Review

Not peer-reviewed version

Genetic and Molecular Bases of Mental Well-Being and Mindfulness

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Posted Date: 18 June 2026

doi: 10.20944/preprints202606.1457.v1

Keywords: mental well-being; genetics; DNA; mindfulness; GWAS; psychology

 doi:10.20944/preprints202606.1457.v1

Review

Genetic and Molecular Bases of Mental Well-Being and Mindfulness

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Abstract

Genetic and Molecular Bases of Mental Well-being and Mindfulness is an exciting and quickly emerging research field that examines how the genetic and molecular bases of our biology (genetics and our molecular biology) can impact our mental well-being and our mindfulness practices, and aims to uncover the biological foundations of how we can begin to engage our mental well-being, stress-resilience, and mindfulness practices.

Keywords: mental well-being; genetics; DNA; mindfulness; GWAS; psychology

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1. Introduction

Genetic and Molecular Bases of Mental Well-being and Mindfulness is an exciting and quickly emerging research field that examines how the genetic and molecular bases of our biology (genetics and our molecular biology) can impact on our mental well-being and our mindfulness practices, and aims to uncover the biological foundations of how we can begin to engage our mental well-being, stress-resilience and mindfulness practices. This comprehensive review will cover overall three main themes:

1. The Genetic Underpinnings of Mental Well-being
2. Molecular Mechanisms Underlying Mindfulness, and
3. Conclusions on how both impact our mental well-being together with our mindfulness practices.

Mental well-being is a complex and dynamic state that encompasses emotional, psychological, and social health. It influences how individuals think, feel, behave, cope with stress, and interact with others [1]. While environmental factors such as upbringing, education, social relationships, and lifestyle play significant roles in shaping mental health, growing scientific evidence highlights the profound influence of the human genome on mental well-being. The relationship between mental health and genetics is not unidirectional; rather, it represents a sophisticated crosstalk in which genes influence mental states, and environmental experiences can, in turn, modify gene expression through epigenetic mechanisms [2–6].

The human genome consists of approximately three billion base pairs of DNA that encode the instructions necessary for the development and functioning of the human body, including the brain. Variations within specific genes can affect neurotransmitter systems, neural connectivity, stress responses, and cognitive functions. For example, genes involved in the regulation of serotonin, dopamine, and other neurotransmitters have been associated with susceptibility to mental health conditions such as depression, anxiety disorders, bipolar disorder, and schizophrenia. However, possessing genetic variants linked to these disorders does not guarantee their development. Instead,

 doi:10.20944/preprints202606.1457.v1

these genetic factors often contribute to vulnerability, which may be activated or mitigated by environmental influences [5–12].

One of the most fascinating aspects of this relationship is the concept of gene–environment interaction. Individuals carrying certain genetic variants may respond differently to stress, trauma, or social support compared to others. For instance, a person with a genetic predisposition to depression may remain mentally healthy in a supportive environment but may experience symptoms when exposed to chronic stress or adverse life events. This interaction demonstrates that genes set the stage, while life experiences shape the final outcome. Therefore, mental well-being emerges from the combined effects of biological inheritance and environmental exposures rather than from either factor alone [8–14].

Recent advances in genomics have also emphasized the importance of epigenetics in mental health. Epigenetics refers to changes in gene activity that occur without altering the DNA sequence itself. Environmental factors such as stress, nutrition, physical activity, sleep quality, and social relationships can influence epigenetic markers, thereby affecting how genes are expressed. Chronic psychological stress, for example, can modify the expression of genes involved in inflammation and stress regulation, potentially increasing the risk of mental disorders. Conversely, positive lifestyle interventions, including mindfulness practices, regular exercise, and supportive social interactions, may promote beneficial epigenetic changes that enhance resilience and psychological well-being [9–14].

The brain itself serves as a critical interface between the genome and mental health. Neural plasticity—the brain's ability to adapt and reorganize in response to experiences—is partly regulated by genetic and epigenetic factors. Genes involved in neuroplasticity influence learning, memory, emotional regulation, and recovery from psychological distress. Environmental enrichment, education, therapy, and positive social engagement can stimulate neural pathways that support mental well-being, illustrating how external experiences can shape biological processes at the molecular level [15–18].

