Review

UDC 616.3-008.6+616.34-002+547.75+577.175.823
https://doi.org/10.56871/CmN-W.2026.20.41.005

The role of tryptofan in celiac disease: review

Anatoly I. Khavkin[1, 3], Andrew V. Nalyotov[2], Stanislav I. Sitkin[4, 5, 6]

[1] Research Clinical Institute of Childhood, Ministry of Health of the Moscow Region, 62 Bolshaya Serpukhovskaya str., Moscow, 115093, Russian Federation

[2] M. Gorky Donetsk State Medical University, 16 Illicha ave., Donetsk, Donetsk People's Republic, 283003, Russian Federation

[3] Belgorod State National Research University, 85 Pobeda str., Belgorod, 308015, Russian Federation

[4] Almazov National Medical Research Center, 2 Akkuratova str., Saint Petersburg, 197341, Russian Federation

[5] North-Western State Medical University named after I.I. Mechnikov, 41 Kirochnaya str., Saint Petersburg, 191015, Russian Federation

[6] Institute of Experimental Medicine, 12 Akademika Pavlova str., Saint Petersburg, 197022, Russian Federation

For citation: Khavkin A.I., Nalyotov A.V., Sitkin S.I. The role of tryptofan in celiac disease: review. *Children's Medicine of the North-West.* 2026;14(1):62–73. (In Russ.). https://doi.org/10.56871/CmN-W.2026.20.41.005.

Received: 25.11.2025 **Revised: 12.01.2026** **Accepted: 20.03.2026**

ABSTRACT. The analysis of the peculiarities of tryptophan metabolism in children suffering from celiac disease is presented. Tryptophan is one of the eight essential amino acids that are not produced in the human body, and their intake from food is necessary for protein synthesis and cell proliferation, including cells of the immune system. Tryptophan is metabolized by the human body to a large number of different signaling molecules and it occurs in three ways: indole, serotonin, kynurenine pathways. Tryptophan metabolism catabolites play a signaling role in the human body and in the intestinal microbial community. It is noted that tryptophan and its metabolites play a key role in suppressing inflammation and maintaining the integrity of the intestinal barrier. Tryptophan metabolites, especially kynurenine, also contribute significantly to immune regulation. In turn, a decrease in tryptophan intake in the body can affect the psychological state of patients with celiac disease through the serotonin pathway of amino acid metabolism, causing the development of depression and anxiety. Therefore, changes in tryptophan metabolism may potentially underlie the impaired immune response in celiac disease, affecting both the development of the disease and the persistence of symptoms, despite following a gluten-free diet.

KEYWORDS: *children, celiac disease, tryptophan, kynurenine, serotonin*

Financing. The article was prepared as part of the research work "Gluten-associated diseases in children: ways to improve diagnostics, personalized algorithms for dispensary observation", state registration number — 125040904988-0.

✉ *Anatoly I. Khavkin*. E-mail: khavkin@nikid.ru

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

Обзор

https://doi.org/10.56871/CmN-W.2026.20.41.005

Роль триптофана при целиакии: обзор литературы

Анатолий Ильич Хавкин[1, 3], Андрей Васильевич Налётов[2], Станислав Игоревич Ситкин[4, 5, 6]

[1] Научно-исследовательский клинический институт детства Министерства здравоохранения Московской области, 115093, г. Москва, ул. Большая Серпуховская, д. 62, Российская Федерация

[2] Донецкий государственный медицинский университет имени М. Горького, 283003, г. Донецк, пр. Ильича, д. 16, Донецкая Народная Республика, Российская Федерация

[3] Белгородский государственный национальный исследовательский университет, 308015, г. Белгород, ул. Победы, д. 85, Российская Федерация

[4] Национальный медицинский исследовательский центр им. В.А. Алмазова, 197341, г. Санкт-Петербург, ул. Аккуратова, д. 2, Российская Федерация

[5] Северо-Западный государственный медицинский университет имени И.И. Мечникова, 191015, г. Санкт-Петербург, ул. Кирочная, д. 41, Российская Федерация

[6] Институт экспериментальной медицины, 197022, г. Санкт-Петербург, ул. Академика Павлова, д. 12, Российская Федерация

Для цитирования: Хавкин А.И., Налётов А.В., Ситкин С.И. Роль триптофана при целиакии: обзор литературы. *Children's Medicine of the North-West*. 2026;14(1):62–73. https://doi.org/10.56871/CmN-W.2026.20.41.005.

Поступила: 25.11.2025 **Одобрена: 12.01.2026** **Принята к печати: 20.03.2026**

РЕЗЮМЕ. Представлен анализ особенностей метаболизма триптофана у детей, страдающих целиакией. Триптофан является одной из восьми незаменимых (эссенциальных) аминокислот, которые не вырабатываются в организме человека, и их поступление с пищей необходимо для синтеза белка, пролиферации клеток, включая клетки иммунной системы. Триптофан метаболизируется организмом человека до большого количества различных сигнальных молекул, и происходит это тремя путями: индольный, серотониновый, кинурениновый пути. Катаболиты триптофанового обмена играют сигнальную роль в организме человека и в микробном сообществе кишечника. Отмечено, что триптофан и его метаболиты играют ключевую роль в подавлении воспаления и поддержании целостности кишечного барьера. Также метаболиты триптофана, особенно кинуренин, вносят значительный вклад в иммунную регуляцию. В свою очередь, снижение поступления триптофана в организм может влиять на психологическое состояние пациентов с целиакией через серотониновый путь метаболизма аминокислоты, вызывая развитие депрессии и тревоги. Следовательно, изменения метаболизма триптофана потенциально могут лежать в основе нарушенного иммунного ответа при целиакии, влияя как на развитие заболевания, так и на сохранение симптомов, несмотря на соблюдение безглютеновой диеты.

КЛЮЧЕВЫЕ СЛОВА: *дети, целиакия, триптофан, кинуренин, серотонин*

Источник финансирования. Статья подготовлена в рамках научно-исследовательской работы «Глютен-ассоциированные заболевания у детей: пути совершенствования диагностики, персонифицированные алгоритмы диспансерного наблюдения», номер государственной регистрации — 125040904988-0.

✉ *Анатолий Ильич Хавкин*. E-mail: khavkin@nikid.ru

INTRODUCTION

Celiac disease is a chronic autoimmune enteropathy caused by gluten intolerance in patients with the HLA-DQ2 or HLA-DQ8 haplotypes [1, 2]. The disease is characterized by gastrointestinal symptoms (abdominal bloating, diarrhea), as well as involvement of other organs and systemic disorders such as osteoporosis, infertility, anemia, depression, skin lesions, and neurological disorders [3]. Currently, the only effective treatment for celiac disease is the complete elimination of gluten from the diet. A gluten-free diet (GFD) can lead to regression of clinical symptoms and serological and histological remission in most patients [1]. However, adhering to strict dietary restrictions is a challenge for some patients due to the limited availability and high cost of gluten-free products, as well as their taste characteristics, which reduces the effectiveness of the GFD [4, 5]. In addition, a patient's self-imposed adherence to dietary restrictions without prior consultation with a dietitian may lead to a reduction in several important nutrients [1, 3].

