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EDITED BY

Silvia Bisti,
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REVIEWED BY

Elizabeth Hernández-Echeagaray,
National Autonomous University of
Mexico, Mexico

*CORRESPONDENCE

Rafael Fernández-Demeneghi
✉ rafael_demeneghi@hotmail.com
Marilú Domínguez-Pantoja
✉ marildominguez@uv.mx
Alma Gabriela Martínez-Moreno
✉ alma.martinez@cusur.udg.mx

†These authors have contributed equally to
this work and share first authorship

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Positioning berries in nutritional psychiatry: potential for prevention and co-therapy in mental health

Rafael Fernández-Demeneghi^{1*†}, Marilú Domínguez-Pantoja^{2*†},
Alma Gabriela Martínez-Moreno^{1*}, Isidro Vargas-Moreno¹ and
Rodrigo Ramirez-Rodriguez³

¹Instituto de Investigaciones en Comportamiento Alimentario y Nutrición, Universidad de Guadalajara, Ciudad Guzmán, Mexico, ²Facultad de Medicina, Universidad Veracruzana, Campus Xalapa, Xalapa, Mexico, ³Instituto Politécnico Nacional, Mexico City, Mexico

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Introduction

Mental health is a critical component of wellbeing and a growing global concern. The World Health Organization (WHO) defines health as complete physical, cognitive, and social wellbeing, emphasizing that mental health is not merely the absence of mental disorders but a foundation for individual and societal functioning (WHO, 2021). Psychiatric conditions—including mood disorders, anxiety, and other psychiatric conditions—are multifactorial in origin and increasingly prevalent worldwide.

While pharmacological treatment remains the first-line therapy for psychiatric disorders, behavioral interventions such as psychotherapy have gained prominence, paving the way for complementary approaches to mental wellbeing (Gilbert, 2020). Lifestyle-based strategies—particularly dietary interventions—are gaining recognition. This perspective has led to the emergence of “*nutritional psychiatry*.” This field investigates how nutrition influences brain function and emotional health and seeks to elucidate the biological mechanisms through which dietary components impact mental health outcomes. Key physiological targets include oxidative stress regulation, neuroinflammation, neurotransmission, synaptic plasticity, and the gut–microbiome–brain axis, interconnected systems highly responsive to nutritional modulation (Logan and Jacka, 2014).

Within this context, berries (e.g., strawberries, raspberries, blueberries, blackberries, and others) have garnered attention due to their rich polyphenols, vitamins, minerals, fiber, and bioactive compounds with neuroprotective potential. This opinion article explores the emerging role of berries as functional foods in psychiatric nutrition, highlighting their potential to complement traditional interventions in preventing and managing mental health disorders. Nevertheless, clinical research focused on psychiatric populations remains scarce, particularly in trials involving individuals with diagnosed conditions, underscoring the need for targeted and well-designed studies to understand their therapeutic relevance better.

Berries: a functional food

Berry fruits—such as blueberries, blackberries, strawberries, raspberries, and blackcurrants—are rich in essential nutrients, including vitamins, minerals, fiber, and diverse bioactive compounds (Seeram, 2012). Their primary phytochemicals are phenolic compounds, notably flavonoids (e.g., anthocyanins, flavonols, flavones, flavanols, flavanones, isoflavonoids), tannins, and phenolic acids (Golovinskaia and Wang, 2021). Certain berry constituents have been linked to reduced mortality and lower risk of cancer, cardiovascular and metabolic diseases, as well as improved cognitive function, neuroinflammation, glucoregulation, cerebrovascular health, neurotransmission, and hippocampal neurogenesis—mechanisms relevant to mental health (Aguilera, 2024).

While berries share common phytochemical categories, their specific profiles—including the type and concentration of bioactive compounds—can differ substantially across species and cultivars. These compositional distinctions may underlie unique biological effects, adding nuance to their potential applications in mental health. As such, future research would benefit from a more differentiated approach that considers berry-specific characteristics when assessing their relevance in psychiatric contexts.

Psychiatric disorders involve dysregulation in dopaminergic, serotonergic, and glutamatergic pathways, alongside alterations in neurotrophic factors, immune and neuroendocrine systems, and epigenetic mechanisms (Sutkow et al., 2021; Fang et al., 2020). This piece aims to discuss key findings on the potential mechanisms by which berry-derived compounds may influence mental health outcomes (Figure 1).

Oxidative stress

Oxidative stress results from an imbalance between reactive oxygen/nitrogen species (ROS/RNS) production and the body's ability to neutralize them (Cecerska-Heryć et al., 2022). The brain is especially vulnerable due to its high oxygen demand, abundance of peroxidizable lipids, and limited antioxidant defenses (Zalachoras et al., 2020). Excess ROS impairs synaptic plasticity, neurogenesis, and contributes to neuronal degradation (Salim, 2017; Singh et al., 2019). To counteract oxidative damage, cells rely on enzymatic antioxidants—superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione reductase (GR)—and non-enzymatic antioxidants like glutathione (GSH), vitamins A, C, E, and trace elements such as zinc (Salim, 2017; Niedzielska et al., 2016; Salim, 2014).

Although pharmacological strategies exist, antioxidants continue to be explored as adjunctive options for their neuroprotective potential in psychiatric disorders. Berries contain up to four times more antioxidants than other fruits, mainly due to phenolic compounds and vitamin C (Golovinskaia and Wang, 2021). In psychiatric populations, elevated oxidative stress markers and reduced antioxidant defenses are consistently reported, supporting the rationale for antioxidant-based interventions (Grabnar et al., 2011; Rasmus and Kozłowska, 2023).

For example, supplementation with 30 g of freeze-dried black raspberries for 4 weeks enhanced CAT and GPx activity in healthy

male smokers, mitigating oxidative stress related to cigarette exposure (Handelman et al., 1996). While informative, such findings do not establish therapeutic relevance in psychiatric populations. Observational studies indicate that individuals with depression often consume fewer antioxidant-rich foods and exhibit lower plasma concentrations of vitamins C and E (Payne et al., 2012; Huang et al., 2019). Vitamin C supplementation has shown antidepressant effects and mood enhancement, although such results are not specific to berry intake. In postmenopausal women, antioxidant-rich diets have correlated with reductions in anxiety and oxidative stress markers (Wu et al., 2022), yet the distinct contribution of berries remains to be clarified.

