Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Clinical Immunology 226 (2021) 108725

Contents lists available at ScienceDirect

Clinical Immunology

journal homepage: www.elsevier.com/locate/yclim

Review Article

The microbiota-mediated dietary and nutritional interventions for COVID-19

Amin Gasmi [a], Torsak Tippairote [b,c], Pavan Kumar Mujawdiya [d], Massimiliano Peana [e], Alain Menzel [f], Maryam Dadar [g], Asma Gasmi Benahmed [h], Geir Bjørklund [i,*]

[a] Société Francophone de Nutrithérapie et de Nutrigénétique Appliquée, Villeurbanne, France
[b] Doctor of Philosophy Program in Nutrition, Faculty of Medicine, Ramathibodi Hospital and Institute of Nutrition, Mahidol University, Bangkok, Thailand
[c] Thailand Institute for Functional Medicine, Bangkok, Thailand
[d] Birla Institute of Technology and Science - Pilani, Hyderabad, India
[e] Department of Chemistry and Pharmacy, University of Sassari, Italy
[f] Laboratoires Réunis, Junglinster, Luxembourg
[g] Razi Vaccine and Serum Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran
[h] Académie Internationale de Médecine Dentaire Intégrative, Paris, France
[i] Council for Nutritional and Environmental Medicine, Mo i Rana, Norway

ARTICLE INFO

Keywords:
COVID-19
SARS-CoV-2
Microbiota
Gut-lung axis
Probiotics
Prebiotics

ABSTRACT

Worldwide, scientists are looking for specific treatment for COVID-19. Apart from the antiviral approach, the interventions to support healthy immune responses to the virus are feasible through diet, nutrition, and lifestyle approaches. This narrative review explores the recent studies on dietary, nutritional, and lifestyle interventions that influence the microbiota-mediated immunomodulatory effects against viral infections. Cumulative studies reported that the airway microbiota and SARS-CoV-2 leverage each other and determine the pathogen-microbiota-host responses. Cigarette smoking can disrupt microbiota abundance. The composition and diversification of intestinal microbiota influence the airway microbiota and the innate and adaptive immunity, which require supports from the balance of macro- and micronutrients from the diet. Colorful vegetables supplied fermentable prebiotics and anti-inflammatory, antioxidant phytonutrients. Fermented foods and beverages support intestinal microbiota. In sensitive individuals, the avoidance of the high immunoreactive food antigens contributes to antiviral immunity. This review suggests associations between airway and intestinal microbiota, antiviral host immunity, and the influences of dietary, nutritional, and lifestyle interventions to prevent the clinical course toward severe COVID-19.

1. Introduction

Since its start in December 2019, the coronavirus disease 2019 (COVID-19) outbreak became a global pandemic in just three months due to the high infectivity and transmission of the causative virus—the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1–3]. According to the WHO-China Joint Mission on Coronavirus Disease 2019, 78% of the infected individuals were asymptomatic [4,5]. 81%, 14%, and 5% of COVID-19 cases had mild, moderate, and severe clinical symptoms, respectively [6]. Individual host metabolic status, including diet, nutrition, lifestyle, and environmental factors, critically determine these different clinical manifestations of SARC-CoV-2 infection [7–10].

The clinical events of COVID-19 include dry cough, fever, breathing difficulties, pneumonia, and respiratory failure [1]. The human airway epithelium is an entering site of SARS-CoV-2 [11]. The microbiome that inhabits the respiratory mucosa, from the upper to the lower respiratory tract, plays a crucial role in health and disease [12–17]. Several studies suggested the mutual relationship between the microbiota to host immunity, respiratory health, viral infection, and the immune responses to viral vaccines [18–20]. The balance of microbiota in the gut, oral cavity, and lung influences the host's immune tolerance to viruses and the clinical severity and duration of the viral infections [20,21]. Alterations in the intestinal microbiome species and metabolites have been highlighted during respiratory viral infections, which may impact the lungs via microbiome-mediated cross-talk along the gut-lung axis [19]. Gut dysbiosis and related lung complications have also been observed during

