of vitamin D in the regulation of hypothalamic-pituitary-adrenal (HPA) axis and adaptive physiological response to stress. Vitamin D also might be a protective factor against dysregulations in stress-response systems, which has long been linked to anxiety disorders. However, more longitudinal studies are needed to understand the direct effects of vitamin D deficiency on anxiety, and if it is one of several risk factors.

This review emphasizes the need to look at positive psychological constructs (such as emotional resilience) in addition to conventional psychiatric measures. Resilience has grown to become one of the key terms in modern psychology because it is a measure of an individual's ability to deal adaptively with adversity and to continue functioning psychologically under stress. While vitamin D's relationship to resilience is not yet well studied, current knowledge indicates that sufficient vitamin D status may promote adaptive emotional function via improvements in cognition, mood, energy, and neurobiology. People with adequate vitamin D levels have shown to have higher emotional stability and more effective coping skills that are associated with resilient functioning. The findings of these observations indicate that vitamin D has a role in not only preventing psychological disorders but also increasing psychological strengths and adaptive capacity.

The review also investigated the link between vitamin D and cognitive reappraisal, which is one of the most adaptive emotion regulation styles. Cognitive reappraisal helps people reinterpret stressful situations in ways that lessen emotional discomfort and help them cope. Reappraisal is dependent on cognitive flexibility, executive functioning, attentional control, and emotional control. Vitamin D can support the neural processes in the prefrontal cortex and associated cognitive networks, so that its deficiency can lead to impaired cognitive resources (CR), required for adaptive emotional regulation. While there is still a lack of empirical studies directly addressing this relationship, there is theoretical and neurobiological evidence that vitamin D might affect emotion regulation via cognitively mediated processes. Further research is needed to see if boosting vitamin D levels can help improve cognitive reappraisal and psychological adaptation.

The results on neuroticism provide further information about the psychological effect of vitamin D deficiency. Neuroticism is defined as emotional instability, negative affectivity, and susceptibility to stress. The literature examined in this study indicates that vitamin D deficiency might be linked to characteristics that are typical of highly neurotic persons such as emotional sensitivity, irritability, mood fluctuations, and psychological distress. While it is generally accepted that personality traits are fairly stable, their expression and the intensity of the same can be influenced by biological factors. Thus, vitamin D deficiency could be a factor in emotional vulnerability via neurochemical and inflammatory mechanisms. This is a possibility that needs to be explored further, as neuroticism has been well established as a risk factor for depression, anxiety and lower well-being.

It was felt that during the review that the concept of locus of control may be another important psychological construct to look at when working with individuals who have ADHD. While evidence is still scarce, it is believed that the effects of vitamin D deficiency on energy, motivation, cognition and emotional functioning could impact on perceptions of personal control. People who suffer from chronic fatigue, depressive symptoms and cognitive impairments may feel a lack of control in life situations and be more likely to develop external control orientations. In turn, successful physical and psychological performance can foster higher self-efficacy and self-efficacy beliefs. The relationship between vitamin D status and locus of control may give important insights concerning psychological adaptation and health-related behaviour.

An important strength of this review is the linkage of the neurobiological mechanisms and psychological outcomes. Vitamin D has been shown to directly affect a number of biological systems important to mental health including serotonin regulation, dopamine functioning, neuroplasticity, neuroprotection, inflammatory regulation and HPA axis activity. These mechanisms give rational explanations to the observed relationships of vitamin D deficiency and psychological outcomes. Importantly, they suggest that vitamin D should not only be regarded as a nutrient influencing physical health but as a biologically active compound that may have important effects on the functioning of the brain and psychological well-being.

These relationships can be explored further in the context of Kerala. Although there is plenty of sunshine, deficiency of vitamin D is common across the state. This paradox underscores the need to take into account influences of behaviour, culture, occupation and environment on vitamin D status. Today's lifestyles, with indoor work, more time spent in front of screens, less time outdoors, and changes in dietary patterns have significantly impacted opportunities for vitamin D production. Meanwhile, Kerala has been facing an increase in psychological stress, depression, anxiety and lifestyle-related disorders. While no direct studies have investigated psychological well-being and vitamin D deficiency in Kerala populations, the co-occurrence of these trends offers a significant direction for future research.

This review can be explained in various ways from the psychological perspective. Resilience theory focuses on biological and environmental resources and their role in promoting adaptive functioning when under stress. Vitamin D might be one such resource that helps to promote resilience and psychological adaptation.