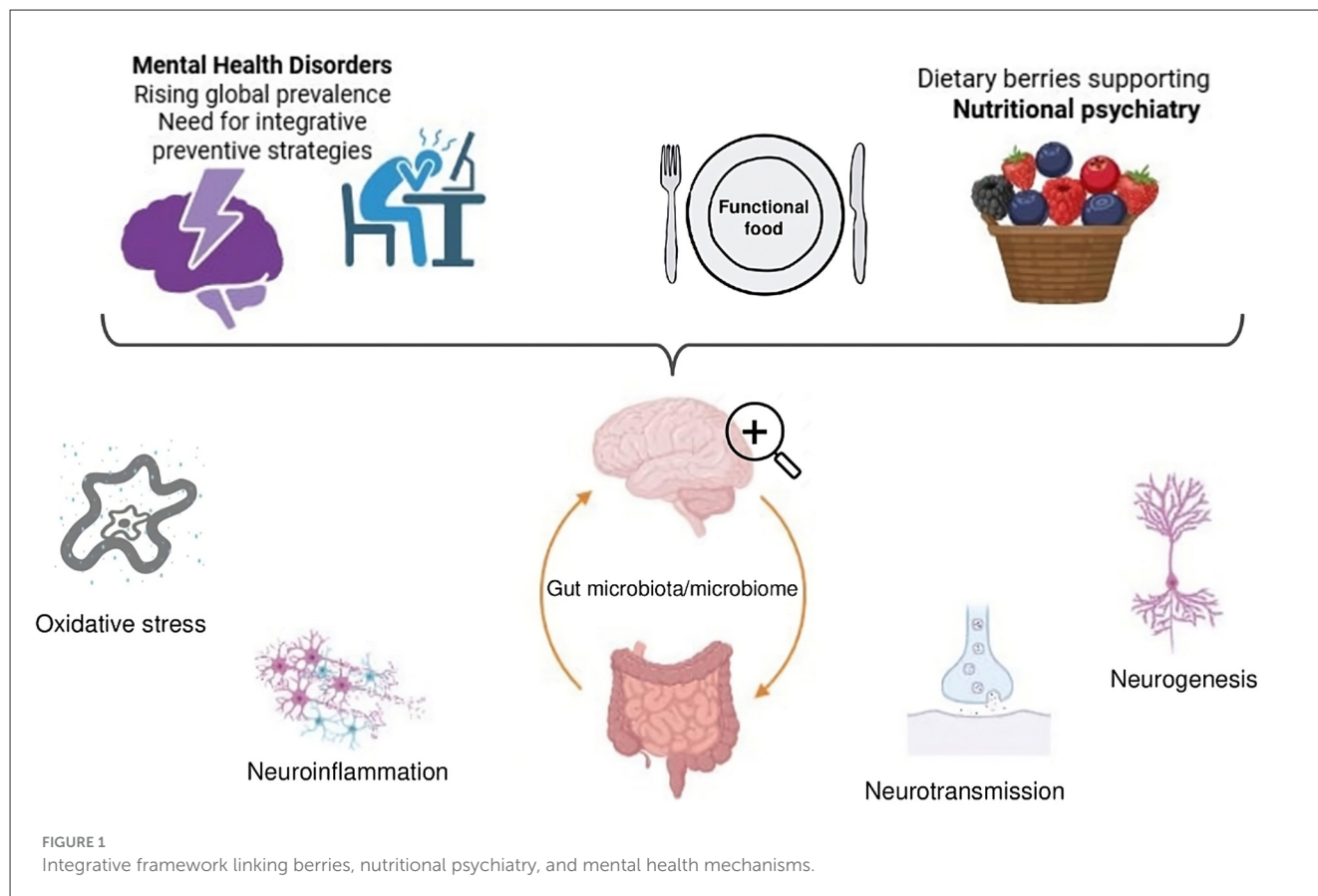
In summary, although berries exhibit strong antioxidant potential, more robust clinical trials are needed to determine whether this biochemical activity translates into meaningful mental health outcomes in individuals with diagnosed psychiatric conditions.

Inflammation

Phytochemicals in berries exhibit anti-inflammatory effects by modulating immune cell activity and inhibiting pro-inflammatory mediators such as TNF- α , IL-1 β , IL-6, IL-8, and C-reactive protein (CRP; Pap et al., 2021). For instance, strawberry extract reduces IL-8 secretion and downregulates TNF- α , IL-1 β , and iNOS via MAPK pathway inhibition (Fumagalli et al., 2016; Lee et al., 2014). In a short-term clinical study, a 7-day intake of a strawberry beverage attenuated postprandial increases in IL-6 and CRP in overweight adults following a high-fat, high-carbohydrate meal (Edirisinghe et al., 2011). Although these results are promising, they were obtained in healthy individuals and not in clinical psychiatric samples.

Chronic low-grade inflammation, including neuroinflammation, is implicated in various psychiatric and neurodegenerative disorders (van Zonneveld et al., 2024). Depression, in particular, is strongly linked to immune-inflammatory mechanisms, with elevated levels of CCL2, CXCL10, proinflammatory cytokines, and CRP reported in affected individuals (Müller, 2013; Hong et al., 2016). Through MAPK and NF- κ B pathway modulation, polyphenols demonstrate anti-inflammatory effects in preclinical and clinical models of depression (Wium-Andersen et al., 2014; Winiarska-Mieczan et al., 2023; Behl et al., 2022). Moreover, remission from depression has been associated with the normalization of inflammatory biomarkers, suggesting a possible mechanistic link between inflammation and symptom improvement (Wang et al., 2022).