* Corresponding author at: Council for Nutritional and Environmental Medicine, Toften 24, 8610 Mo i Rana, Norway.
E-mail address: bjorklund@conem.org (G. Bjørklund).

https://doi.org/10.1016/j.clim.2021.108725
Received 11 March 2021; Received in revised form 6 April 2021; Accepted 7 April 2021
Available online 9 April 2021

COVID-19 disease progression [22–25]. Among many potential molecular targeted drugs and the newly arrived vaccines, diet and nutrition determine the microbiota's composition and diversity and thus affect host immunity. However, the discussion of these simple options is still limited, as though it is the elephant in the room [26–31]. Herein, we review the dietary and nutritional interventions to maintain the healthy microbiome balances that potentially modulate the host immunity to COVID-19.

2. Microbiota and host immunity

As humans do not live in sterile bubbles, the hosts dynamically interact with their external environments, including foods, environmental toxins, and germs such as bacteria, parasites, fungi, and viruses [32–34]. Microbiota mediates these interactions' healthy balances throughout all surface linings, including skin, gut, lung, cornea, and vagina [19,35–37]. The gastrointestinal tract, particularly the colon, harbors the most populated microbiota in a human body: with the number of microbial cells and their genomes' count at ten and a hundred times more than those of the host, respectively [15].

The barrier linings' integrated functions, protective mucous, and antimicrobial peptides initially protect the internal host environment from microbial translocation [38]. However, the tissue-resident antigen-presenting cells - such as dendritic cells and macrophages- continuously sampling and processing the external microbial antigens and relaying the messages to the host immune cells [38]. These processed molecular patterns comprise the various signals of self, non-self, damaging, or dangerous signals: the pathogen- and the danger-associated molecular patterns [39]. The combined processing of these external signals determines the dynamic internal balance of pro-inflammatory and anti-inflammatory responses, the host tolerances to pathogens, and the composition and diversification of microbiota [38]. These interactions modulate the proliferation, differentiation, and maturation of the various immune cells [40–42].

Apart from those, several microbe metabolites, particularly the short-chain fatty acids (SCFAs), serve as the metabolic fuel for colon cells, the messengers, and the mediators of microbe-host immunity synchronization [13,40–42]. The fermentable dietary fibers and the resulting colonic microbiota compositions determine the SCFAs synthesis, which maintains the intestinal health, barrier functions, and lumen homeostasis: thus, protects the host from several disorders, such as inflammatory bowel disease [43–45]. Interestingly, influenza A infection disrupts these SCFAs production, creating the microbiota imbalances that contribute to the clinical symptoms [46].

3. The lungs and airways microbiota

Far from the historical concept of a sterile environment of lungs, the lung microbiota significantly contributes to the airway tolerance and immune responses to respiratory infection [15,47]. However, the lungs' microbial count is less compared to those in the colon [15]. The changes in microbial abundance and diversification in the upper and lower respiratory tracts correlate to the airway pathologies such as asthma and lung infections [48]. For example, the immunomodulatory *Prevotella* species promote lung homeostasis. The pro-inflammatory environment in the lung increases the outgrowth of several gram-negative bacteria, such as Gammaproteobacteria, through the nutrient enrichment processes: the mucous production and the enhanced vasculature, and the increased endothelial permeability [49].

The airway-associated lifestyle factors, such as cigarette smoking, significantly change the lung microbial composition toward the increased number of pro-inflammatory *Proteobacteria* and *Firmicutes* while decreasing the anti-inflammatory *Oceanospirillales*, *Desulfuromonadales, Nesterenkonia*, and *Lactobacillaceae* [50]. Interestingly, a recent systematic review suggested the associations between cigarette smoking and the negative clinical outcomes of COVID-19 [51]. However, recent studies agree that cigarette smoking increases significantly the risk of progressing and severe viral infection [8]. This finding suggests the close relationship between lifestyle, microbiota, and antiviral immunity.