Understanding the crosstalk between the human genome and mental well-being has important implications for healthcare and personalized medicine. Advances in genomic technologies are enabling researchers to identify genetic risk factors for mental disorders and develop more targeted interventions. Personalized approaches may one day allow clinicians to predict an individual's susceptibility to certain conditions and tailor preventive strategies or treatments accordingly. However, it is equally important to recognize that genetics is not destiny. Mental health outcomes are influenced by a broad network of biological, psychological, social, and environmental factors, many of which are modifiable [19–23].

Overall, mental well-being and the human genome are engaged in a continuous and intricate dialogue. Genes contribute to the biological foundation of mental health, while environmental experiences influence how these genes are expressed and function. The interplay of genetics, epigenetics, and life experiences shapes individual resilience, vulnerability, and psychological outcomes. As scientific understanding of this relationship continues to expand, it offers promising opportunities for improving mental health prevention, diagnosis, and treatment while reinforcing the importance of nurturing supportive environments that promote well-being across the lifespan [97,98] (Figure 1).

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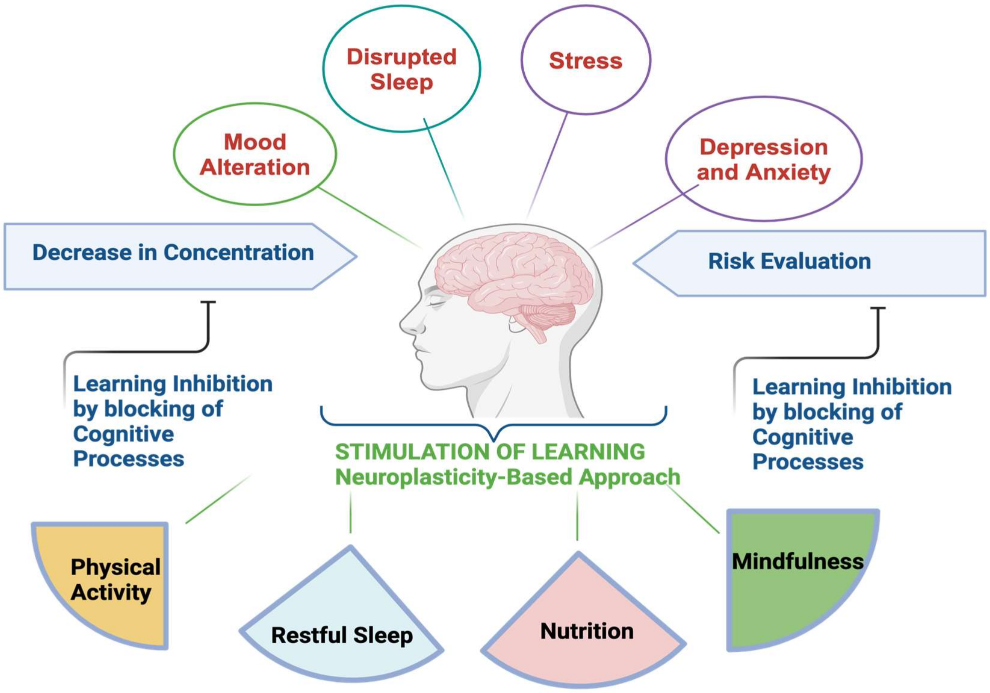

Figure 1. A Crosstalk between Mental Well-being and Human Genome (Prepared in BioRender).