Inflammatory mediators also induce indoleamine 2,3-dioxygenase, promoting tryptophan degradation to kynurenine and thus reducing serotonin availability—an essential factor in depression (Mondanelli et al., 2020). In animal models, blueberries reduced proinflammatory cytokines and anxiety in PTSD (Ebenezer et al., 2016), while blackberry extract decreased IL-6 and increased IL-10 in a bipolar disorder model (Chaves et al., 2020). While mechanistic evidence is encouraging, clinical research in psychiatric populations remains limited. Given the diversity in berry phytochemistry, future trials should consider species-specific effects and diagnostic relevance.



Gut microbiota/microbiome

The gut microbiome plays a critical role in the gut–brain axis, influencing neurotransmission, inflammation, and blood–brain barrier integrity (Ebenezer et al., 2016; Chaves et al., 2020). Antioxidants may modulate gut microbiota by altering the redox environment, enhancing short-chain fatty acid (SCFA) production, reducing inflammation, and promoting beneficial bacterial growth (Silva et al., 2020; Majumdar et al., 2023).

The gut microbiota predominantly comprises Firmicutes and Bacteroidetes (~90%), with smaller proportions of Proteobacteria, Actinobacteria, Fusobacteria, and Verrucomicrobia (Pap et al., 2021; Neri-Numa et al., 2020). Diets rich in polyphenols and fiber improve microbial diversity and abundance of beneficial taxa. In contrast, Western-style diets can reduce species like *Faecalibacterium prausnitzii*, *Akkermansia muciniphila*, *Lactobacillus*, and *Bifidobacterium* (Neri-Numa et al., 2020; Healey et al., 2017), while polyphenol-rich diets improve microbial balance. Dysbiosis—microbial imbalance—has been linked to metabolic, immune, and neuropsychiatric disorders (Neri-Numa et al., 2020). For instance, antibiotic-induced dysbiosis increases depression risk by 20–50% (Lurie et al., 2015), with reduced Firmicutes levels noted in depressed patients (Bosch et al., 2022). Individuals with depression show lower levels of anti-inflammatory butyrate-producing bacteria (*Faecalibacterium*, *Coprococcus*) and higher levels of pro-inflammatory species (*Eggerthella*; Winiarska-Mieczan et al., 2023; Nikolova et al., 2021).

Altered microbiota also impairs neurotransmitter synthesis, including serotonin and dopamine, potentially contributing to psychiatric symptoms such as anxiety, depression, and schizophrenia (Horn et al., 2022). Specific taxa such as *Oscillibacter* and members of *Actinobacteria* and *Bacteroidetes* have been associated with depression (Naseribafrouei et al., 2014), while bipolar disorder is linked to increased *Bacteroidetes*, *Clostridiales*, and decreased *Faecalibacterium* (Evans et al., 2017; Rong et al., 2019). Anxiety correlates with reduced *Lactobacillus* and increased *Lachnospiraceae* (Ouabbou et al., 2020; Hemmings et al., 2017).

While research on berries is still emerging in this domain, some preclinical studies suggest they may modulate gut microbiota in ways relevant to mental health. For example, *Lycium barbarum* (goji berry) intake increased butyrate-producing bacteria and the expression of butyryl-CoA transferase, a key enzyme in SCFA synthesis, in mice (Kang et al., 2018). Both animal and human studies report reduced SCFA levels in depression (Deng et al., 2019; Szczesniak et al., 2016; Kelly et al., 2017), and butyrate has been shown to reverse behavioral deficits in animal models (Burokas et al., 2017). Given the anti-inflammatory and neuroactive properties of SCFAs, their depletion may contribute to mood disorder pathophysiology (Silva et al., 2020).

Although mechanistic links between berry fruits and gut microbiota modulation are promising, their effects in clinical psychiatric populations remain underexplored. Future research is warranted to clarify species-specific contributions and evaluate whether microbiome changes can support meaningful improvements in mental health.

Neuroplasticity and behavior

Although the neurobiological basis of anxiety and depression remains partially understood, monoaminergic neurotransmitters—serotonin (5-HT), dopamine (DA), and norepinephrine (NE)—have long been central to their pathophysiology (Shao and Zhu, 2020; Olivier and Olivier, 2020). More recently, impaired neuroplasticity has emerged as a unifying mechanism across psychiatric disorders, with chronic stress inducing structural and functional changes in emotional brain circuits such as the prefrontal cortex, hippocampus, amygdala, striatum, and raphe nuclei (Drevets, 2004).

Within this context, growing attention has turned to the role of diet, particularly berries, as a source of bioactive compounds capable of modulating mood-related pathways (Fernández-Demeneghi et al., 2019b). Rich in polyphenols and anthocyanins, berries exert polypharmacological effects. Preclinical studies show these compounds inhibit monoamine oxidase A (MAO-A), increasing central levels of 5-HT, DA, and NE and enhancing receptor activity (Imran et al., 2021; Tomić et al., 2016; Dreiseitel et al., 2009). Additionally, certain flavonoids appear to interact with GABA_A receptors, suggesting an anxiolytic mechanism (Imran et al., 2021; Gutierrez et al., 2014).

These biochemical actions align with observed behavioral and neuroplastic outcomes. Previous studies reported anxiolytic-like effects of blackberry extract in rats (Fernández-Demeneghi et al., 2019a), and wild blueberry anthocyanins reversed stress-induced dopaminergic and oxidative changes in the prefrontal cortex (Rahman et al., 2008). Similarly, anthocyanins reduced behavioral despair in rodents, comparable to the antidepressant mianserin, and improved neuronal integrity in the hippocampal CA3 region under oxidative stress (Drenska et al., 2008; Varadinova et al., 2013).

Berry extracts have also shown antidepressant-like effects in models of post-stroke depression. Extracts from *Hypericum androsaemum* and *Aristotelia chilensis* reduced immobility in standard behavioral tests (Nabavi et al., 2018; Di Lorenzo et al., 2019). While clinical evidence remains limited, some human studies are emerging. Blueberry juice has been associated with reduced depression risk in youth (Mestrom et al., 2024; Godos et al., 2018; Park et al., 2021), and anthocyanin-rich diets correlate with lower depressive symptoms in adults. A placebo-controlled trial further confirmed reduced depressive symptoms in adolescents after 4 weeks of blueberry supplementation (Fisk et al., 2020).