4. The lung-intestinal microbiota connection

Animal studies reported the increased numbers and the gradual changes of lung microbiota composition during the first two-week of life [52]. These changes influenced the lung immune tolerance toward specific allergens by the increased number of regulatory T-cells [14]. Several studies revealed the association between the lung and intestinal microbiota [53,54]. The neomycin-induced microbiota imbalance, aka gut dysbiosis, increased the lung infection from influenza virus in the animal models through the inactivation of the inflammasome, dendritic cells, and T-cells responses [55]. During the *S. pneumoniae*-induced lung infection, the microbiota-depleted mice had higher inflammation, more organ damages, and fewer phagocytotic activities of the alveolar macrophages than their controls [56]. The healthy fecal microbiota transfer into the microbiota-depleted mice ameliorated their respiratory symptom severities and reduced the levels of pro-inflammatory cytokines [56]. Intestinal dysbiosis can predispose an individual to respiratory tract infection, including pneumonia and other respiratory conditions such as chronic obstructive pulmonary disease, cystic fibrosis, and lung cancer [57,58]. Despite their different locations, these two microbial communities are closely influencing and interacting with each other.

5. Microbiota and the protection against SARS-CoV-2 infections

Cumulative studies suggested that the microbiota is significantly involved in the host responses to many viral infections, either through the facilitation of viral attachment to host cells or the supports of antiviral immunity such as interferon and innate immune activation [59–61]. Specific evidence of microbiota and infection is starting to be available also for SARS-CoV-2 [62–66].

In the mice's lung, the commensal bacteria enhanced the antiviral activity of type I interferon, which was blunted by antibiotics [67]. While germ-free mice were prone to death from influenza infection, their intestinal microbiota's re-colonization promoted the anti-inflammatory polarization of macrophages [68]. Kanmani et al. reported that the colonization of a gram-positive bacteria, *Corynebacterium pseudodiphtheriticum*, in mice's nasal cavities reduced their symptoms of respiratory syncytial virus infections and prevented secondary pneumococcal pneumonia [69]. The mechanisms of these antiviral responses were the increased innate immune activation of toll-like receptor 3 signalings in the alveolar macrophages, the interferon signaling, and the T-cells activation [69]. Wu et al. also reported the intestinal microbiota-mediated activation of toll-like receptor 7 signalings in response to the respiratory influenza viral infection [70].

Apart from these mechanisms, the microbiota can exert antiviral effects through their metabolites, particularly the butyrate-an important SCFA. Trompetee et al. demonstrated that SCFAs enhanced the energy metabolism and the activities of effector T-cells and ameliorated influenza infection symptoms [71]. The seven-day pretreatment of SCFAs, including butyrate, restored the CD8+ T-cell functions, increased antibody responses, and prevented the influenza infection in mice [36,72]. Butyrate and propionate treatment in the mice model of asthma increased their production of the master transcription factor for anti-inflammatory regulatory T-cells, FOXP3, while suppressing the pro-inflammatory cytokines, interleukin 9, mast cell activation, and the lung infiltration with eosinophils and Th9 T-helper cells [73]. A study of 360 patients with immunosuppressive treatment during the allogeneic hematopoietic stem cell transplantation reported the five-fold associations between the abundance of butyrate-producing intestinal bacteria and the decreased chances of lower respiratory infection [74].

The intestinal and lung microbiota influence the host antiviral

immunity by several immunomodulating mechanisms. The interventions that balance the microbiota composition and diversification, thus, potentially play roles in COVID-19.

6. Potential microbiota-related dietary and nutritional interventions

6.1. General aspects

Healthy immunity requires integrating supports from various macro- and micronutrients derived from the individual dietary pattern. Specific nutrient deficiencies, such as vitamin D, zinc, and selenium, compromise host antiviral responses when the specific nutrient supplementation may be beneficial [7,10,75–82]. In general, a balanced diet, adequate nutritional status, together with regular consumption of anti-inflammatory and antioxidant phytonutrients, from the colorful vegetables, can support the host responses to SARS-CoV-2 and reduce the severity, duration, and mortality associated with COVID-19 [83,84].