1.1. Genetic Underpinnings of Mental Well-Being

Mental well-being is a complex and multifaceted construct that has been found to have a significant genetic component [1]. Genetic influences on measures of mental well-being, such as emotional and social well-being, reflect a single, highly heritable factor, suggesting a shared genetic basis. Emerging evidence suggests that mental well-being, including traits such as neuroticism, demonstrated that these psychological characteristics are moderately heritable, with additive genetic effects accounting for a significant portion of the observed variance [2]. While the exact genetic basis remains fully elucidated, researchers [2,3] have begun identifying specific genetic variants and chromosomal regions associated with various aspects of mental well-being. For instance, studies have linked chromosomal region 9q to anxiety and panic disorder, highlighting the potential genetic underpinnings of these conditions. Additionally, genome-wide association studies have implicated common DNA sequence variations in the etiology of major depressive disorder, with a focus on genes involved in neurotransmitter systems and stress sensitivity [3,4]. These findings suggest that a complex interplay of genetic factors contributes to an individual's susceptibility to mental well-being challenges [2].

1.2. Neurobiological Basis of Mental Well-Being

The neurobiological basis of mental well-being has been an area of increasing research interest. Studies have identified brain regions and neural circuits that are associated with various aspects of mental well-being. According to King, M.L. (2019), regions of the prefrontal cortex, which are involved in cognitive control, emotion regulation, and decision-making, have been linked to emotional well-being. Additionally, the limbic system, which includes structures like the amygdala and hippocampus, plays a crucial role in the processing of emotions and the regulation of stress response [5]. Neuroimaging studies have revealed that individuals with higher levels of mental well-being exhibit increased activity and connectivity in these brain regions, suggesting a neurobiological foundation for positive mental well-being.

1.3. Epigenetic Influences on Mental Well-Being

Epigenetic mechanisms, which involve modifications to the Deoxyribonucleic acid (DNA) and its associated chromatin structures without altering the underlying genetic sequence, have emerged as an important factor in understanding the regulation of mental well-being [6–8]. Studies have shown that epigenetic changes, such as DNA methylation and histone modifications, can influence the expression of genes involved in neural plasticity, stress response, and emotional regulation – all of which are critical for mental well-being [9–12].

Exposure to stressful life events, for example, has been associated with epigenetic changes that can lead to altered gene expression and contribute to the development of mental well-being issues, such as depression and anxiety [13].

Conversely, positive lifestyle factors, including mindfulness-based practices, have been linked to epigenetic modifications that promote resilience and enhance mental well-being [14].

1.4. Neurotransmitter Systems and Mental Well-Being

Key neurotransmitter systems, such as serotonin, dopamine, and gamma-aminobutyric acid, have been extensively studied as they relate to mental well-being [15,16]. Alterations in the levels and functioning of these neurotransmitters have been implicated in various mental well-being conditions, including mood disorders, anxiety, and cognitive impairments [17]. For example, reduced serotonin signaling has been associated with the development of depression, while dysregulation of dopaminergic pathways has been linked to the emergence of anhedonia, a core symptom of depression [18].

Interventions targeting these neurotransmitter systems, such as selective serotonin reuptake inhibitors and other psychopharmaceuticals, have proven effective in the management of mental well-being conditions, further underscoring the pivotal role of neurotransmitter systems in mental well-being [17].

1.5. Stress Pathways and Mental Well-Being

Chronic stress exposure is a well-established risk factor for the development of mental well-being issues. The hypothalamic-pituitary-adrenal axis, which is responsible for the physiological stress response, has been a focus of research relating to mental well-being [19,20]. Dysregulation of this stress system, leading to sustained elevations of glucocorticoids, has been linked to structural and functional changes in brain regions involved in emotional processing and cognitive function, ultimately contributing to the onset and progression of mental well-being challenges, including anxiety disorders, depression, bipolar disorder, and other mood disorders, disruptive behavior disorders, such as oppositional defiant disorder and conduct disorder [21].

Furthermore, stress-induced alterations in excitatory neurotransmission, particularly the glutamatergic system, have been implicated in the pathophysiology of mood and anxiety disorders [22]. Chronic stress can lead to enhanced glutamate release and changes in the structure and function of glutamate synapses, which may underlie the neuroplastic changes associated with the development of mental well-being conditions, including disorders that affect your mood, thinking, and behavior [21,22]. Antidepressant medications and stress-reducing interventions, such as mindfulness-based therapies, have been shown to modulate these stress pathways, highlighting their importance in the maintenance of and sustainability of mental well-being [21–23].