Essential amino acids play a crucial role in immune system function, maintaining intestinal integrity, and regulating metabolism. Insufficient absorption of these amino acids during an inflammatory process in the intestine, as well as adherence to strict dietary restrictions in GFD, may play a role in the pathogenesis of the disease. Moreover, changes in the amino acid composition of plasma and feces correlate with disease progression [6, 7].

The gastrointestinal tract (GIT) is the first to come into contact with antigens entering our body along with food. Furthermore, the GIT initiates the processes of nutrient metabolism with the participation of the gut microbiota. The intestinal immune system, together with the mucosal epithelium, provides a protective barrier that prevents toxins and antigens from entering the systemic circulation and causing damage [8]. The nature of the immune response to antigens derived from food or produced as a result of nutrient metabolism is largely determined by the phenotype of intestinal dendritic cells and their degree of maturation, which is shaped by their interaction with regulatory T cells (Treg) [9, 10]. Dendritic cells are distributed throughout the intestine, in addition to mesenteric lymph nodes, lymphoid follicles, and Peyer's patches. The function of dendritic cells is to take up antigens for subsequent presentation to naive T cells. Based on their functional activity, dendritic cells are classified as immunogenic and tolerogenic. The former activates T-cell immunity, while the latter participate in inducing tolerance in peripheral T cells [11]. The primary function of Tregs is to control the intensity and duration of the immune response by regulating the function of T-effector cells (T-helpers and T-killers) [12]. To suppress the immune response, Tregs secrete transforming growth factor β, interleukins (IL) 10 and 35. Additionally, Tregs express cytotoxic T-lymphocyte glycoprotein 4 (CTLA-4), that is a membrane protein that serves as a cell receptor of the immunoglobulin superfamily and inhibits T-cell activation by binding to B7 ligands (CD80/CD86) on the surface of dendritic cells. It has been suggested that tryptophan catabolism is an important factor influencing Treg function [9]. Furthermore, it has been established that low concentrations of this amino acid limit T-cell proliferation while simultaneously increasing Treg production [13]. In turn, tryptophan catabolism is limited by the cytosolic heme protein indoleamine 2,3-dioxygenase (IDO). This enzyme participates in inhibiting the immune response, preventing a potential exacerbation of inflammatory reactions and inducing antigen tolerance [14].

The aim of this review was to analyze data in the latest literature devoted to tryptophan metabolism in patients with celiac disease.

MECHANISMS OF TRYPTOPHAN METABOLISM IN HUMANS

Tryptophan is one of the eight essential amino acids that cannot be produced. Their intake through food is necessary for protein synthesis and cell proliferation, including immune system cells. Catabolites of tryptophan metabolism play a signaling role in the human body and in the gut microbiome. Receptors and signaling pathways for so-called tryptophan signaling molecules (TSMs), their cellular targets, and their physiological and metabolic effects are currently being actively studied. It has been established that virtually all catabolites of tryptophan metabolism are signaling molecules. Many of them exert their signaling role through aryl hydrocarbon receptors (AhR). The dominant pathway of tryptophan metabolism is the kynurenine pathway, which is

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

the source of universal signaling molecules: kynurenine, quinolinic acid, and kynurenic acid. The indole pathway of tryptophan catabolism is the primary for microbes, with the exception of indole formation reactions in immune cells. It serves as a source of interkingdom and interspecies signaling molecules such as indole and its derivatives: indole-3-pyruvate, indole-3-lactate, indole-3-acetate, indole-3-propionate, indole-3-acrylate, indole-3-butyrate, and indole-3-acetaldehyde. Serotonin and melatonin are also universal signaling molecules and have been extensively studied in various diseases of the nervous system [15]. A decrease in tryptophan concentration in biological fluids will affect cellular functions and the state of homeostasis. Various factors can influence tryptophan bioavailability, ranging from the composition of the gut microbiome to systemic inflammatory signals. Gut microorganisms can absorb tryptophan themselves and thus limit its availability to the host organism. Formed metabolites exert a local effect on both the microbiome and the host's cells. Tryptophan can also be formed through microbial synthesis and recycling of other amino acids resulting from peptide breakdown [16]. This amino acid is found in bread, chocolate, cheese, cottage cheese, yogurt, oatmeal, peanuts, bananas, beans, milk, fish, turkey, chicken, and dried prunes, and in small amounts in corn [17]. Consequently, a strict restrictive gluten-free diet, impaired absorption, as well as prolonged stress which contributes to elevated cortisol levels that compete with tryptophan in celiac disease, can lead to a reduction in tryptophan intake in the patient.