Beyond monoamines, berries also influence neuroplasticity. *Grewia asiatica* has shown pro-cognitive, anxiolytic, and antidepressant effects in rodents (Imran et al., 2021). Blueberry phytochemicals have been linked to increased neurogenesis in the dentate gyrus (Casadesus et al., 2004) and improved spatial memory alongside hippocampal remodeling (Rendeiro et al., 2012). These effects are believed to involve activation of ERK–CREB–BDNF and PI3K/Akt/mTOR pathways, leading to increased BDNF expression, synaptogenesis, and dendritic complexity (Vauzour et al., 2021; Fang et al., 2020).

Taken together, these preclinical findings suggest that berries may influence neurobiological pathways relevant to mood and cognition, although a significant gap remains in their clinical translation. Future studies should prioritize rigorous trials in

psychiatric populations, using well-defined outcomes related to both symptoms and neurobiological markers.

Discussion and future directions

Berries are increasingly recognized for their nutritional and neuroprotective properties, primarily due to their high content of polyphenols—particularly anthocyanins, vitamins, and other bioactive compounds. These constituents have demonstrated potential to modulate pathophysiological mechanisms central to mental health disorders, including oxidative stress, neuroinflammation, gut dysbiosis, and impaired neuroplasticity. However, while preclinical research robustly supports these effects, translation into clinical psychiatric populations remains limited.

Recent systematic reviews report that berry consumption can improve cognitive domains such as memory, executive function, processing speed, and attention (Bonyadi et al., 2022; De Amicis et al., 2022; Wang et al., 2023)—areas frequently compromised in depression, anxiety, and stress-related disorders. Observational data further support an inverse association between anthocyanin-rich fruit intake and depressive symptoms, perceived stress, and poor sleep (Micek et al., 2022), suggesting possible indirect or adjunctive benefits. However, much of the existing research relies on non-clinical samples. While biomarker improvements have been reported in healthy or cognitively impaired individuals, evidence of symptom reduction in well-characterized psychiatric populations remains scarce. To bridge this gap, rigorous trials are needed that define psychiatric diagnoses, assess symptom severity, and apply standardized measures across affective, cognitive, and neurobiological outcomes.

A further challenge is the heterogeneity of berry interventions. Phytochemical composition varies markedly by species, cultivar, ripeness, and processing. For instance, blueberries are rich in anthocyanins, while strawberries contain more ellagic acid and vitamin C (Miller et al., 2019). Additionally, the form of administration—whole fruit, juice, powder, or extract—significantly influences bioavailability and metabolic response (De Amicis et al., 2022; Wang et al., 2023). Future research should avoid overgeneralization and instead compare specific berry types, formulations, and polyphenol doses using standardized protocols.

Mechanistic evidence is also emerging. Aronia berry supplementation, for example, has been linked to improved arterial stiffness and greater gut microbial gene richness—particularly in butyrate-producing species—suggesting modulation of the gut–brain axis (Le Sayec et al., 2022). Although findings on oxidative stress are mixed, about one-third of biomarkers showed significant improvements in a recent review (Stote et al., 2023), pointing to plausible systemic effects even in the absence of direct psychiatric endpoints.

An essential but often overlooked issue is the potential for pharmacokinetic interactions. Some flavonoids can inhibit cytochrome P450 enzymes or modulate transporters like P-glycoprotein, potentially altering the metabolism of psychotropic medications. While such interactions are unlikely at dietary levels, the increasing use of concentrated extracts and nutraceuticals highlights the need for targeted pharmacological studies.

Toxicological considerations, though rare, also merit attention. Certain berries or their unripe forms may contain saponins or solanine, compounds linked to gastrointestinal damage or possible carcinogenicity. Wild species like *Nandina domestica* are toxic to animals, though not typically consumed by humans (Fernández-Demeneghi et al., 2019b). As berry-based supplements become more common, further safety assessments and public health guidance will be essential.

Despite these limitations, berries offer a biologically plausible, low-risk, and multitarget intervention aligned with the principles of nutritional psychiatry. Their ability to modulate inflammation, oxidative stress, gut microbiota, and cognition makes them promising adjuncts to conventional care—particularly within lifestyle-based or personalized models.

In light of current evidence, several research priorities emerge: a) Mechanistic studies in humans to elucidate how specific berry compounds influence neurotransmission, synaptic plasticity, inflammatory cascades, and microbiota-derived metabolites linked to mood regulation; b) Clinical trials involving well-defined psychiatric populations, stratified by diagnosis, baseline symptomatology, and treatment status, using consistent and validated outcome measures; c) Comparative studies of different berry species, polyphenol doses, and delivery forms (e.g., whole fruit vs. extract vs. juice) to determine optimal therapeutic profiles; d) Longitudinal and preventive research in at-risk groups (e.g., adolescents, older adults, individuals exposed to chronic stress) to evaluate resilience-building effects and potential for primary prevention; and e) Safety and pharmacokinetic evaluations, particularly in populations using psychotropic medications, to guide clinical application.

Advancing toward a preventive and salutogenic model of mental health care requires more than symptom management—it calls for systemic strategies that foster emotional resilience and neurobiological integrity. Within this framework, nutrition is not a cure-all, but a meaningful, accessible, and underutilized tool. Including culturally relevant, locally available berries as part of dietary interventions offers a cost-effective and non-invasive approach to support mental health. As ‘Nutritional Psychiatry’ evolves, integrating functional foods like berries may help bridge disciplines—linking neuroscience, nutrition, and clinical care in new and impactful ways.

Author contributions

RF-D: Funding acquisition, Writing – review & editing, Validation, Supervision, Writing – original draft, Investigation, Conceptualization, Visualization. MD-P: Validation, Writing – review & editing, Writing – original draft, Conceptualization, Supervision, Investigation. AM-M: Supervision, Validation,

Writing – review & editing, Writing – original draft, Funding acquisition. IV-M: Writing – review & editing, Supervision, Visualization, Investigation, Validation. RR-R: Validation, Supervision, Writing – review & editing, Investigation.