6.2. Prebiotics

Dietary prebiotics is the fermentable and non-digestible fiber compounds that feed the intestinal microbes and contribute to SCFAs production [85]. These prebiotics, including galactooligosaccharides, trans-galactooligosaccharides, and fructooligosaccharides, maintain the number of beneficial microbiota strains and sustain the production of beneficial SCFAs, therefore, potentially modulate the healthy host antiviral immunity. The fiber-rich diet protects mice from the severe pathological symptoms and the respiratory tract inflammation of the influenza virus infection [86]. Mice with a high-fiber diet and butyrate supplementation showed the reduction of chemokine expression, increasing circulating monocytes number, lowering neutrophil infiltration, and promoting T-cells bioenergetics, the reduction of lung inflammation, and enhancing the clearance of influenza virus [86].

Luoto et al. reported the incidence reduction in infants from the rhinovirus-induced respiratory tract infection with the combined usage of prebiotics and a probiotic, *Lactobacillus rhamnosus GG* [87]. The elders with the supplementation of an experimental formula containing the fermentable oligosaccharides, vitamins, and other antioxidants, showed shorter duration of symptoms to the influenza vaccine, higher antibody titers, and higher lymphocyte proliferation than their controls [88].

A recent study reported that COVID-19 patients showed intestinal dysbiosis and reduced *Lactobacillus* and *Bifidobacterium* [89]. Despite a few pieces of supporting evidence, prebiotics is a potential immunomodulatory strategy for COVID-19. However, the regular consumption of colorful vegetables also provides the non-digestible fibers for the prebiotics function and the phytonutrients that provide the anti-inflammatory and antioxidant effects. This dietary pattern can support microbiota-mediated antiviral immunity [89].

6.3. Probiotics

Probiotics are the pre-determined specific strains of beneficial microbiota that may mediate the intestinal microbiome balance and diversification, thus, augment the host immunity against pathogens, including the viral infection [90]. The combined usage of multivitamin and mineral, together with the probiotic strains of *Lactobacillus* and *Bifidobacterium,* reduces the duration and the severity of influenza-induced common cold while increasing the number of T-helper cells [85,91]. The administration of the probiotics, *Lactobacillus Plantarum DK119* or the *Lactobacillus casei DN-114001*, protects the host against influenza infection and reduces the duration of common infectious diseases. These relevant mechanisms are the increased production of interleukin 12 and interferon γ, the modulation of macrophages and dendritic cells' activities, and the lowering of host inflammatory responses [92–94].

Therefore, probiotics are the sensible immunomodulatory option for COVID-19. However, the cumulating evidence is premature to conclude the role of specific probiotic strain in therapeutic management [89,95,96].

6.4. Fermented foods and drinks

Despite the limited number of available published studies, an omics-based study reported an association between fermented food consumption and differences in beneficial microbiota [97]. Fermentation processes break down the sugars in foods by bacteria and yeasts. Fermented foods and drinks contain live bacteria and prebiotic fibers. The fermentation of dairy products yields kefir, yogurt, and cottage cheese. Other fermented foods and beverages include fermented vegetables, tempeh, miso, pickles, sauerkraut, kimchi, kombucha, and other drinks such as beet kvass and apple cider. Consumption of these fermented foods is potentially beneficial for the microbiota and host metabolic health [97–99].

Kefir is an inexpensive, homemade, fermented milk drink that modulates the host immunity, reduces the chances of viral and bacterial infections, and benefits many host metabolic conditions [100,101]. The fermentation process of kefir involves the symbiotic activities of lactic acid bacteria and yeast [100,102]. The cell line studies reported the effects of kefir on reducing T-cell proliferation and cytopathic effects of Zika virus exposure [103]. Novel kefir that contains *Lactobacillus* acted as a natural adjuvant of dendritic cells to enhance the secretion of several cytokines, augmenting the activities of cytotoxic T-cells and acting against the viral infection [84,104].

6.5. Restricted diet

Several studies reported that intestinal microbiota is among other host predisposing factors that influence the food sensitivities through the mechanisms of food antigen degradation, gut barrier integrity, and anti-inflammatory regulatory T cell promotion [105]. The virus-host interactions disrupt these homeostases and induce the pathogenic responses to food antigens [105,106]. This concern is particularly crucial in an individual with a known history of food sensitivities or allergy during the SARS-CoV-2 pandemics.