Likewise, Lazarus and Folkman's cognitive appraisal theory indicates that emotional responses are a function of the meaning people attribute to and their reaction to stressful events. Vitamin D can indirectly impact on appraisal processes and coping outcomes by its effects on cognitive functioning and emotional regulation. Health psychology approaches also highlight the interplay of biological, psychological and social factors in health and well-being. The current results argue for a biopsychosocial perspective on vitamin D deficiency and its psychological implications.

However, the existing literature has a number of limitations. Most of the existing studies are cross sectional and do not allow causal interpretations. There is a large variation among studies in measurement approaches, especially as it pertains to the definition of vitamin D deficiency and measurement of psychological outcomes. Most studies mainly take depression and anxiety into account without considering other constructs like resilience, cognitive reappraisal, neuroticism, and locus of control. Moreover, cultural and contextual aspects have not been sufficiently explored, especially in the context of developing countries and regionally in Kerala.

All in all, the results of this review suggest that vitamin D deficiency could be a potentially powerful but controllable determinant of psychological health. While more research is required to better understand causal links and mechanisms, current evidence suggests a need for the incorporation of nutrition considerations into mental health research, clinical practice, and public health intervention. Therefore, correcting vitamin D deficiency could be a key to better physical health as well as better psychological functioning, emotional resilience, and overall well-being.

6. Conceptual Framework

The literature reviewed suggests a conceptual framework that can be used to explain the relationship between vitamin D and psychological well-being.

Proposed Conceptual Model

Vitamin D Deficiency
↓
Neurobiological Dysregulation
• Reduced Serotonin Synthesis
• Dopamine Dysfunction
• Increased Inflammation
• Impaired Neuroplasticity
• HPA Axis Dysregulation
↓
Psychological Vulnerability
↓
• Reduced Emotional Resilience
• Impaired Cognitive Reappraisal
• Increased Neuroticism
Individuals who believe that life's events are determined by external factors.
↓
Mental Health Outcomes
↓
• Depression
• Anxiety
• Psychological Distress
A decrease in the quality of life.
• Lower Psychological Well-Being

This model indicates that vitamin D deficiency might indirectly affect mental health outcomes via neurobiological and psychological mechanisms. Empirical studies in the future could use mediation and moderation analysis to test the proposed model.

7. Research Gaps

The review revealed several key areas of the literature that were missing.

7.1 Limited Kerala-Specific Research

Despite the high prevalence of vitamin D deficiency in Kerala, there is limited research exploring the psychological implications of the deficiency in Kerala. Current studies have mostly centered on physical health impacts, and metabolic disorders and prevalence statistics.

7.2 Lack of Longitudinal Studies
The majority of research examining vitamin D and psychological outcomes have been cross-sectional. Therefore, it is challenging to conclude causal links.

7.3 Lack in attention to the positive psychological constructs
Most of the research has been conducted on depression and anxiety. Emotional resilience, psychological well-being, optimism, emotional intelligence, and post-traumatic growth have received too little research.

7.4 limited research on cognitive reappraisal exists.
There is limited evidence of direct investigations on which the relationship between vitamin D status and cognitive reappraisal is investigated. This is a substantial lack considering the relevance of emotion law in mental well-being.

7.5 Limited evidence on Neuroticism and Personality Factors

Despite the increasing evidence that biological factors can contribute to personality functioning, little is known about the relationship between vitamin D deficiency and personality traits.

7.6Research on absence of Locus of Control is available.
Locus of control has been studied very few times in terms of vitamin D deficiency. This variable can offer some insight into coping processes and psychological adaptation.

7.7 Limited Intervention Studies
While there are a number of studies that have examined supplementation, very few have focused specifically on resilience, emotion regulation, coping or personality related outcomes after vitamin D intervention.

8. Theoretical Implications
The outcomes of the review are helpful to a variety of theories in psychology.

8.1 Resilience Theory
According to the resilience theory, it is biological, psychological, and environmental resources that affect adaptation to adversity. The review proposes that sufficient vitamin D levels can serve as a biological buffer for resilience and adaptation of psychological functioning.

8.2 Cognitive Appraisal Theory
According to Lazarus and Folkman's (1984) Cognitive Appraisal Theory, emotional reactions are shaped by cognitive interpretations. Vitamin D might affect appraisal processes by impacting cognition, executive functioning and emotional regulation.

8.3 Biopsychosocial Model
The results are in line with the biopsychosocial approach as interactions between biological factors (vitamin D status), psychological factors (resilience/neuroticism/locus of control), and social factors (lifestyle/culture/occupation) were found.

8.4 Nutritional Psychiatry Framework
The review echoes the growing nutritional psychiatry views on the role of nutrition in mental health, confirming the impact of nutrition on psychological processes.