1.6. Immune Function and Mental Well-Being

Emerging evidence suggests a bidirectional relationship between the immune system and mental well-being. Chronic stress and inflammation have been linked to the development of mental well-being issues, such as depression and anxiety [24]. Proinflammatory cytokines, released during the inflammatory response, can influence the activity of neurotransmitter systems, neural plasticity, and brain function, thereby contributing to the pathogenesis of mental well-being disorders [25].

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Conversely, mental well-being conditions have also been associated with alterations in immune function, with impaired immune responses and increased vulnerability to infections observed in individuals with mental well-being challenges [26].

Interventions targeting the immune system, such as anti-inflammatory medications or immune-modulating therapies, have shown promise in the management of certain mental well-being conditions, further underscoring the importance of the immune system in the maintenance of mental well-being [27,28].

1.7. Gut-Brain Axis and Mental Well-Being

The gut-brain axis, a bidirectional communication system between the gastrointestinal tract and the central nervous system, has emerged as a key player in the regulation of mental well-being [29–31]. The gut microbiome, the complex community of microorganisms residing in the intestine, has been found to influence various aspects of brain function and behavior, including mood, cognition, and stress response [32].

Alterations in the gut microbiome composition, often referred to as dysbiosis, have been associated with the development of mental well-being conditions, such as depression, anxiety, and cognitive impairments [33,34].

The mechanisms by which the gut microbiome influences mental well-being are multifaceted, involving the modulation of neuroactive compounds, immune function, and the hypothalamic-pituitary-adrenal axis [33,35].

Interventions targeting the gut-brain axis, such as dietary modifications, probiotic supplementation, and fecal transplantation, have shown promising results in the management of certain mental well-being conditions, highlighting the importance of this bidirectional communication system in the maintenance of mental well-being [35].

1.8. Circadian Rhythms and Mental Well-Being

Circadian rhythms, the internal biological clocks that regulate the 24-hour sleep-wake cycle, have a significant impact on mental well-being [36,37]. Disruptions in circadian rhythms, such as those observed in shift work or jet lag, have been linked to the development of mental well-being issues, including mood disorders, cognitive impairments, and sleep disturbances [38].

The mechanism by which circadian rhythm disruption influences mental well-being is complex, involving the modulation of neurotransmitter systems, hormone secretion, and neural plasticity [39].

Interventions targeting the restoration of circadian rhythms, such as bright light therapy, melatonin supplementation, and cognitive-behavioral therapy for insomnia, have shown beneficial effects on mental well-being, underscoring the importance of maintaining healthy circadian rhythms for optimal mental well-being and overall well-being [40,41].

1.9. Neuroplasticity and Mental Well-Being

Neuroplasticity, the ability of the brain to undergo structural and functional changes in response to various stimuli, plays a crucial role in the maintenance of mental well-being [42]. Factors such as stress, environmental enrichment, and physical activity can influence neuroplasticity, leading to changes in brain structure, connectivity, and function [43,44].

Impairments in neuroplasticity have been associated with the development of mental well-being conditions, such as depression, anxiety, and cognitive decline. Interventions that enhance neuroplasticity, such as cognitive-behavioral therapy, physical exercise, and mindfulness-based practices, have been shown to have positive effects on mental well-being, highlighting the importance of neuroplasticity in the maintenance of mental well-being [45–47].

1.10. Mitochondrial Function and Mental Well-Being

Mitochondria, the powerhouses of the cell, are increasingly recognized as key players in the regulation of mental well-being [48,49]. Impairments in mitochondrial function, such as those observed in neurodegenerative disorders including Alzheimer's disease and other memory disorders, Ataxia, Huntington's disease, and Parkinson's disease, have been linked to the development of various mental well-being conditions, including depression, anxiety, and cognitive impairments [48].

The mechanisms by which mitochondrial dysfunction contributes to mental well-being challenges are multifaceted, involving oxidative stress, energy dysregulation, and disruptions in neurotransmitter signaling [50,51].