Apart from those interventions for the healthy microbiota balance, the dietary avoidance of foods that contain high immunoreactive antigens contributes to host antiviral potentials. Gluten sensitivity underlies the development of autoimmune celiac disease [107]. The virus-induced interferon γ responses aggravate celiac disease progression during several virus infections, including adenovirus, enterovirus, rotavirus, and hepatitis C virus [108–111]. Interestingly, a non-virulent species – reovirus– interacts with gluten and initiates the immune responses that lead to celiac disease progression [106].

With these pieces of evidence, an individual with known food sensitivities, allergy, or risk for autoimmune conditions, may consider the restricted diet to promote host tolerance during the outbreak of COVID-19.

7. Conclusion

Scientists are looking for specific treatment for COVID-19 to date. Apart from the antiviral approach, the interventions to support the healthy immune responses to the virus are feasible through diet, nutrition, and lifestyle approaches. As illustrated in Fig. 1, airway microbiota and SARS-CoV-2 influence each other and determine the host immune responses. Viral infection can disrupt microbiota abundance; however, the intestinal microbiota composition and diversification influence airway microbiota and its immunity. Smoking compromises airway microbiota. Healthy immunity requires the balance of macro- and micronutrients from the diet. Colorful vegetables supplied fermentable prebiotics and anti-inflammatory, antioxidant phytonutrients.

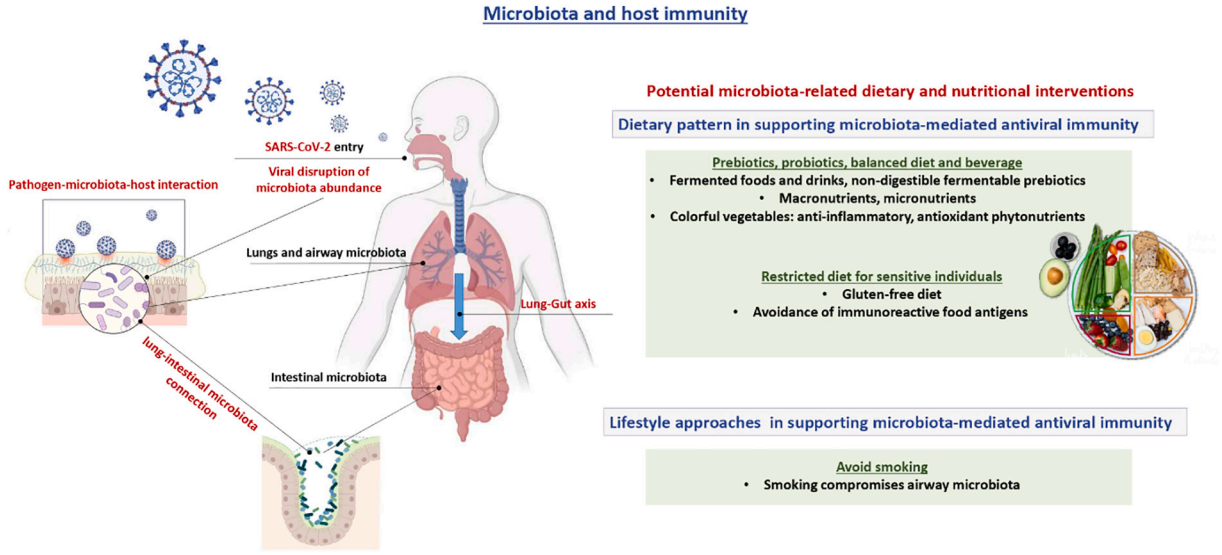

Fig. 1. The interrelationship between SARS-CoV-2 and airway microbiota determines the host immune responses. Intestinal microbiota composition and diversification influence airway microbiota, innate, and adaptive immunity. Viral infection disrupts microbiota abundance and the relevant host responses. Smoking compromises airway microbiota and its antiviral responses. Healthy immunity requires the balance of macro- and micronutrients from the diet. Colorful vegetables supplied fermentable prebiotics and anti-inflammatory, antioxidant phytonutrients. Fermented foods and beverages support intestinal microbiota. In the sensitive individual, avoiding the high immunoreactive food antigens contribute to antiviral immunity and prevents the clinical course toward severe COVID-19.