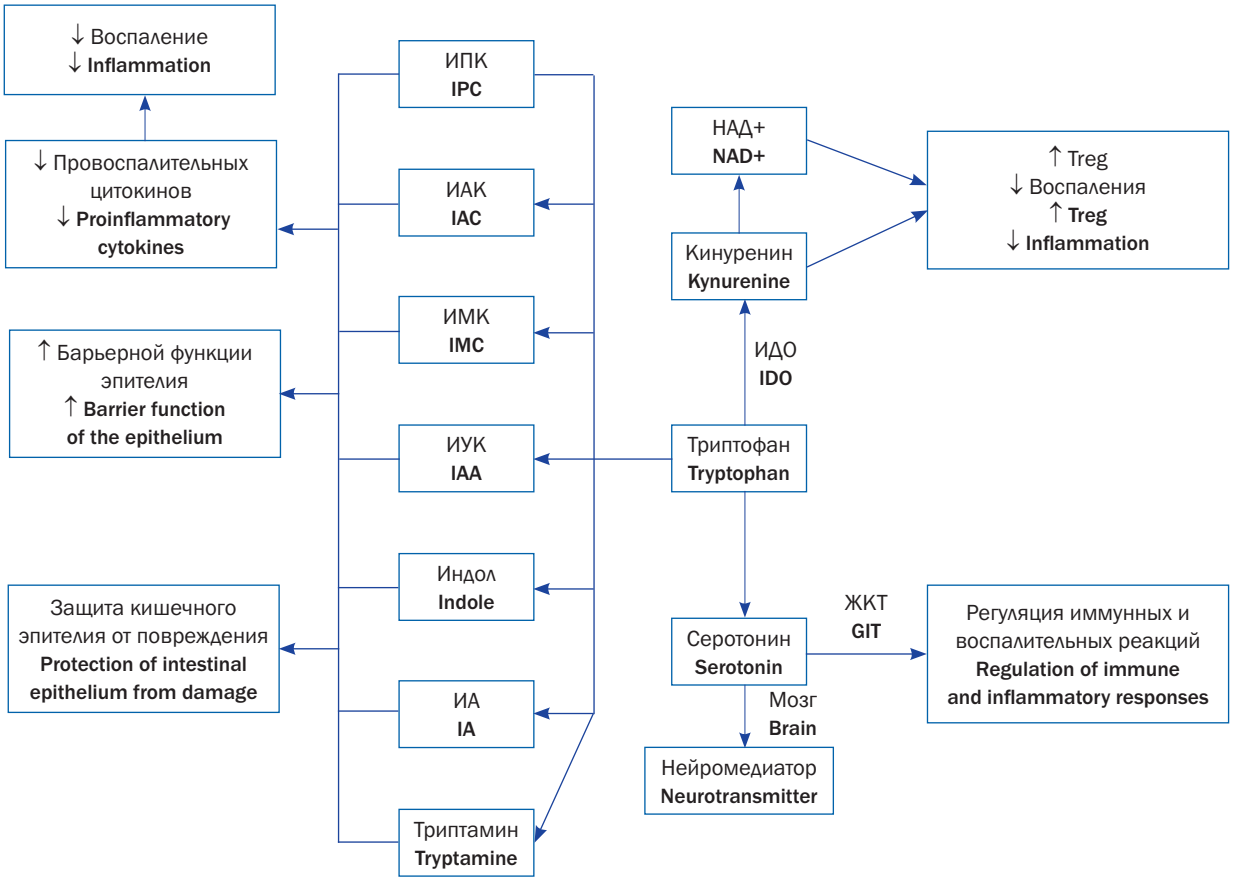

Fig. 1. The main pathways and effects of tryptophan metabolism: GIT — gastrointestinal tract; IA — indole-3-aldehyde; IAC — indoleacrylic acid; IDO — indoleamine-2,3-dioxygenase; IMC — indolelactic acid; IPC — indolepropionic acid; IAA — indole-3-acetic acid; NAD+ — nicotinamide adenine dinucleotide; Treg — regulatory T cells (borrowed from [20], with modifications)

Рис. 1. Основные пути и эффекты метаболизма триптофана: ЖКТ — желудочно-кишечный тракт; ИА — индол-3-альдегид; ИАК — индолакриловая кислота; ИДО — индоламин-2,3-диоксигеназа; ИМК — индолмолочная кислота; ИПК — индолпропионовая кислота; ИУК — индол-3-уксусная кислота; НАД+ — никотинамидадениндинуклеотид; Treg — регуляторные Т-клетки (заимствовано из [20], с изменениями)

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

Tryptophan is metabolized into a large number of different signaling molecules [18, 19], and this occurs via three pathways (Fig. 1).

INDOLE PATHWAY

The indole metabolic pathway involves the gut microbiota, which converts tryptophan into indole and its derivatives, which in turn act as ligands for aryl hydrocarbon receptors (AhR) [20]. Indole is the most common microbial indole catabolite of tryptophan and is synthesized by *Proteus vulgaris, Bacteroides thetaiotaomicron*, and *Escherichia coli* [15, 17, 21]. *Clostridium sporogenes* converts tryptophan into tryptamine, indole-lactic acid (ILA), and indolepropionic acid (IPA). ILA is also produced by *Bifidobacterium* spp. and *Ruminococcus gnavus* [20, 22]. IPA contributes to the expression of tight junction proteins, zonulin-1 and occludin, maintaining the integrity of the intestinal epithelium, which reduces the entry of bacterial lipopolysaccharides into the bloodstream [20]. *Peptostreptococcus* spp. metabolize tryptophan into indole-acrylic acid (IAcrA), which also improves the intestinal barrier function and reduces inflammatory responses of immune cells. M. Wlodarska et al. found that treatment of mouse bone marrow macrophages stimulated by bacterial lipopolysaccharide with IAcrA resulted in increased anti-inflammatory cytokine IL-10, accompanied by a decrease in IL-1β and IL-6 [23]. Some members of *Bacteroides* spp. and *Clostridium* spp. produce ILA and indole-3-acetic acid (IAA), which is decarboxylated to form skatole. *Lactobacillus* spp. metabolize tryptophan into indole-3-aldehyde (IA) and ILA [20].

Indole has a beneficial effect on intestinal mucosal cells, increasing the expression of genes involved in maintaining the intestinal barrier function, and also inhibits inflammatory processes [24]. In addition, indole stimulates the secretion of glucagon-like peptide 1 by enteroendocrine cells, suppressing gastric secretion and peristalsis, which creates a feeling of satiety [25].

The AhR (aryl hydrocarbon receptor) signaling pathway is activated, serving as a key system of cellular regulation. Inactive AhR in the cytoplasm can bind various ligands and translocate to the nucleus, activating genes responsible for xenobiotic metabolism, immunity, and maintenance of barrier function, which is essential for regulating immune mechanisms, regeneration, growth, and differentiation of immunocompetent cells. Impaired activation of this pathway underlies the pathogenesis of certain metabolic diseases as well as malignant neoplasms [26]. AhR ligands include not only indoles but also flavonoids, polyphenols, and other compounds involved in maintaining the integrity of the intestinal barrier [27]. Activation of AhR by indole and its derivatives, such as the tryptophan metabolite tryptamine, regulates intestinal motility [26]. In addition, tryptamine interacts with IDO and AhR, participating in immunological control and reducing the expression of pro-inflammatory cytokines, normalizing the expression of the epithelial tight junction protein zonulin-1, which leads to improved barrier function of the intestinal wall and reduced inflammation [25]. Furthermore, AhR expression by intestinal mucosal cells decreases during periods of celiac disease exacerbation. However, interaction between the intestinal microbiota and AhR in patients with celiac disease remains not fully established [28].

SEROTONIN PATHWAY

The gut-brain axis is a bidirectional system of communication, linking the brain's emotional and cognitive centers with the peripheral functioning of the digestive tract. It is becoming increasingly evident that the gut microbiota influences behavior, as do tryptophan and serotonin, suggesting that changes in the gut may play a significant role in the pathophysiology of human central nervous system (CNS) disorders [29]. It is known that more than 90% of serotonin is synthesized in the enterochromaffin cells of the intestine and in the brain. There, through a series of chemical reactions, 5-hydroxylation and decarboxylation by tryptophan decarboxylase in the presence of iron ions and the pteridine cofactor, tryptophan is converted into serotonin and 5-hydroxyindoleacetic acid [17]. Serotonin (5-hydroxytryptamine) is a key regulator of adaptive responses to environmental factors, as well as states and changes in the central nervous system, including mood, libido, cognitive abilities, aggression, anxiety, nociception, body temperature, and eating behavior. Up to 3% of dietary tryptophan is used for serotonin synthesis. The blood-brain barrier is considered impermeable to serotonin, and its primary function is to regulate inflammatory and immune processes in the gastrointestinal tract [17, 30].

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

The gut microbiota controls the serotonin pathway of tryptophan metabolism by synthesizing deoxycholic acid, a stimulator of serotonin synthesis [31]. Since *Escherichia, Streptococcus, Enterococcus, Pseudomonas*, and *Candida* are capable of synthesizing serotonin, it can be assumed that modulating the gut microbiota may be effective for normalizing the levels of this biogenic amine [17].

K.Z. Sanidad found that serotonin signals T cells to increase intracellular IA levels and suppress mTOR activation, thereby promoting Treg differentiation both *ex vivo* and *in vivo* in the intestines of newborn mice. Oral administration of serotonin to newborn mice led to the formation of long-term antigen-specific immune tolerance, mediated by T cells, to both food antigens and commensal bacteria [30].