Interventions targeting mitochondrial function, such as the use of antioxidants, metabolic modulators, and mitochondrial-targeted therapies, have shown promise in the management of certain mental well-being conditions, such as depression (including subthreshold disorders), anxiety disorders, including panic disorder, phobias, and social anxiety disorder, highlighting the importance of mitochondrial health in the maintenance of mental well-being [49,52].

1.11. Genetic Predispositions to Mental Well-Being

Genetic factors play a significant role in the susceptibility and resilience to various mental well-being conditions, including depression, anxiety disorders, panic disorder, phobias, and social anxiety disorder. Genome-wide association studies have identified numerous genetic variants associated with the risk of developing mental well-being disorders, such as depression, anxiety, and schizophrenia [2,53].

These genetic factors can influence the expression and function of genes involved in neurotransmitter systems, neural plasticity, immune function, and mitochondrial function, all of which are important in the maintenance of mental well-being [49,55].

Genetic testing and personalized approaches to mental well-being care, such as pharmacogenomic-guided treatment, have the potential to improve the management of mental well-being conditions by identifying individual genetic predispositions and tailoring interventions accordingly [55,56].

1.12. Molecular Signatures of Mental Well-Being

The molecular underpinnings of mental well-being are complex and involve the interplay of various biological systems, including the nervous system, the immune system, and the endocrine system [6].

Specific molecular signatures, such as alterations in neurotransmitter levels, inflammation markers, and oxidative stress indicators, have been associated with mental well-being conditions such as depression, anxiety disorders, schizophrenia, eating disorders, and addictive behaviors [57,58].

Understanding these molecular signatures can provide valuable insights into the pathophysiology of mental well-being disorders and guide the development of targeted therapeutic interventions [59,60].

1.13. Psychoneuroimmunology of Mental Well-Being

The field of psychoneuroimmunology explores the bidirectional communication between the brain, the immune system, and mental well-being [61]. Chronic stress, inflammation, and immune dysregulation have been linked to the development of various mental well-being conditions, including depression, anxiety, and cognitive impairments [62,63].

Interventions that modulate the immune system, such as anti-inflammatory agents, immunomodulators, and lifestyle modifications, have shown promise in the management of certain

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mental well-being conditions, highlighting the importance of the psychoneuroimmune axis in mental well-being [27,64,65].

2. Molecular Mechanisms Underlying Mindfulness

Alongside the growing understanding of the genetic basis of mental well-being, recent research has also shed light on the molecular mechanisms underlying mindfulness and its beneficial effects on mental well-being. Studies have shown that mindfulness can influence various physiological processes, including brain function, autonomic nervous system regulation, stress hormone levels, and immune system responses [12].

At the molecular level, mindfulness has been associated with changes in gene expression, epigenetic modifications, and alterations in neurotransmitter systems [66,67]. For instance, mindfulness-based interventions have been linked to increased expression of genes involved in stress response and immune function and decreased expression of genes associated with inflammatory processes. These molecular changes have been correlated with clinical improvements, such as reduced stress, improved mood, and enhanced immune function. Furthermore, twin studies have suggested that genetic factors may moderate the effects of mindfulness-based interventions, with individual differences in genetic variants related to neurotransmitter systems and stress sensitivity influencing the impact of mindfulness on positive affective states [1,10].

Mindfulness practices, such as meditation, have been shown to influence a variety of physiological processes, including the autonomic nervous system, stress hormones, and immune function [12]. At the molecular level, mindfulness has been associated with changes in gene expression, epigenetic modifications, and neurotransmitter systems [11].

2.1. Lifestyle Factors and Mental Well-Being

Lifestyle factors, such as physical activity, nutrition, sleep, and social engagement, play a crucial role in the maintenance of mental well-being [69–71]. Regular exercise, a balanced diet, adequate sleep, and strong social connections have been associated with improved mental well-being outcomes, including reduced stress, anxiety, and depression, as well as enhanced cognitive function and emotional well-being [71,72].

The underlying mechanisms by which these lifestyle factors influence mental well-being are multifaceted, involving the modulation of neurotransmitter systems, neuroplasticity, immune function, and mitochondrial health [73,74]. The implementation of lifestyle interventions targeting these pathways has shown promise in the management of mental well-being conditions, underscoring the importance of a holistic approach to mental well-being [73,75].