9. Clinical Implications
The findings have implications from a mental health practice perspective.

9.1 Screening and Assessment
Vitamin D status should be evaluated by mental health care providers in subjects with:

- Depression
- Anxiety
- Chronic stress

- Fatigue
- Cognitive complaints
- Reduced psychological well-being

9.2 Integrative Mental Health Care
The work of psychologists, psychiatrists, physicians and nutritionists should be done in tandem to solve the issue of nutrition and mental health problems.

9.3 Preventive Mental health approaches
The identification and correction of the vitamin D deficiency could be a cheap, preventive measure that can improve emotional functioning and decrease psychological vulnerability.

9.4 Treatment Planning
A vitamin D status assessment can be added to current psychological/psychiatric treatment strategies, especially in patients with chronic mood disorders.

10. Public Health Implications
The results have wider public health implications.

10.1 Awareness Campaigns
Health authorities should raise awareness about:
- Safe sunlight exposure
- Vitamin D-rich foods
- Psychological effects of low vitamin D levels

10.2 Food Fortification
Widespread vitamin D food fortification can help decrease community vitamin D deficiency.

10.3 School and University Interventions
Schools to promote outdoor activities and healthy life habits among students.

10.4 Workplace Health Promotion
Wellness program initiatives should be created for organizations to encourage outdoor activity and nutritional awareness.

10.5 Kerala-Specific Strategies
Based on the Kerala paradox, state level programmes should consider tackling behavioural and lifestyle factors that may be associated with vitamin D deficiency, although the state is blessed with ample sun.

11. The Review's limitations
A number of restrictions must be recognized.
They used mostly published literature in the review, which might have created a publication bias.
Second, many incorporated studies were cross sectional and therefore conclusions about cause and effect were limited.
Third, there was significant heterogeneity in the definition of vitamin D deficiency and in the way this was measured.
Finally, emotional resilience, cognitive reappraisal, neuroticism, or locus of control has been directly studied in relatively few studies.
Fifth, evidence is still limited in Kerala, and is difficult to interpret in context.
Finally, the review used narrative synthesis and not quantitative meta-analysis; consequently, it was not possible to systematically compare effect sizes across studies.
Given these disadvantages, the review offers a thorough review of the current knowledge and highlights key pathways for future research.

12. Recommendations
Based on the findings, a number of recommendations are proposed.

Research Recommendations

Take up psychological studies on a large scale basis in Kerala.
Make use of longitudinal research designs.
Directly examine resilience, cognitive reappraisal, neuroticism and locus of control.
Do RCTs on vitamin D effects on psychological outcomes.
To establish interdisciplinary research partnerships with psychology, psychiatry, nutrition and public health.

Clinical Recommendations

- Make vitamin D testing a routine component of mental health assessments.
- Foster Joint Care Models.
- Raise awareness of the role of nutrition in mental health among the health care community.

Policy Recommendations

- Improve vitamin D fortification programmes.
- Promote safe sunlight exposure campaigns.
- Conduct school and community awareness raising campaigns.
- Have regular screening in high-risk groups.

13. Conclusion

Vitamin D deficiency is more than a bone health issue – it is a major public health problem. The current systematic review focused on the association between vitamin D deficiency and psychological functioning, especially the psychological factors of depression, anxiety, emotional resilience, cognitive reappraisal, neuroticism, and locus of control. Results showed consistent relationships between low vitamin D and poor psychological outcomes such as more depressive symptoms, psychological distress, anxiety and lower quality of life.

The review also identifies new evidence that vitamin D could affect other areas of psychological functioning by neurobiological pathways related to serotonin regulation, dopamine functioning, neuroplasticity, inflammatory pathways, and stress-response systems. The mechanisms give biological plausibility to the observed relationships between vitamin D deficiency and emotional resilience, cognitive functioning, personality characteristics and perception of personal control.

This vitamin D deficiency problem in Kerala with plenty of sunshine strongly highlights the role of lifestyle, behavioural, occupational and cultural factors. Despite the lack of direct evidence of vitamin D deficiency and psychological outcomes in Kerala, there is still potential to study this further. The Kerala Paradox offers a unique opportunity to study the interplay between environment, nutrition and mental health.

In summary, the review confirms the emerging understanding of the importance of nutrition in mental health and psychological functioning. Correction of vitamin D deficiency could be a simple, inexpensive and readily available intervention for the improvement of emotional resilience, psychological well-being, and population mental health. Further interdisciplinary studies involving psychology, psychiatry, nutrition, neuroscience, and public health are needed to boost knowledge in this critical field.

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