THE KYNURENINE PATHWAY

More than 90% of all tryptophan in the body is metabolized in the liver via the kynurenine pathway, forming nicotinic acid via kynurenine with the participation of IDO. This enzyme is expressed throughout the human body depending on the concentration of pro-inflammatory cytokines, primarily interferon γ. However, its maximum expression is found in the brain, gastrointestinal tract, and liver [16]. Through the catabolic products of IDO, kinurenines, tryptophan suppresses immune processes by modulating the activity of T-effector cells and stimulating the proliferation of Tregs, thereby inducing immunological tolerance [32]. In addition, tryptophan participates in regulating neuronal functions and maintaining intestinal homeostasis via the kynurenine pathway [15, 17]. Kynurenine is considered a signaling molecule that exerts effects via AhR. It can also be metabolized into signaling molecules that regulate inflammation and promote increased immunological tolerance [33]. Creating a local or systemic environment with high kynurenine levels and low tryptophan levels alters the function of surrounding cells. T-lymphocytes are also susceptible to these changes, as tryptophan exerts immunomodulatory and immunosuppressive effects on T-cells, regulating their activation and function, including the induction of tolerance via the AhR receptor. Tryptophan also influences the differentiation of T-regulatory cells, which is important in the context of inflammation, autoimmune diseases, and neuroimmune processes [15]. Tryptophan catabolism occurs in inflamed tissue areas, reducing their damage [34]. Pro-inflammatory cytokines shift tryptophan metabolism toward kynurenine formation [34, 35].

It is believed that tryptophan catabolism via the kynurenine pathway is one of the mechanisms that ensures tolerance of the human immune system. The breakdown of tryptophan reduces the levels and availability of this amino acid, thereby suppressing T-cell proliferation. In addition, products of tryptophan catabolism, such as kynurenine, 3-hydroxykinurenine, and 3-hydroxyanthranilate, inhibit T-cell proliferation, possibly through apoptotic mechanisms [36].

A high nicotinamide content in the diet likely deactivates the mechanism that halts the body's production of nicotinamide from tryptophan via kynurenine and causes immune intolerance, including in the fetus, and infertility. It is hypothesized that the decline in birth rates in certain regions may be associated with the consumption of meat low in tryptophan [37].

TRYPTOPHAN INFLUENCES IMMUNO-INFLAMMATORY PROCESS

The described functions of tryptophan enable control of immune and inflammatory reactions in the gut by altering its concentration and inducing its biologically active metabolites. Enzymes that limit the rate of amino acid metabolism play an important role in each of its degradation pathways. The role of certain amino acids and vitamins in modulating the immune response and inflammatory reactions in immunopathological diseases of the gastrointestinal tract has now been established [7, 12]. For example, changes in the metabolism of essential amino acids have been identified in patients with celiac disease, which may result from a combination of genetic predisposition, dietary changes, and the activity of the gut microbiota [38, 39]. The gut microbiome participates in regulating the production of tryptophan-derived bioactive metabolites, utilizing both dietary and microorganism-synthesized amino acids [31].

Tryptophan metabolism can potentially influence an immune response in several ways. First, the conversion of tryptophan to kynurenine via IDO can lead to local depletion of the amino acid, which

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

inhibits the proliferation of T cells, which are key players in the immune response. Second, certain tryptophan metabolites formed via the kynurenine pathway promote the production of Tregs, which perform an important role in maintaining immune tolerance [7].

TRYPTOPHAN DEFICIENCY AND CELIAC DISEASE

Adherence to a strict gluten-free diet by patients with celiac disease can lead to reduced tryptophan intake, which alters amino acid metabolism and may potentially exacerbate inflammatory processes in patients with celiac disease [40].

Thus, according to N. Van Hees et al., long-term adherence to a gluten-free diet led to reduced plant protein intake in patients with celiac disease. The blood levels of essential amino acids, including tryptophan, were lower in these patients compared to those who did not follow any dietary restrictions [41]. A study by V. Lamas et al. found that patients with celiac disease experience a decrease in AhR ligand concentrations during disease exacerbation, which reduces the activity of this signaling pathway [42]. S. Nikolaus et al. reported that serum tryptophan concentrations in patients with inflammatory bowel diseases were significantly lower than in the control group. The lowest tryptophan concentrations were observed in patients with Crohn's disease. Analysis of tryptophan metabolite concentrations reveals high degradation activity in patients with inflammatory bowel disease, suggesting that tryptophan deficiency may contribute to the development or exacerbation of the disease. S. Nikolaus et al. conclude that the administration of high doses of tryptophan metabolites (nicotinamide, IA) as dietary supplements may alter the state of the gut microbiome, thereby enhancing the anti-inflammatory effect of tryptophan [43].

A study by F. Asgari showed that gliadin enhances the expression of maturation markers such as CD83, CD86, and HLA-DR, and promotes the secretion of tumor necrosis factor-α and IL-12 in dendritic cells. Vitamin A, tryptophan, and their metabolites increase the expression of CD103 while simultaneously limiting the expression of HLA-DR, CD83, and CD86. They also enhance the expression of RALDH2 and IDO and promote the secretion of TGF-β (transforming growth factor β) and IL-10, while simultaneously limiting the secretion of IL-12 and TNF-α (tumor necrosis factor α). The data obtained indicate that vitamin A and tryptophan have a beneficial effect on the course of celiac disease, highlighting their potential as therapeutic agents for this condition [12].

Given that tryptophan is a precursor of serotonin, a neurotransmitter that plays a key role in mood regulation, its reduced consumption may lead to the onset of depressive symptoms in patients with celiac disease [44].

CONCLUSION

Tryptophan metabolism plays an important role in maintaining physiological processes in the gastrointestinal tract. Tryptophan derivatives produced via the indole pathway have a significant effect on the integrity and function of the intestinal barrier, increasing the expression of tight junction proteins and reducing inflammation. The conversion of tryptophan to kynurenine via IDO can lead to local depletion of the amino acid, which inhibits the proliferation of T cells, key participants in the immune response in celiac disease (see Fig. 1). In addition, certain metabolites formed via the kynurenine pathway promote the generation of Tregs, which play a crucial role in maintaining immune tolerance. A strict gluten-free diet may lead to reduced consumption of tryptophan-rich foods. In turn, decreased dietary tryptophan intake and disturbances in its metabolism may potentially influence the immune response in celiac disease. These factors contribute to the pathogenesis of the disease and the persistence of clinical symptoms despite adherence to a gluten-free diet. Dietary adjustments and increased consumption of tryptophan-rich foods, on the one hand, and modulation of the gut microbiota to normalize the metabolism of this amino acid, on the other, may represent promising therapeutic strategies for patients with inflammatory bowel diseases.

ADDITIONAL INFORMATION

Authors' contribution. A.I. Khavkin — formulation and development of the idea, main goal and objectives of the study, final editing; A.V. Nalyotov, S.I. Sitkin — preparation and writing of the initial version of the manuscript.

All authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and re-

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

vising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

Competing interests. The authors declare that they have no competing interests.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. А.И. Хавкин — формулирование и развитие идеи, основной цели и задач исследования, финальное редактирование; А.В. Налетов, С.И. Ситкин — подготовка, написание первоначального варианта рукописи.

Все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией.

Конфликт интересов. Авторы статьи подтверждают отсутствие конфликта интересов.