2.2. Contemplative Practices and Mental Well-Being

Contemplative practices, such as meditation, mindfulness, and yoga, have gained increasing attention for their potential to enhance mental well-being [76]. These practices have been shown to modulate various biological processes, including gene expression, epigenetic modifications, and the autonomic nervous system, which can lead to improved stress management, emotional regulation, and cognitive function [11].

The molecular mechanisms underlying the benefits of contemplative practices on mental well-being are not fully understood, but emerging evidence suggests that they may involve the regulation of stress hormones, inflammatory markers, and neurotransmitter systems [73].

The integration of contemplative practices into clinical and educational settings has shown promising results in the management and prevention of mental well-being conditions, highlighting their potential as complementary approaches to maintaining and promoting mental well-being [76].

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2.3. Mindfulness and Neurobiological Changes

Mindfulness-based interventions have been increasingly studied for their effects on brain structure and function, providing insights into the neurobiological underpinnings of mental well-being [77]. Neuroimaging studies have demonstrated that regular mindfulness practice is associated with enhanced activity and connectivity in brain regions involved in attention, emotion regulation, and self-awareness, as well as structural changes in brain regions associated with learning, memory, and emotional processing [78].

These neurobiological changes may contribute to the observed improvements in cognitive function, emotional regulation, and overall well-being observed in individuals who engage in mindfulness practices [79,80].

2.4. Meditation and Molecular Regulation

Emerging research has shed light on the molecular mechanisms by which meditation and other contemplative practices can influence mental well-being [9,81]. Studies have shown that meditation can modulate gene expression and epigenetic markers, leading to changes in the regulation of stress response pathways, inflammation, and cellular aging [12,82]. For example, regular meditation has been associated with the downregulation of genes involved in inflammatory pathways and the upregulation of genes related to cellular repair and anti-aging processes [83,84]. These molecular changes may underlie the observed benefits of meditation on stress reduction, immune function, and overall physical and mental well-being [84,85].

By understanding the genetic and molecular bases of mental well-being and the effects of contemplative practices, researchers and clinicians can develop more targeted and personalized approaches to promoting and maintaining mental well-being [11,12,83].

2.5. Yoga and Genetic Expression

Yoga, a comprehensive mind-body practice, has also been studied for its effects on genetic expression and molecular pathways related to mental well-being [86,87]. Studies have shown that the practice of yoga can induce rapid changes in gene expression in peripheral blood lymphocytes, suggesting that yoga can modulate the activity of genes involved in stress response, inflammation, and cellular signaling [88].

The specific genetic and molecular pathways affected by yoga practice are diverse and may involve the regulation of transcription factors, epigenetic modifications, and the expression of genes related to neurotransmitter systems, oxidative stress, and immune function [89].

By understanding the genetic and molecular mechanisms underlying the effects of yoga on mental well-being, researchers can explore the potential of yoga-based interventions as complementary therapies for mental well-being conditions, as well as for the promotion of overall cognitive and emotional resilience [86,89]. The molecular mechanisms by which yoga influences mental well-being are not yet fully elucidated, but the available evidence suggests that yoga may have a positive impact on the regulation of stress-related genes, inflammatory pathways, and pathways involved in cellular repair and regeneration [11,88,89].

2.6. Tai Chi and Epigenetic Modifications

Similar to meditation and yoga, the practice of Tai Chi, which originates from Eastern Cultures [90–92], has also been associated with changes in gene expression and epigenetic modifications that may contribute to its beneficial effects on mental well-being [93]. Tai Chi practice has been linked to the downregulation of genes involved in inflammation and the upregulation of genes related to cellular repair and regeneration [11,94,95].

These epigenetic changes may be mediated by the modulation of stress-related pathways and the regulation of transcription factors, which can ultimately influence the expression of genes involved in neuroplasticity, emotion regulation, and cognitive function [46,47,84].