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References

- Aguilera, J. M. (2024). Berries as foods: processing, products, and health implications. *Annu. Rev. Food Sci. Technol.* 15, 1–26. doi: 10.1146/annurev-food-072023-034248
- Behl, T., Rana, T., Alotaibi, G. H., Shamsuzzaman, Md., Naqvi, M., Sehgal, A., et al. (2022). Polyphenols inhibiting MAPK signalling pathway mediated oxidative stress and inflammation in depression. *Biomed. Pharmacother.* 146:112545. doi: 10.1016/j.biopha.2021.112545
- Bonyadi, N., Dolatkah, N., Salekzamani, Y., and Hashemian, M. (2022). Effect of berry-based supplements and foods on cognitive function: a systematic review. *Sci. Rep.* 12:3239. doi: 10.1038/s41598-022-07302-4

- Bosch, J. A., Nieuwdorp, M., Zwiderman, A. H., Deschasaux, M., Radjabzadeh, D., Kraaij, R., et al. (2022). The gut microbiota and depressive symptoms across ethnic groups. *Nat. Commun.* 13:7129. doi: 10.1038/s41467-022-34504-1
- Burokas, A., Arbolea, S., Moloney, R. D., Peterson, V. L., Murphy, K., Clarke, G., et al. (2017). Targeting the microbiota-gut-brain axis: prebiotics have anxiolytic and antidepressant-like effects and reverse the impact of chronic stress in mice. *Biol. Psychiatry* 82, 472–487. doi: 10.1016/j.biopsych.2016.12.031
- Casadesus, G., Shukitt-Hale, B., Stellwagen, H. M., Zhu, X., Lee, H. G., Smith, M. A., et al. (2004). Modulation of hippocampal plasticity and cognitive behavior by short-term blueberry supplementation in aged rats. *Nutr. Neurosci.* 7, 309–316. doi: 10.1080/10284150400020482
- Cecerska-Heryć, E., Polikowska, A., Serwin, N., Roszak, M., Grygorciewicz, B., Heryć, R., et al. (2022). Importance of oxidative stress in the pathogenesis, diagnosis, and monitoring of patients with neuropsychiatric disorders, a review. *Neurochem. Int.* 153:105269. doi: 10.1016/j.neuint.2021.105269
- Chaves, V. C., Soares, M. S. P., Spohr, L., Teixeira, F., Vieira, A., Constantino, L. S., et al. (2020). Blackberry extract improves behavioral and neurochemical dysfunctions in a ketamine-induced rat model of mania. *Neurosci. Lett.* 714:134566. doi: 10.1016/j.neulet.2019.134566
- De Amicis, R., Mambrini, S. P., Pellizzari, M., Foppiani, A., Bertoli, S., Battezzati, A., et al. (2022). Systematic review on the potential effect of berry intake in the cognitive functions of healthy people. *Nutrients* 14:2977. doi: 10.3390/nu14142977
- Deng, F. L., Pan, J. X., Zheng, P., Xia, J. J., Yin, B. M., Liang, W. W., et al. (2019). Metabonomics reveals peripheral and central short-chain fatty acid and amino acid dysfunction in a naturally occurring depressive model of macaques. *Neuropsychiatr. Dis. Treat.* 15, 1077–1088. doi: 10.2147/NDT.S186071
- Di Lorenzo, A., Sobolev, A. P., Nabavi, S. F., Sureda, A., Moghaddam, A. H., Khanjani, S., et al. (2019). Antidepressive effects of a chemically characterized maqui berry extract (*Aristotelia chilensis* (molina) stuntz) in a mouse model of Post-stroke depression. *Food Chem. Toxicol.* 129, 434–443. doi: 10.1016/j.fct.2019.04.023
- Dreisel, A., Korte, G., Schreier, P., Oehme, A., Locher, S., Domani, M., et al. (2009). Berry anthocyanins and their aglycons inhibit monoamine oxidases A and B. *Pharmacol. Res.* 59, 306–311. doi: 10.1016/j.phrs.2009.01.014
- Drenka, D., V. M., B. N., and B. P. A. (2008). Effect of anthocyanins and mianserin on neuronal density in rat hippocampus in a model of oxidative stress. *Pharmacology online*. 2, 133–138.
- Drevets, W. C. (2004). Neuroplasticity in mood disorders. *Dialogues Clin. Neurosci.* 6, 199–216. doi: 10.31887/DCNS.2004.6.2/wdrevets
- Ebenezer, P. J., Wilson, C. B., Wilson, L. D., Nair, A. R., and J. F. (2016). The anti-inflammatory effects of blueberries in an animal model of post-traumatic stress disorder (PTSD). *PLoS ONE* 11:e0160923. doi: 10.1371/journal.pone.0160923
- Edirisinghe, I., Banaszewski, K., Cappozzo, J., Sandhya, K., Ellis, C. L., Tadapaneni, R., et al. (2011). Strawberry anthocyanin and its association with postprandial inflammation and insulin. *Br. J. Nutr.* 106, 913–922. doi: 10.1017/S0007114511001176
- Evans, S. J., Bassis, C. M., Hein, R., Assari, S., Flowers, S. A., Kelly, M. B., et al. (2017). The gut microbiome composition associates with bipolar disorder and illness severity. *J. Psychiatr. Res.* 87, 23–29. doi: 10.1016/j.jpsychires.2016.12.007
- Fang, J. L., Luo, Y., Jin, S. H., Yuan, K., and Guo, Y. (2020). Ameliorative effect of anthocyanin on depression mice by increasing monoamine neurotransmitter and up-regulating BDNF expression. *J. Funct. Foods*. 66:103757. doi: 10.1016/j.jff.2019.103757
- Fernández-Demeneghi, R., Rodríguez-Landa, J. F., Guzmán-Gerónimo, R. I., Acosta-Mesa, H. G., Meza-Alvarado, E., Vargas-Moreno, I., et al. (2019a). Effect of blackberry juice (*Rubus fruticosus* L.) on anxiety-like behaviour in Wistar rats. *Int. J. Food Sci. Nutr.* 70, 856–867. doi: 10.1080/09637486.2019.1580680
- Fernández-Demeneghi, R., Vargas-Moreno, I., Acosta-Mesa, H.-G., Puga-Olguín, A., Campos-Uscanga, Y., Romo-González, T., et al. (2019b). “Berry supplementation and their beneficial effects on some central nervous system disorders,” in *Behavioral Pharmacology*, eds R.-L. Juan Francisco, and C.-E. Jonathan (Rijeka: IntechOpen).
- Fisk, J., Khalid, S., Reynolds, S. A., and Williams, C. M. (2020). Effect of 4 weeks daily wild blueberry supplementation on symptoms of depression in adolescents. *Br. J. Nutr.* 124, 181–188. doi: 10.1017/S0007114520000926
- Fumagalli, M., Sangiovanni, E., Vrhovsek, U., Piazza, S., Colombo, E., Gasperotti, M., et al. (2016). Strawberry tannins inhibit IL-8 secretion in a cell model of gastric inflammation. *Pharmacol. Res.* 111, 703–712. doi: 10.1016/j.phrs.2016.07.028
- Gilbert, P. (2020). Compassion: from its evolution to a psychotherapy. *Front. Psychol.* 11:586161. doi: 10.3389/fpsyg.2020.586161