REFERENCES

1. Averkina N.A., Baranov A.A., Bel'mer S.V., Boraeva T.T., Borovik T.A. et al. Project of clinical guidelines for the diagnosis and treatment of celiac disease in children. *Pediatric pharmacology*. 2025;22(4):495–522. (In Russ.). https://doi.org/10.15690/pf.v22i4.2941.
2. Khavkin A.I., Nalyotov A.V., Kuropyatnik P.I. The role of viruses in celiac disease pathogenesis: current status. *Pediatric pharmacology*. 2024;21(4):369–374. (In Russ.). https://doi.org/10.15690/pf.v21i4.2771.
3. Zingone F., Bai J.C., Cellier C., Ludvigsson J.F. Celiac diseaserelated conditions: who to test. *Gastroenterology*. 2024;167(1):64–78. https://doi.org/10.1053/j.gastro.2024.02.044.
4. Khavkin A.I., Nalyotov A.V., Pavlovskaya E.V., Yablokova E.A., Kur'yaninova V.A. et al. Quality of life of patients with celiac disease on gluten-free diet: narrative review. *Current Pediatrics*. 2025;24(3):157–161. (In Russ.). https://doi.org/10.15690/vsp.v24i3.2923.
5. Khavkin A.I., Grechanyi S.V., Malakhova A.A., Odinaeva N.D., Kondratyeva E.I. et al. Psychological factors influencing the adherence to a gluten-free diet in children and adolescents. *Pediatric Nutrition*. 2025;23(5):18–30. (In Russ.). https://doi.org/10.20953/1727-5784-2025-5-18-30.
6. Bakhtiari S., Asri N., Masotti A., Jahani-Sherafat S., Tavirani M.R. et al. Essential amino acids in celiac disease: key roles in immunogenicity, pathogenesis, and therapeutic approaches. *Crit Rev Clin Lab Sci*. 2025:1–16. https://doi.org/10.1080/10408363.2025.2551656.
7. Ding X., Bin P., Wu W., Yajie Chang Y., Zhu G. Tryptophan metabolism, regulatory T cells, and inflammatory bowel disease: a mini review. *Mediators Inflamm*. 2020;2020:9706140. https://doi.org/10.1155/2020/9706140.
8. Khavkin A.I., Nalyotov A.V., Sitkin S.I., Boraeva T.T., Matsynina M.A. et al. Characteristics of the gut microbiota in patients with celiac disease. *Pediatric Nutrition*. 2025; 23(4):47–54. (In Russ.). https://doi.org/10.20953/1727-5784-2025-4-47-54.
9. Asgari F., Khodadoust M., Nikzamir A., Sherafat S.J., Tavirani M.R. et al. The role of tryptophan metabolism and tolerogenic dendritic cells in maintaining immune tolerance: Insights into celiac disease pathogenesis. *Immun Inflamm Dis*. 2024;12(8):e1354. https://doi.org/10.1002/iid3.1354.
10. Chernykh E.R., Tyrinova T.V., Leplina O.Yu., Tikhonova M.A., Kurochkina Yu.D., Oleynik E.A. et al. Phenotype and functions of human dendritic cells derived from CD14+ monocyte subsets opposed to CD16 expression. *Bulletin of Siberian Medicine*. 2019;18(1):266–276. (In Russ.). https://doi.org/10.20538/1682-0363-2019-1-266-276.
11. Soto J.A., Gálvez N.M.S., Andrade C.A., Pacheco G.A., Bohmwald K. et al. The role of dendritic cells during infections caused by highly prevalent viruses. *Front Immunol*. 2020;11:1513. https://doi.org/10.3389/fimmu.2020.01513.
12. Asgari F., Nikzamir A., Baghaei K., Salami S., Masotti A. et al. Immunomodulatory and anti-inflammatory effects of Vitamin A and tryptophan on monocyte-derived dendritic cells stimulated with gliadin in celiac disease patients. *Inflammation*. 2024;47(5):1706–1727. https://doi.org/10.1007/s10753-024-02004-7.
13. Blagih J., Hennequart M., Zani F. Tissue nutrient environments and their effect on regulatory T cell biology. *Front Immunol*. 2021;12:637960. https://doi.org/10.3389/fimmu.2021.637960.
14. Kozlov V.A., Demina D.V. Tryptophan and indoleamine-2,3-dioxygenase (IDO) in pathogenesis of immunosuppressive clinical conditions. *Medical Immunology*. 2017;19(3):225–240. (In Russ.). https://doi.org/10.15789/1563-0625-2017-3-225-240.
15. Shatova O.P., Shestopalov A.V. Tryptophan metabolism: a new look at the role of tryptophan derivatives in the human body. *Advances in Current Biology*. 2023;143(1):3–15. (In Russ.). https://doi.org/10.31857/S0042132423010076.