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5. Conclusions

These genetic and molecular changes associated with contemplative practices, such as meditation, yoga, and Tai Chi, may contribute to their beneficial effects on mental well-being. The modulation of gene expression, epigenetic modifications, and the regulation of stress-related pathways and transcription factors can lead to improvements in neurotransmitter systems, neuroplasticity, immune function, and mitochondrial health. The integration of these holistic approaches into clinical and educational settings holds promise for the management and prevention of mental well-being conditions, highlighting their potential as complementary therapies for promoting overall cognitive, emotional, and physical resilience [96–98].

The genetic and molecular mechanisms underlying the benefits of contemplative practices, such as meditation, yoga, and Tai Chi, on mental well-being are complex and not yet fully understood. However, emerging evidence suggests that these practices can induce significant changes in gene expression, epigenetic modifications, and the regulation of key molecular pathways that are essential for maintaining cognitive, emotional, and physical resilience [99].

Through the modulation of stress-related pathways, inflammatory markers, and neurotransmitter systems, contemplative practices have been shown to downregulate genes involved in inflammatory processes and upregulate genes related to cellular repair and anti-aging mechanisms. These molecular changes may underlie the observed improvements in overall well-being, including enhanced cognitive function, emotional regulation, and stress management [85,100].

Furthermore, the practice of these mind-body techniques has been linked to structural and functional changes in the brain, with increased activity and connectivity in regions associated with attention, self-awareness, and emotional processing. These neurobiological adaptations likely contribute to the positive effects of contemplative practices on mental well-being [101,102].

As researchers continue to unravel the genetic and molecular bases of mental well-being, the integration of contemplative practices into clinical and educational settings holds great promise for the management and prevention of mental well-being conditions. By understanding the underlying mechanisms, healthcare professionals and policymakers can develop more targeted and personalized approaches to promoting overall cognitive, emotional, and physical resilience.

By integrating a deeper understanding of the genetic and molecular bases of mental well-being with the application of holistic, contemplative approaches, researchers and clinicians can develop more targeted and personalized interventions for the management and prevention of mental well-being conditions. This multifaceted approach holds great promise for promoting overall cognitive, emotional, and physical resilience in clinical and educational settings.

The authors reviewed the existing evidence reported in the current literature on the benefits of mindfulness practice, including its impact on emotional distress, positive mental states, and overall quality of life. The review also discussed the potential neurobiological mechanisms underlying the effects of mindfulness, including changes in brain function, autonomic nervous system activity, stress hormone levels, immune function, and health behaviors.

Regular yoga and related contemplative practices hold great potential for promoting mental well-being and resilience through their ability to modulate gene expression, epigenetic modifications, and key molecular pathways involved in stress response, neuroplasticity, and evidence, although the underlying mechanisms are not yet fully understood.

The wide review of the literature provides comprehensive insights into the field of "Mental Well-being and Mindfulness". It shows the effects of meditation on mental and physical health, which found that mindfulness practices can contribute to enhanced immune function, reduced inflammation, and improved adaptation to chronic health conditions such as cancer, as well as more positive mental states and enhanced quality of life [9,103].

The genetic and molecular bases of mental well-being and mindfulness provide a deeper understanding of the biological factors that contribute to mental well-being. Genetic variations in neurotransmitter systems, stress response pathways, and neuroplasticity-related genes play critical roles in shaping an individual's emotional stability and vulnerability to stress. Meanwhile, molecular

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mechanisms such as epigenetics and neuroplasticity further modulate mental well-being, and mindfulness practices have been shown to influence these pathways positively (Figure 2).

Future research is needed that continues to bridge genetics and mindfulness will pave the way for personalized approaches to mental well-being, empowering individuals to harness their genetic predispositions and biological potential for enhanced well-being. In this way, mindfulness practices, informed by molecular science, may offer transformative benefits for mental well-being in the years to come.