Fermented foods and beverages support intestinal microbiota. In the sensitive individual, avoiding the high immunoreactive food antigens contribute to antiviral immunity. These dietary and nutritional interventions can prevent the clinical course toward severe COVID-19.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare they have no actual or potential competing financial interests.

References

[1] L. Wang, Y. Wang, D. Ye, Q. Liu, Review of the 2019 novel coronavirus (SARS-CoV-2) based on current evidence, Int. J. Antimicrob. Agents 55 (2020) 105948, https://doi.org/10.1016/j.ijantimicag.2020.105948.
[2] T. Singhal, A review of coronavirus Disease-2019 (COVID-19), Indian J. Pediatr. 87 (2020) 281–286, https://doi.org/10.1007/s12098-020-03263-6.
[3] Y. Yang, W. Shang, X. Rao, Facing the COVID-19 outbreak: what should we know and what could we do? J. Med. Virol. 92 (2020) 536–537, https://doi.org/10.1002/jmv.25720.
[4] M. Day, Covid-19: four fifths of cases are asymptomatic, China figures indicate, BMJ 369 (2020) m1375, https://doi.org/10.1136/bmj.m1375.
[5] World Health Organization, Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19), 2020, p. 40.
[6] Z. Wu, J.M. McGoogan, Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese center for disease control and prevention, JAMA 323 (2020) 1239–1242, https://doi.org/10.1001/jama.2020.2648.
[7] A. Gasmi, S. Noor, T. Tippairote, M. Dadar, A. Menzel, G. Bjørklund, Individual risk management strategy and potential therapeutic options for the COVID-19 pandemic, Clin. Immunol. 108409 (2020), https://doi.org/10.1016/j.clim.2020.108409.
[8] A. Gasmi, M. Peana, L. Pivina, S. Srinath, A. Gasmi Benahmed, Y. Semenova, A. Menzel, M. Dadar, G. Bjorklund, Interrelations between COVID-19 and other disorders, Clin. Immunol. 224 (2021) 108651, https://doi.org/10.1016/j.clim.2020.108651.
[9] T. Tippairote, M. Peana, S. Chirumbolo, G. Bjørklund, Individual risk management strategy for SARS-CoV2 infection: a step toward personalized healthcare, Int. Immunopharmacol. 107629 (2021), https://doi.org/10.1016/j.intimp.2021.107629.
[10] A. Gasmi, S. Chirumbolo, M. Peana, S. Noor, A. Menzel, M. Dadar, G. Bjorklund, The role of diet and supplementation of natural products in COVID-19 prevention, Biol. Trace Elem. Res. (2021), https://doi.org/10.1007/s12011-021-02623-3.
[11] K. Dhama, K. Sharun, R. Tiwari, M. Dadar, Y.S. Malik, K.P. Singh, W. Chaicumpa, COVID-19, an emerging coronavirus infection: advances and prospects in designing and developing vaccines, immunotherapeutics, and therapeutics, Hum. Vaccin Immunother. (2020) 1–7, https://doi.org/10.1080/21645515.2020.1735227.