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

16. Cervenka I., Agudelo L.Z., Ruas J.L. Kynurenines: Tryptophan's metabolites in exercise, inflammation, and mental health. *Science*. 2017;357(6349):eaaf9794. https://doi.org/10.1126/science.aaf9794.
17. Shatova O.P., Zabolotneva A.A., Mikin I.E., Bril D.V., Shestopalov A.V. et al. The role of tryptophan metabolites in metabolism and pathogenesis of obesity. *Russian Journal of Preventive Medicine*. 2022;25(10):97–103. (In Russ.) https://doi.org/10.17116/profmed20222510197.
18. Gao K., Mu C., Farzi A., Zhu W.Y. Tryptophan metabolism: a link between the gut microbiota and brain. *Adv Nutr*. 2020;11(3):709–723. https://doi.org/10.1093/advances/nmz127.
19. Kumar P., Lee J.H., Lee J. Diverse roles of microbial indole compounds in eukaryotic systems. *Biol Rev Camb Philos Soc*. 2021;96(6):2522–2545. https://doi.org/10.1111/brv.12765.
20. Shcherbakova E.S., Sall T.S., Sitkin S.I., Vakhitov T.Ya., Demyanova E.V. The role of bacterial metabolites derived from aromatic amino acids in non-alcoholic fatty liver disease. *Almanac of Clinical Medicine*. 2020;48(6):375–386. (In Russ.). https://doi.org/10.18786/2072-0505-2020-48-066.
21. Philips C.A., Augustine P., Yerol P.K., Ramesh G.N., Ahamed R. et al. Modulating the intestinal microbiota: Therapeutic opportunities in liver disease. *J Clin Transl Hepatol*. 2020;8(1):87–99. https://doi.org/10.14218/JCTH.2019.00035.
22. Roager H.M., Licht T.R. Microbial tryptophan catabolites in health and disease. *Nat Commun*. 2018;9(1):3294. https://doi.org/10.1038/s41467-018-05470-4.
23. Wlodarska M., Luo C., Kolde R., d'Hennezel E., Annand J.W. et al. Indoleacrylic acid produced by commensal peptostreptococcus species suppresses inflammation. *Cell Host Microbe*. 2017;22(1):25–37.e6. https://doi.org/10.1016/j.chom.2017.06.007.
24. Portune K., Beaumont M., Davila A., Tomé D., Blachier F., Sanz Y. Gut microbiota role in dietary protein metabolism and health-related outcomes: The two sides of the coin. *Trends Food Sci Technol*. 2016;57:213–232. https://doi.org/10.1016/j.tifs.2016.08.011.
25. Oliphant K., Allen-Vercoe E. Macronutrient metabolism by the human gut microbiome: major fermentation by-products and their impact on host health. *Microbiome*. 2019;7(1):91. https://doi.org/10.1186/s40168-019-0704-8.
26. Vyhlidalova B., Krrasulova K., Pecinkova P., Marcalíková A., Vrzal R. et al. Gut microbial catabolites of tryptophan are ligands and agonists of the aryl hydrocarbon receptor: a detailed characterization. *Int J Mol Sci*. 2020;21(7):2614. https://doi.org/10.3390/ijms21072614.
27. Khavkin A.I., Nalyotov A.V., Matsynina M.A. Anti-inflammatory effects of olive oil and its components. prospects of application in the treatment of inflammatory bowel diseases. *Pediatric pharmacology*. 2024;21(3):249–255. (In Russ.). https://doi.org/10.15690/pf.v21i3.2754.
28. Dinallo V., Marafini I., Di Fusco D., Di Grazia A., Laudisi F. et al. Protective effects of aryl hydrocarbon receptor signaling in celiac disease mucosa and in poly I:C-induced small intestinal atrophy mouse model. *Front Immunol*. 2019;10:91. https://doi.org/10.3389/fimmu.2019.00091.
29. Jenkins T.A., Nguyen J.C., Polglaze K.E., Bertrand P.P. Influence of tryptophan and serotonin on mood and cognition with a possible role of the gut-brain. *Nutrients*. 2016;8(1):56. https://doi.org/10.3390/nu8010056.
30. Sanidad K.Z., Rager S.L., Carrow H.C., Ananthanarayanan A., Callaghan R. et al. Gut bacteria-derived serotonin promotes immune tolerance in early life. *Sci Immunol*. 2024;9(93):eadj4775. https://doi.org/10.1126/sciimmunol.adj4775.
31. Grifka-Walk H.M., Jenkins B.R., Kominsky D.J. Amino acid TRP: the far out impacts of host and commensal tryptophan metabolism. *Front Immunol*. 2021;12:2005. https://doi.org/10.3389/fimmu.2021.653208.
32. Asgari F., Mahinpour R., Moradi L., Haghighipour N. The chromene derivative 4-Clpgc inhibits cell proliferation and induces apoptosis in the K562 cell line. *J Cell Commun Signal*. 2020;14(1):77–91. https://doi.org/10.1007/s12079-019-00530-w.
33. Marszalek-Grabska M., Katarzyna Walczak K., Gawel K., Wicha-Komsta K., Wnorowska S. et al. Kynurenine emerges from the shadows — current knowledge on its fate and function. *Pharmacol Therap*. 2021;225:107845. https://doi.org/10.1016/j.pharmthera.2021.107845.
34. Sorgdrager F.J.H., Naudé P.J.W., Kema I.P., Nollen E.A., De Deyn P.P. et al. Tryptophan metabolism in inflammaging: from biomarker to therapeutic target. *Front Immunol*. 2019;10:2565. https://doi.org/10.3389/fimmu.2019.02565.
35. Mondanelli G., Ugel S., Grohmann U., Bronte V. The immune regulation in cancer by the amino acid metabolizing enzymes ARG and IDO. *Curr Opin Pharmacol*. 2017;35:30–39. https://doi.org/10.1016/j.coph.2017.05.002.
36. Stone T.W., Williams R.O. Modulation of T-cells by tryptophan metabolites in the kynurenine pathway. *Trends Pharmacol Sci*. 2023;44(7):442–456. https://doi.org/10.1016/j.tips.2023.04.006.
37. Williams A.C., Hill L.J. Meat and nicotinamide: a causal role in human evolution, history, and demographics. *Int J Tryptophan Res*. 2017;10:1178646917704661. https://doi.org/10.1177/1178646917704661.
38. Olivares M., Walker A.W., Capilla A., Benítez-Páez A., Palau F. et al. Gut microbiota trajectory in early life may predict development of celiac disease. *Microbiome*. 2018;6(1):36. https://doi.org/10.1186/s40168-018-0415-6.
39. Gao J., Xu K., Liu H., Liu G., Bai M. et al. Impact of the gut microbiota on intestinal immunity mediated by tryp-

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

tophan metabolism. *Front Cell Infect Microbiol*. 2018;8:13. https://doi.org/10.3389/fcimb.2018.00013.
40. Fallah S., Asri N., Nikzamir A. Ahmadipour Sh., Sadeghi A. et al. Investigating the impact of vitamin A and amino acids on immune responses in celiac disease patients. *Diseases*. 2024;12(1):13. https://doi.org/10.3390/diseases12010013.
41. Van Hees N.J.M., Giltay E.J., Tielemans S.M.A.J., Geleijnse J.M., Puvill T. et al. Essential amino acids in the gluten-free diet and serum in relation to depression in patients with celiac disease. *PLoS One*. 2015;10(4):e0122619. https://doi.org/10.1371/journal.pone.0122619.
42. Lamas B., Hernandez-Galan L., Galipeau H.J., Constante M., Clarizio A. et al. Aryl hydrocarbon receptor ligand production by the gut microbiota is decreased in celiac disease leading to intestinal inflammation. *Sci Transl Med*. 2020;12(566):eaba0624. https://doi.org/10.1126/scitranslmed.aba0624.
43. Nikolaus S., Schulte B., Al-Massad N., Thieme F., Schulte D.M. et al. Increased tryptophan metabolism is associated with activity of inflammatory bowel diseases. *Gastroenterology*. 2017;153(6):1504–1516.e2. https://doi.org/10.1053/j.gastro.2017.08.028.
44. Dochat C., Afari N., Satherley R.S., Coburn S., McBeth J.F. Celiac disease symptom profiles and their relationship to gluten-free diet adherence, mental health, and quality of life. *BMC Gastroenterology*. 2024;24(1):9. https://doi.org/10.1186/s12876-023-03101-x.