- Godos, J., Castellano, S., Ray, S., Grosso, G., and Galvano, F. (2018). Dietary polyphenol intake and depression: results from the mediterranean healthy eating, lifestyle and aging (MEAL) study. *Molecules* 23:999. doi: 10.3390/molecules23050999
- Golovinskai, O., and Wang, C. K. (2021). Review of functional and pharmacological activities of berries. *Molecules* 26:3904. doi: 10.3390/molecules26133904
- Grabnar, I., Vovk, T., Kores Plesnicar, B., and Boskovic, M. (2011). Oxidative stress in schizophrenia. *Curr. Neuropharmacol.* 9, 301–312. doi: 10.2174/157015911795596595
- Gutierrez, J. M., Carvalho, F. B., Schetinger, M. R. C., Marisco, P., Agostinho, P., Rodrigues, M., et al. (2014). Anthocyanins restore behavioral and biochemical changes caused by streptozotocin-induced sporadic dementia of Alzheimer's type. *Life Sci.* 96, 7–17. doi: 10.1016/j.lfs.2013.11.014
- Handelman, G., Packer, L., and Cross, C. (1996). Destruction of tocopherols, carotenoids, and retinol in human plasma by cigarette smoke. *Am. J. Clin. Nutr.* 63, 559–565. doi: 10.1093/ajcn/63.4.559
- Healey, G. R., Murphy, R., Brough, L., Butts, C. A., and Coad, J. (2017). Interindividual variability in gut microbiota and host response to dietary interventions. *Nutr. Rev.* 75, 1059–1080. doi: 10.1093/nutrit/nux062
- Hemmings, S. M. J., Malan-Müller, S., van den Heuvel, L. L., Demmitt, B. A., Stanislawski, M. A., Smith, D. G., et al. (2017). The microbiome in posttraumatic stress disorder and trauma-exposed controls: an exploratory study. *Psychosom. Med.* 79, 936–946. doi: 10.1097/PSY.0000000000000512
- Hong, H., Kim, B. S., and Im, H. I. (2016). Pathophysiological role of neuroinflammation in neurodegenerative diseases and psychiatric disorders. *Int. Neurol.* 120, S2–7. doi: 10.5213/inj.1632604.302
- Horn, J., Mayer, D. E., Chen, S., and Mayer, E. A. (2022). Role of diet and its effects on the gut microbiome in the pathophysiology of mental disorders. *Transl. Psychiatry* 12:164. doi: 10.1038/s41398-022-01922-0
- Huang, Q., Liu, H., Suzuki, K., Ma, S., and Liu, C. (2019). Linking what we eat to our mood: a review of diet, dietary antioxidants, and depression. *Antioxidants* 8:376. doi: 10.3390/antiox8090376
- Imran, I., Javid, S., Waheed, A., Rasool, M. F., Majeed, A., Samad, N., et al. (2021). Grewia asiatica berry juice diminishes anxiety, depression, and scopolamine-induced learning and memory impairment in behavioral experimental animal models. *Front. Nutr.* 7:587367. doi: 10.3389/fnut.2020.587367
- Kang, Y., Yang, G., Zhang, S., Ross, C. F., and Zhu, M. (2018). Goji berry modulates gut microbiota and alleviates colitis in IL-10-deficient mice. *Mol. Nutr. Food Res.* 62:e1800535. doi: 10.1002/mnfr.201800535
- Kelly, J. R., Minuto, C., Cryan, J. F., Clarke, G., and Dinan, T. G. (2017). Cross talk: the microbiota and neurodevelopmental disorders. *Front. Neurosci.* 11:490. doi: 10.3389/fnins.2017.00490
- Le Sayec, M., Xu, Y., Laiola, M., Gallego, F. A., Katsikioti, D., Durbidge, C., et al. (2022). The effects of Aronia berry (poly)phenol supplementation on arterial function and the gut microbiome in middle aged men and women: results from a randomized controlled trial. *Clin. Nutr.* 41, 2549–2561. doi: 10.1016/j.clnu.2022.08.024
- Lee, J., Kim, S., Namgung, H., Jo, Y. H., Bao, C., Choi, H. K., et al. (2014). Ellagic acid identified through metabolomic analysis is an active metabolite in strawberry ('seolhyang') regulating lipopolysaccharide-induced inflammation. *J. Agric. Food Chem.* 62, 3954–3962. doi: 10.1021/jf4038503
- Logan, A. C., and Jacka, F. N. (2014). Nutritional psychiatry research: an emerging discipline and its intersection with global urbanization, environmental challenges and the evolutionary mismatch. *J. Physiol. Anthropol.* 33:22. doi: 10.1186/1880-6805-33-22
- Lurie, I., Yang, Y. X., Haynes, K., Mamtani, R., and Boursi, B. (2015). Antibiotic exposure and the risk for depression, anxiety, or psychosis. *J. Clin. Psychiatry* 76, 1522–1528. doi: 10.4088/JCP.15m09961
- Majumdar, A., Siva Venkatesh, I. P., and Basu, A. (2023). Short-chain fatty acids in the microbiota-gut-brain axis: role in neurodegenerative disorders and viral infections. *ACS Chem. Neurosci.* 14, 1045–1062. doi: 10.1021/acscchemneuro.2c00803
- Mestrom, A., Charlton, K. E., Thomas, S. J., Larkin, T. A., Walton, K. L., Ellgallie, A., et al. (2024). Higher anthocyanin intake is associated with lower depressive symptoms in adults with and without major depressive disorder. *Food Sci. Nutr.* 12, 2202–2209. doi: 10.1002/fsn3.3850
- Micek, A., Owczarek, M., Jurek, J., Guerrero, I., Torrisi, S. A., Grosso, G., et al. (2022). Anthocyanin-rich fruits and mental health outcomes in an Italian cohort. *J. Berry Res.* 12, 551–564. doi: 10.3233/JBR-220054
- Miller, K., Feucht, W., and Schmid, M. (2019). Bioactive compounds of strawberry and blueberry and their potential health effects based on human intervention studies: a brief overview. *Nutrients* 11:1510. doi: 10.3390/nu11071510
- Mondanelli, G., Coletti, A., Greco, F. A., Pallotta, M. T., Orabona, C., Iacono, A., et al. (2020). Positive allosteric modulation of indoleamine 2,3-dioxygenase 1 restrains neuroinflammation. *Proc. Nat. Acad. Sci.* 117, 3848–3857. doi: 10.1073/pnas.1918215117
- Müller, N. (2013). The role of anti-inflammatory treatment in psychiatric disorders. *Psychiatr. Danub.* 25, 292–298.
- Nabavi, S. M., Nabavi, S. F., Sureda, A., Caprioli, G., Iannarelli, R., Sokeng, A. J. T., et al. (2018). The water extract of tutsan (*Hypericum androsaemum* L.) red berries exerts antidepressant-like effects and *in vivo* antioxidant activity in a mouse model of post-stroke depression. *Biomed. Pharmacother.* 99, 290–298. doi: 10.1016/j.biopha.2018.01.073
- Naseribafrouei, A., Hestad, K., Avershina, E., Sekelja, M., Linlokken, A., Wilson, R., et al. (2014). Correlation between the human fecal microbiota and depression. *Neurogastroenterol. Motil.* 26, 1155–1162. doi: 10.1111/nmo.12378