[12] Y. Wang, L.V. Hooper, Immune control of the microbiota prevents obesity, Science 365 (2019) 316–317, https://doi.org/10.1126/science.aay2057.
[13] M. Levy, C.A. Thaiss, E. Elinav, Metabolites: messengers between the microbiota and the immune system, Genes Dev. 30 (2016) 1589–1597, https://doi.org/10.1101/gad.284091.116.
[14] D.N. O'Dwyer, R.P. Dickson, B.B. Moore, The lung microbiome, immunity, and the pathogenesis of chronic lung disease, J. Immunol. 196 (2016) 4839–4847, https://doi.org/10.4049/jimmunol.1600279.
[15] E. Mathieu, U. Escribano-Vazquez, D. Descamps, C. Cherbuy, P. Langella, S. Riffault, A. Remot, M. Thomas, Paradigms of lung microbiota functions in health and disease, particularly, in asthma, Front. Physiol. 9 (2018) 1168, https://doi.org/10.3389/fphys.2018.01168.
[16] R.J. Lamont, H. Koo, G. Hajishengallis, The oral microbiota: dynamic communities and host interactions, Nat. Rev. Microbiol. 16 (2018) 745–759, https://doi.org/10.1038/s41579-018-0089-x.
[17] L. Gao, T. Xu, G. Huang, S. Jiang, Y. Gu, F. Chen, Oral microbiomes: more and more importance in oral cavity and whole body, Protein Cell 9 (2018) 488–500, https://doi.org/10.1007/s13238-018-0548-1.
[18] A.N. Vlasova, S. Takanashi, A. Miyazaki, G. Rajashekara, L.J. Saif, How the gut microbiome regulates host immune responses to viral vaccines, Curr. Opin. Virol. 37 (2019) 16–25, https://doi.org/10.1016/j.coviro.2019.05.001.
[19] T.P. Wypych, L.C. Wickramasinghe, B.J. Marsland, The influence of the microbiome on respiratory health, Nat. Immunol. (2019), https://doi.org/10.1038/s41590-019-0451-9.
[20] C. Domínguez-Díaz, A. García-Orozco, A. Riera-Leal, J.R. Padilla-Arellano, M. Fafutis-Morris, Microbiota and its role on viral evasion: is it with us or against us? Front. Cell. Infect. Microbiol. 9 (2019) 256, https://doi.org/10.3389/fcimb.2019.00256.
[21] A.T. Dang, B.J. Marsland, Microbes, metabolites, and the gut–lung axis, Mucosal Immunol. 12 (2019) 843–850, https://doi.org/10.1038/s41385-019-0160-6.
[22] N. Haiminen, F. Utro, E. Seabolt, L. Parida, Functional profiling of COVID-19 respiratory tract microbiomes, Sci. Rep. 11 (2021) 6433, https://doi.org/10.1038/s41598-021-85750-0.
[23] E. Stavropoulou, K. Kantartzi, C. Tsigalou, T. Konstantinidis, C. Voidarou, E. Bezirtzoglou, Unraveling the interconnection patterns across lung microbiome, respiratory diseases, and COVID-19, Front. Cell. Infect. Microbiol. 10 (2020) 619075, https://doi.org/10.3389/fcimb.2020.619075.
[24] R. Xu, R. Lu, T. Zhang, Q. Wu, W. Cai, X. Han, Z. Wan, X. Jin, Z. Zhang, C. Zhang, Temporal association between human upper respiratory and gut bacterial microbiomes during the course of COVID-19 in adults, Commun. Biol. 4 (2021) 240, https://doi.org/10.1038/s42003-021-01796-w.