ЛИТЕРАТУРА

1. Аверкина Н.А., Баранов А.А., Бельмер С.В., Бораева Т.Т., Боровик Т.Э. и др. «Целиакия-2025»: проект клинических рекомендаций по диагностике и лечению целиакии у детей. *Педиатрическая фармакология*. 2025;22(4):495–522. https://doi.org/10.15690/pf.v22i4.2941.
2. Хавкин А.И., Налетов А.В., Куропятник П.И. Роль вирусов в патогенезе целиакии: современное состояние вопроса. *Педиатрическая фармакология*. 2024;21(4):369–374. https://doi.org/10.15690/pf.v21i4.2771.
3. Zingone F., Bai J.C., Cellier C., Ludvigsson J.F. Celiac diseaserelated conditions: who to test. *Gastroenterology*. 2024;167(1):64–78. https://doi.org/10.1053/j.gastro.2024.02.044.
4. Хавкин А.И., Налетов А.В., Павловская Е.В., Яблокова Е.А., Курьянинова В.А. и др. Качество жизни пациентов с целиакией, соблюдающих безглютеновую диету: обзор литературы. *Вопросы современной педиатрии*. 2025;24(3):157–161. https://doi.org/10.15690/vsp.v24i3.2923.
5. Хавкин А.И., Гречаный С.В., Малахова А.А., Одинаева Н.Д., Кондратьева Е.И. и др. Психологические факторы приверженности безглютеновой диете у детей и подростков. *Вопросы детской диетологии*. 2025;23(5):18–30. https://doi.org/10.20953/1727-5784-2025-5-18-30.
6. Bakhtiari S., Asri N., Masotti A., Jahani-Sherafat S., Tavirani M.R. et al. Essential amino acids in celiac disease: key roles in immunogenicity, pathogenesis, and therapeutic approaches. *Crit Rev Clin Lab Sci*. 2025:1–16. https://doi.org/10.1080/10408363.2025.2551656.
7. Ding X., Bin P., Wu W., Yajie Chang Y., Zhu G. Tryptophan metabolism, regulatory T cells, and inflammatory bowel disease: a mini review. *Mediators Inflamm*. 2020;2020:9706140. https://doi.org/10.1155/2020/9706140.
8. Хавкин А.И., Налетов А.В., Ситкин С.И., Бораева Т.Т., Мацынина М.А. и др. Особенности состояния кишечной микробиоты у пациентов с целиакией. *Вопросы детской диетологии*. 2025;23(4):47–54. https://doi.org/10.20953/1727-5784-2025-4-47-54.
9. Asgari F., Khodadoust M., Nikzamir A., Sherafat S.J., Tavirani M.R. et al. The role of tryptophan metabolism and tolerogenic dendritic cells in maintaining immune tolerance: Insights into celiac disease pathogenesis. *Immun Inflamm Dis*. 2024;12(8):e1354. https://doi.org/10.1002/iid3.1354.
10. Черных Е.Р., Тыринова Т.В., Леплина О.Ю., Тихонова М.А., Курочкина Ю.Д., Олейник Е.А. и др. Фенотип и функции дендритных клеток человека, генерированных из субпопуляций моноцитов CD14+, оппозитных по экспрессии CD16. *Бюллетень сибирской медицины*. 2019;18(1):266–276. https://doi.org/10.20538/1682-0363-2019-1-266-276.
11. Soto J.A., Gálvez N.M.S., Andrade C.A., Pacheco G.A., Bohmwald K. et al. The role of dendritic cells during infections caused by highly prevalent viruses. *Front Immunol*. 2020;11:1513. https://doi.org/10.3389/fimmu.2020.01513.
12. Asgari F., Nikzamir A., Baghaei K., Salami S., Masotti A. et al. Immunomodulatory and anti-inflammatory effects of Vitamin A and tryptophan on monocyte-derived dendritic cells stimulated with gliadin in celiac disease patients. *Inflammation*. 2024;47(5):1706–1727. https://doi.org/10.1007/s10753-024-02004-7.
13. Blagih J., Hennequart M., Zani F. Tissue nutrient environments and their effect on regulatory T cell biology. *Front Immunol*. 2021;12:637960. https://doi.org/10.3389/fimmu.2021.637960.
14. Козлов В.А., Демина Д.В. Триптофан и indoleamine-2,3-dioxygenase (IDO) в патогенезе иммунокомпрометированных заболеваний. *Медицинская иммунология*. 2017;19(3):225–240. https://doi.org/10.15789/1563-0625-2017-3-225-240.

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

15. Шатова О.П., Шестопалов А.В. Метаболизм триптофана: новый взгляд на роль триптофановых производных в организме человека. *Успехи современной биологии*. 2023;143(1):3–15. https://doi.org/10.31857/S0042132423010076.
16. Cervenka I., Agudelo L.Z., Ruas J.L. Kynurenines: Tryptophan's metabolites in exercise, inflammation, and mental health. *Science*. 2017;357(6349):eaaf9794. https://doi.org/10.1126/science.aaf9794.
17. Шатова О.П., Заболотнева А.А., Микин И.Е., Бриль Д.В., Шестопалов А.В. и др. Роль метаболитов триптофана в обмене веществ и патогенезе ожирения. *Профилактическая медицина*. 2022;25(10):97–103. https://doi.org/10.17116/profmed20222510197.
18. Gao K., Mu C., Farzi A., Zhu W.Y. Tryptophan metabolism: a link between the gut microbiota and brain. *Adv Nutr*. 2020;11(3):709–723. https://doi.org/10.1093/advances/nmz127.
19. Kumar P., Lee J.H., Lee J. Diverse roles of microbial indole compounds in eukaryotic systems. *Biol Rev Camb Philos Soc*. 2021;96(6):2522–2545. https://doi.org/10.1111/brv.12765.
20. Щербакова Е.С., Салль Т.С., Ситкин С.И., Вахитов Т.Я., Демьянова Е.В. Роль бактериальных производных ароматических аминокислот в развитии неалкогольной жировой болезни печени. *Альманах клинической медицины*. 2020;48(6):375–386. https://doi.org/10.18786/2072-0505-2020-48-066.
21. Philips C.A., Augustine P., Yerol P.K., Ramesh G.N., Ahamed R. et al. Modulating the intestinal microbiota: Therapeutic opportunities in liver disease. *J Clin Transl Hepatol*. 2020;8(1):87–99. https://doi.org/10.14218/JCTH.2019.00035.
22. Roager H.M., Licht T.R. Microbial tryptophan catabolites in health and disease. *Nat Commun*. 2018;9(1):3294. https://doi.org/10.1038/s41467-018-05470-4.
23. Wlodarska M., Luo C., Kolde R., d'Hennezel E., Annand J.W. et al. Indoleacrylic acid produced by commensal peptostreptococcus species suppresses inflammation. *Cell Host Microbe*. 2017;22(1):25–37.e6. https://doi.org/10.1016/j.chom.2017.06.007.
24. Portune K., Beaumont M., Davila A., Tomé D., Blachier F., Sanz Y. Gut microbiota role in dietary protein metabolism and health-related outcomes: The two sides of the coin. *Trends Food Sci Technol.* 2016;57:213–232. https://doi.org/10.1016/j.tifs.2016.08.011.
25. Oliphant K., Allen-Vercoe E. Macronutrient metabolism by the human gut microbiome: major fermentation by-products and their impact on host health. *Microbiome*. 2019;7(1):91. https://doi.org/10.1186/s40168-019-0704-8.
26. Vyhlidalova B., Krrasulova K., Pecinkova P., Marcalíková A., Vrzal R. et al. Gut microbial catabolites of tryptophan are ligands and agonists of the aryl hydrocarbon receptor: a detailed characterization. *Int J Mol Sci*. 2020;21(7):2614. https://doi.org/10.3390/ijms21072614.
27. Хавкин А.И., Налетов А.В., Мацынина М.А. Противовоспалительные эффекты оливкового масла и его компонентов. Перспективы применения в лечении воспалительных заболеваний кишечника. *Педиатрическая фармакология*. 2024;21(3):249–255. https://doi.org/10.15690/pf.v21i3.2754.
28. Dinallo V., Marafini I., Di Fusco D., Di Grazia A., Laudisi F. et al. Protective effects of aryl hydrocarbon receptor signaling in celiac disease mucosa and in poly I:C-induced small intestinal atrophy mouse model. *Front Immunol*. 2019;10:91. https://doi.org/10.3389/fimmu.2019.00091.
29. Jenkins T.A., Nguyen J.C., Polglaze K.E., Bertrand P.P. Influence of tryptophan and serotonin on mood and cognition with a possible role of the gut-brain. *Nutrients*. 2016;8(1):56. https://doi.org/10.3390/nu8010056.
30. Sanidad K.Z., Rager S.L., Carrow H.C., Ananthanarayanan A., Callaghan R. et al. Gut bacteria-derived serotonin promotes immune tolerance in early life. *Sci Immunol*. 2024;9(93):eadj4775. https://doi.org/10.1126/sciimmunol.adj4775.
31. Grifka-Walk H.M., Jenkins B.R., Kominsky D.J. Amino acid TRP: the far out impacts of host and commensal tryptophan metabolism. *Front Immunol*. 2021;12:2005. https://doi.org/10.3389/fimmu.2021.653208.
32. Asgari F., Mahinpour R., Moradi L., Haghighipour N. The chromene derivative 4-Clpgc inhibits cell proliferation and induces apoptosis in the K562 cell line. *J Cell Commun Signal*. 2020;14(1):77–91. https://doi.org/10.1007/s12079-019-00530-w.
33. Marszalek-Grabska M., Katarzyna Walczak K., Gawel K., Wicha-Komsta K., Wnorowska S. et al. Kynurenine emerges from the shadows — current knowledge on its fate and function. *Pharmacol Therap*. 2021;225:107845. https://doi.org/10.1016/j.pharmthera.2021.107845.
34. Sorgdrager F.J.H., Naudé P.J.W., Kema I.P., Nollen E.A., De Deyn P.P. et al. Tryptophan metabolism in inflammaging: from biomarker to therapeutic target. *Front Immunol*. 2019;10:2565. https://doi.org/10.3389/fimmu.2019.02565.
35. Mondanelli G., Ugel S., Grohmann U., Bronte V. The immune regulation in cancer by the amino acid metabolizing enzymes ARG and IDO. *Curr Opin Pharmacol*. 2017;35:30–39. https://doi.org/10.1016/j.coph.2017.05.002.
36. Stone T.W., Williams R.O. Modulation of T-cells by tryptophan metabolites in the kynurenine pathway. *Trends Pharmacol Sci*. 2023;44(7):442–456. https://doi.org/10.1016/j.tips.2023.04.006.
37. Williams A.C., Hill L.J. Meat and nicotinamide: a causal role in human evolution, history, and demographics. *Int*