- Neri-Numa, I. A., Cazarin, C. B. B., Ruiz, A. L. T. G., Paulino, B. N., Molina, G., Pastore, G. M., et al. (2020). Targeting flavonoids on modulation of metabolic syndrome. *J. Funct. Foods* 73:104132. doi: 10.1016/j.jff.2020.104132
- Niedzińska, E., Smaga, I., Gawlik, M., Moniczewski, A., Stankowicz, P., Pera, J., et al. (2016). Oxidative stress in neurodegenerative diseases. *Mol. Neurobiol.* 53, 4094–4125. doi: 10.1007/s12035-015-9337-5
- Nikolova, V. L., Smith, M. R. B., Hall, L. J., Cleare, A. J., Stone, J. M., Young, A. H., et al. (2021). Perturbations in gut microbiota composition in psychiatric disorders. *JAMA Psychiatry* 78:1343. doi: 10.1001/jamapsychiatry.2021.2573
- Olivier, J. D. A., and Olivier, B. (2020). Translational studies in the complex role of neurotransmitter systems in anxiety and anxiety disorders. *Adv. Exp. Med. Biol.* (2020) 1191, 121–140. doi: 10.1007/978-981-32-9705-0_8
- Ouabbou, S., He, Y., Butler, K., and Tsuang, M. (2020). Inflammation in mental disorders: is the microbiota the missing link? *Neurosci. Bull.* 36, 1071–1084. doi: 10.1007/s12264-020-00535-1
- Pap, N., Fidelis, M., Azevedo, L., do Carmo, M. A. V., Wang, D., Mocan, A., et al. (2021). Berry polyphenols and human health: evidence of antioxidant, anti-inflammatory, microbiota modulation, and cell-protecting effects. *Curr. Opin. Food Sci.* 42, 167–186. doi: 10.1016/j.cofs.2021.06.003
- Park, S. J., Jaiswal, V., and Lee, H. J. (2021). Dietary intake of flavonoids and carotenoids is associated with anti-depressive symptoms: epidemiological study and in silico—mechanism analysis. *Antioxidants* 11:53. doi: 10.3390/antiox11010053
- Payne, M. E., Steck, S. E., George, R. R., and Steffens, D. C. (2012). Fruit, vegetable, and antioxidant intakes are lower in older adults with depression. *J. Acad. Nutr. Diet.* 112, 2022–2027. doi: 10.1016/j.jand.2012.08.026
- Rahman, M. M., Ichiyangi, T., Komiyama, T., Sato, S., and Konishi, T. (2008). Effects of anthocyanins on psychological stress-induced oxidative stress and neurotransmitter status. *J. Agric. Food Chem.* 56, 7545–7550. doi: 10.1021/jf800930s
- Rasmus, P., and Kozłowska, E. (2023). Antioxidant and anti-inflammatory effects of carotenoids in mood disorders: an overview. *Antioxidants* 12:676. doi: 10.3390/antiox12030676
- Rendeiro, C., Vauzour, D., Kean, R. J., Butler, L. T., Rattray, M., Spencer, J. P. E., et al. (2012). Blueberry supplementation induces spatial memory improvements and region-specific regulation of hippocampal BDNF mRNA expression in young rats. *Psychopharmacology* 223, 319–330. doi: 10.1007/s00213-012-2719-8
- Rong, H., Xie, X. H., Zhao, J., Lai, W. T., Wang, M. B., Xu, D., et al. (2019). Similarly in depression, nuances of gut microbiota: Evidences from a shotgun metagenomics sequencing study on major depressive disorder versus bipolar disorder with current major depressive episode patients. *J. Psychiatr. Res.* 113, 90–99. doi: 10.1016/j.jpsychires.2019.03.017
- Salim, S. (2014). Oxidative stress and psychological disorders. *Curr. Neuropharmacol.* 12, 140–147. doi: 10.2174/1570159X11666131120230309
- Salim, S. (2017). Oxidative stress and the central nervous system. *J. Pharmacol. Exp. Ther.* 360, 201–205. doi: 10.1124/jpet.116.237503
- Seeram, N. P. (2012). Emerging research supporting the positive effects of berries on human health and disease prevention. *J. Agric. Food Chem.* 60, 5685–5686. doi: 10.1021/jf203455z
- Shao, X., and Zhu, G. (2020). Associations among monoamine neurotransmitter pathways, personality traits, and major depressive disorder. *Front. Psychiatry* 11:381. doi: 10.3389/fpsy.2020.00381
- Silva, Y. P., Bernardi, A., and Frozza, R. L. (2020). The role of short-chain fatty acids from gut microbiota in gut-brain communication. *Front. Endocrinol.* 11:25. doi: 10.3389/fendo.2020.00025