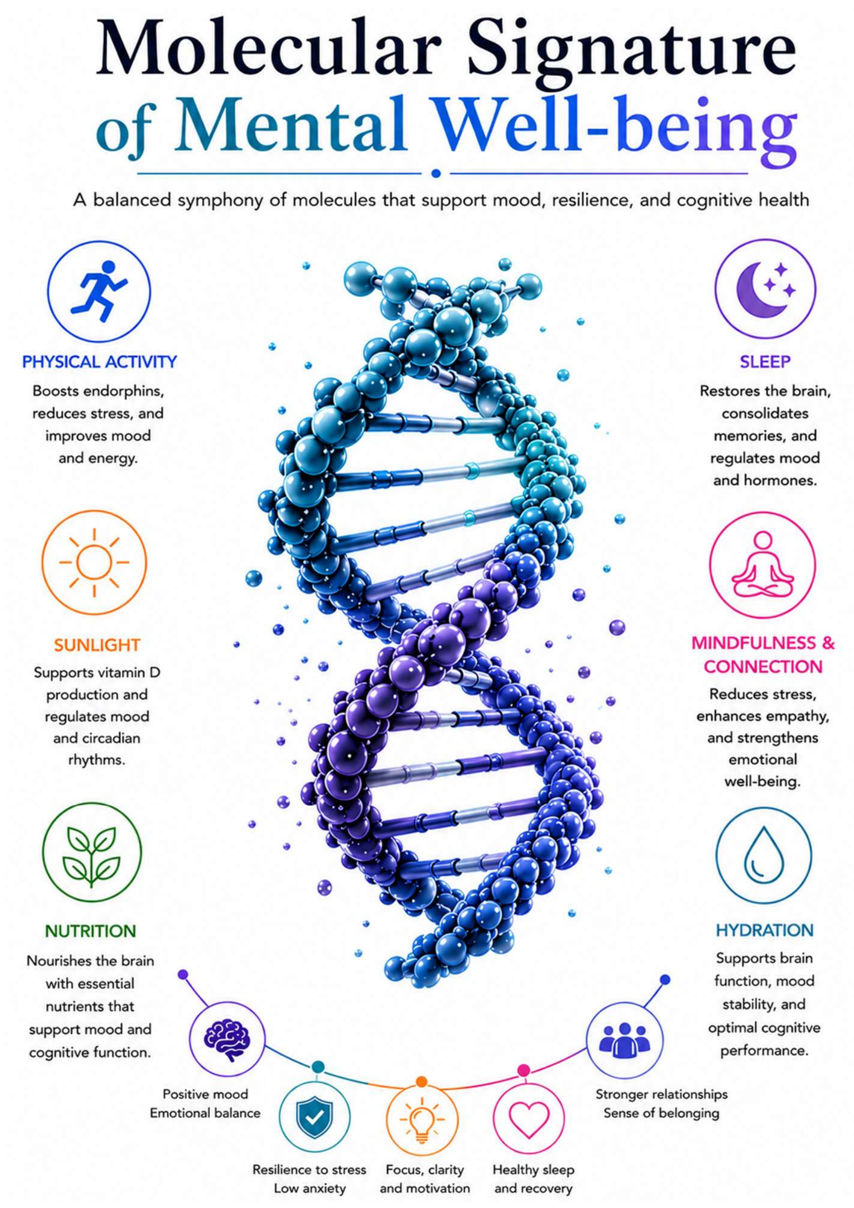

Figure 2. Mental well-being is not defined by a single molecule, but by harmony: A dynamic balance of biology, environment, and cognitive health (Prepared in BioRender).

Author Contributions: Conceptualization, Şükrü Tüzmen; Methodology, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi, and Veronique Genniker; software, Şükrü Tüzmen ; validation, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi, and Veronique Genniker; formal analysis, Şükrü Tüzmen, Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; investigation, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; resources, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; data curation, Şükrü

 doi:10.20944/preprints202606.1457.v1

Tüzmen, Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; writing—original draft preparation, Şükrü Tüzmen ; writing—review and editing, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; visualization, Şükrü Tüzmen , Deniz Tüzmen, Abdallah Rafi and Veronique Genniker; supervision, Şükrü Tüzmen , and Veronique Genniker.; project administration, Şükrü Tüzmen ; funding acquisition, N/A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study.

Conflicts of Interest: The authors declare no conflicts of interest.

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