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)

J Tryptophan Res. 2017;10:1178646917704661. https://doi.org/10.1177/1178646917704661.
38. Olivares M., Walker A.W., Capilla A., Benítez-Páez A., Palau F. et al. Gut microbiota trajectory in early life may predict development of celiac disease. *Microbiome*. 2018;6(1):36. https://doi.org/10.1186/s40168-018-0415-6.
39. Gao J., Xu K., Liu H., Liu G., Bai M. et al. Impact of the gut microbiota on intestinal immunity mediated by tryptophan metabolism. *Front Cell Infect Microbiol*. 2018;8:13. https://doi.org/10.3389/fcimb.2018.00013.
40. Fallah S., Asri N., Nikzamir A. Ahmadipour Sh., Sadeghi A. et al. Investigating the impact of vitamin A and amino acids on immune responses in celiac disease patients. *Diseases*. 2024;12(1):13. https://doi.org/10.3390/diseases12010013.
41. Van Hees N.J.M., Giltay E.J., Tielemans S.M.A.J., Geleijnse J.M., Puvill T. et al. Essential amino acids in the gluten-free diet and serum in relation to depression in patients with celiac disease. *PLoS One*. 2015;10(4):e0122619. https://doi.org/10.1371/journal.pone.0122619.
42. Lamas B., Hernandez-Galan L., Galipeau H.J., Constante M., Clarizio A. et al. Aryl hydrocarbon receptor ligand production by the gut microbiota is decreased in celiac disease leading to intestinal inflammation. *Sci Transl Med*. 2020;12(566):eaba0624. https://doi.org/10.1126/scitranslmed.aba0624.
43. Nikolaus S., Schulte B., Al-Massad N., Thieme F., Schulte D.M. et al. Increased tryptophan metabolism is associated with activity of inflammatory bowel diseases. *Gastroenterology*. 2017;153(6):1504–1516.e2. https://doi.org/10.1053/j.gastro.2017.08.028.
44. Dochat C., Afari N., Satherley R.S., Coburn S., McBeth J.F. Celiac disease symptom profiles and their relationship to gluten-free diet adherence, mental health, and quality of life. *BMC Gastroenterology*. 2024;24(1):9. https://doi.org/10.1186/s12876-023-03101-x.

Authors' info

✉ **Anatoly I. Khavkin** — Dr. Sci. (Med.), Professor, Head of the Moscow Regional Center of Pediatric Gastroenterology and Hepatology of the Research Clinical Institute of Childhood; Professor, Department of Pediatrics with a Course in Pediatric Surgical Diseases of the Medical Institute of the Belgorod National Research University. E-mail: khavkin@nikid.ru; https://orcid.org/0000-0001-7308-7280; SPIN: 6070-9473

Andrew V. Nalyotov — Dr. Sci. (Med.), Professor, Head of the Department of Pediatrics No. 2, M. Gorky Donetsk State Medical University; Chief Pediatric Gastroenterologist Ministry of Health of the Donetsk People's Republic. E-mail: nalyotov-a@mail.ru; https://orcid.org/0000-0002-4733-3262; SPIN: 5876-7445

Stanislav I. Sitkin — Cand. Sci. (Med.), Head of the Epigenetics and Metagenomics Research Group of the Institute of Perinatology and Pediatrics, Almazov National Medical Research Centre; Associate Professor, S.M. Ryss Department of Propaedeutics of Internal Diseases, Gastroenterology and Dietetics, North-Western State Medical University named after I.I. Mechnikov; Leading Researcher, Institute of Experimental Medicine. E-mail: sitkins@yandex.ru https://orcid.org/0000-0003-0331-0963; SPIN: 3961-8815

Об авторах

✉ **Анатолий Ильич Хавкин** — д.м.н., профессор, руководитель Московского областного центра гастроэнтерологии и гепатологии, Научно-исследовательский клинический институт детства Министерства здравоохранения Московской области; профессор, кафедра педиатрии с курсом детских хирургических болезней медицинского института Белгородского государственного исследовательского университета. E-mail: khavkin@nikid.ru; https://orcid.org/0000-0001-7308-7280; SPIN: 6070-9473

Андрей Васильевич Налётов — д.м.н., профессор, заведующий кафедрой педиатрии № 2, Донецкий государственный медицинский университет им. М. Горького; главный внештатный детский специалист гастроэнтеролог Минздрава Донецкой Народной Республики. E-mail: nalyotov-a@mail.ru; https://orcid.org/0000-0002-4733-3262; SPIN: 5876-7445

Станислав Игоревич Ситкин — к.м.н., заведующий научно-исследовательской группой эпигенетики и метагеномики Института перинатологии и педиатрии Национального медицинского исследовательского центра им. В.А. Алмазова; доцент, кафедра пропедевтики внутренних болезней, гастроэнтерологии и диетологии им. С.М. Рысса, Северо-Западный государственный медицинский университет им. И.И. Мечникова; ведущий научный сотрудник, Институт экспериментальной медицины. E-mail: sitkins@yandex.ru https://orcid.org/0000-0003-0331-0963; SPIN: 3961-8815

ISSN 3034-6312 (Print) ISSN 3034-6320 (Online)