- Singh, A., Kukreti, R., Saso, L., and Kukreti, S. (2019). Oxidative stress: a key modulator in neurodegenerative diseases. *Molecules* 24:1583. doi: 10.3390/molecules24081583
- Stote, K. S., Burns, G., Mears, K., Sweeney, M., and Blanton, C. (2023). The effect of berry consumption on oxidative stress biomarkers: a systematic review of randomized controlled trials in humans. *Antioxidants* 12:1443. doi: 10.3390/antiox12071443
- Sutkowy, P., Wozniak, A., Miła-Kierzenkowska, C., Szewczyk-Golec, K., Wesółowski, R., Pawłowska, M., et al. (2021). Physical activity vs. redox balance in the brain: brain health, aging and diseases. *Antioxidants* 11:95. doi: 10.3390/antiox11010095
- Szczesniak, O., Hestad, K. A., Hanssen, J. F., and Rudi, K. (2016). Isovaleric acid in stool correlates with human depression. *Nutr. Neurosci.* 19, 279–283. doi: 10.1179/1476830515Y.0000000007
- Tomić, M., Ignjatović, Đ., Tovilović-Kovačević, G., Krstić-Milošević, D., Ranković, S., Popović, T., et al. (2016). Reduction of anxiety-like and depression-like behaviors in rats after one month of drinking aronia melanocarpa berry juice. *Food Funct.* 7, 3111–3120. doi: 10.1039/C6FO00321D
- van Zonneveld, S. M., van den Oever, E. J., Haarman, B. C. M., Grandjean, E. L., Nuninga, J. O., van de Rest, O., et al. (2024). An anti-inflammatory diet and its potential benefit for individuals with mental disorders and neurodegenerative diseases—a narrative review. *Nutrients* 16:2646. doi: 10.3390/nu16162646
- Varadinova, M., Docheva-Drenska, D., and Boyadjieva, N. (2013). Effects of anthocyanins on active avoidance test of rats exposed to disruption of diurnal rhythm. *Am. J. Ther.* 20, 172–177. doi: 10.1097/MJT.0b013e3182589188
- Vauzour, D., Rendeiro, C., D'Amato, A., Waffo-Tégou, P., Richard, T., Méron, J. M., et al. (2021). Anthocyanins promote learning through modulation of synaptic plasticity related proteins in an animal model of ageing. *Antioxidants* 10:1235. doi: 10.3390/antiox10081235
- Wang, Q., Zeng, L., Hong, W., Luo, M., Zhao, N., Hu, X., et al. (2022). Inflammatory cytokines changed in patients with depression before and after repetitive transcranial magnetic stimulation treatment. *Front. Psychiatry* 13:925007. doi: 10.3389/fpsy.2022.925007
- Wang, Y., Haskell-Ramsay, C., Gallegos, J. L., and Lodge, J. K. (2023). Effects of chronic consumption of specific fruit (berries, cherries and citrus) on cognitive health: a systematic review and meta-analysis of randomised controlled trials. *Eur. J. Clin. Nutr.* 77, 7–22. doi: 10.1038/s41430-022-01138-x
- WHO, Z. Z. (2021). *Comprehensive Mental Health Action Plan 2013–2030*. Geneva: World Health Organization.
- Winiarska-Mieczan, A., Kwiecień, M., Jachimowicz-Rogowska, K., Donaldson, J., Tomaszewska, E., Baranowska-Wójcik, E., et al. (2023). Anti-inflammatory, antioxidant, and neuroprotective effects of polyphenols—polyphenols as an element of diet therapy in depressive disorders. *Int. J. Mol. Sci.* 24:2258. doi: 10.3390/ijms24032258
- Wium-Andersen, M. K., Ørsted, D. D., and Nordestgaard, B. G. (2014). Elevated C-reactive protein, depression, somatic diseases, and all-cause mortality: a mendelian randomization study. *Biol. Psychiatry* 76, 249–257. doi: 10.1016/j.biopsych.2013.10.009
- Wu, S. X., Li, J., Zhou, D. D., Xiong, R. G., Huang, S. Y., Saimaiti, A., et al. (2022). Possible effects and mechanisms of dietary natural products and nutrients on depression and anxiety: a narrative review. *Antioxidants* 11:2132. doi: 10.3390/antiox11112132
- Zalachoras, I., Hollis, F., Ramos-Fernández, E., Trovo, L., Sonnay, S., Geiser, E., et al. (2020). Therapeutic potential of glutathione-enhancers in stress-related psychopathologies. *Neurosci. Biobehav. Rev.* 114, 134–155. doi: 10.1016/j.neubiorev.2020.03.015