[25] S. Villapol, Gastrointestinal symptoms associated with COVID-19: impact on the gut microbiome, Transl. Res. 226 (2020) 57–69, https://doi.org/10.1016/j.trsl.2020.08.004.

[26] E. Rinninella, M. Cintoni, P. Raoul, L.R. Lopetuso, F. Scaldaferri, G. Pulcini, G.A. D. Miggiano, A. Gasbarrini, M.C. Mele, Food components and dietary habits: keys for a healthy gut microbiota composition, Nutrients 11 (2019) 2393, https://doi.org/10.3390/nu11102393.

[27] E. Dimidi, S.R. Cox, M. Rossi, K. Whelan, Fermented foods: definitions and characteristics, impact on the gut microbiota and effects on gastrointestinal health and disease, Nutrients 11 (2019) 1806, https://doi.org/10.3390/nu11081806.

[28] E.A. Klingbeil, C.B.D.L. Serre, Microbiota modulation by eating patterns, dietary and macronutrient composition; impact on food intake, Am. J. Phys. Regul. Integr. Comp. Phys. 315 (2018) R1254–R1260, https://doi.org/10.1152/ajpregu.00037.2018.

[29] J.D.C. Pereira, K. Rea, Y.M. Nolan, O.F. O'Leary, T.G. Dinan, J.F. Cryan, Depression's unholy trinity: dysregulated stress, immunity, and the microbiome, Annu. Rev. Psychol. 71 (2020) 49–78, https://doi.org/10.1146/annurev-psych-122216-011613.

[30] K. Rea, T.G. Dinan, John F. Cryan, The microbiome: a key regulator of stress and neuroinflammation, Neurobiol. Stress (2016) 1–11, https://doi.org/10.1016/j.ynstr.2016.03.001.

[31] L.J. Mailing, J.M. Allen, T.W. Buford, C.J. Fields, J.A. Woods, Exercise and the gut microbiome: a review of the evidence, potential mechanisms, and implications for human health, Exerc. Sport Sci. Rev. 47 (2019) 75–85, https://doi.org/10.1249/jes.0000000000000183.

[32] O. Perdijk, B.J. Marsland, The microbiome: toward preventing allergies and asthma by nutritional intervention, Curr. Opin. Immunol. 60 (2019) 10–18, https://doi.org/10.1016/j.coi.2019.04.001.

[33] L.-I. McCall, C. Callewaert, Q. Zhu, S.J. Song, A. Bouslimani, J.J. Minich, M. Ernst, J.F. Ruiz-Calderon, H. Cavallin, H.S. Pereira, A. Novoselac, J. Hernandez, R. Rios, O.H. Branch, M.J. Blaser, L.C. Paulino, P.C. Dorrestein, R. Knight, M.G. Dominguez-Bello, Home chemical and microbial transitions across urbanization, Nat. Microbiol. 5 (2020) 108–115, https://doi.org/10.1038/s41564-019-0593-4.

[34] N. Zmora, J. Suez, E. Elinav, You are what you eat: diet, health and the gut microbiota, Nat. Rev. Gastroenterol. Hepatol. 16 (2019) 35–56, https://doi.org/10.1038/s41575-018-0061-2.

[35] V. Buchta, Vaginal microbiome, Ceska Gynekol. 83 (2018) 371–379.

[36] J. Lyon, Even the eye has a microbiome, JAMA 318 (2017) 689, https://doi.org/10.1001/jama.2017.10599.

[37] A.L. Byrd, Y. Belkaid, J.A. Segre, The human skin microbiome, Nat. Rev. Microbiol. 16 (2018) 143–155, https://doi.org/10.1038/nrmicro.2017.157.

[38] Y. Belkaid, W. Timothy, Hand, role of the microbiota in immunity and inflammation, Cell 157 (2014) 121–141, https://doi.org/10.1016/j.cell.2014.03.011.

[39] H. Herwald, A. Egesten, On PAMPs and DAMPs, J. Innate Immun. 8 (2016) 427–428, https://doi.org/10.1159/000448437.

[40] E. Thursby, N. Juge, Introduction to the human gut microbiota, Biochem. J. 474 (2017) 1823–1836, https://doi.org/10.1042/BCJ20160510.

[41] S.M. Jandhyala, R. Talukdar, C. Subramanyam, H. Vuyyuru, M. Sasikala, D. N. Reddy, Role of the normal gut microbiota, World J. Gastroenterol. 21 (2015) 8787, https://doi.org/10.3748/wjg.v21.i29.8787.

[42] J. Kałużna-Czaplińska, P. Gątarek, M.S. Chartrand, M. Dadar, G. Bjørklund, Is there a relationship between intestinal microbiota, dietary compounds, and obesity? Trends Food Sci. Technol. 70 (2017) 105–113, https://doi.org/10.1016/j.tifs.2017.10.010.

[43] Y.P. Silva, A. Bernardi, R.L. Frozza, The role of short-chain fatty acids from gut microbiota in gut-brain communication, Front. Endocrinol. (Lausanne) 11 (2020) 25, https://doi.org/10.3389/fendo.2020.00025.

[44] D.P. Venegas, K. Marjorie, G. Landskron, M.J. González, R. Quera, G. Dijkstra, H. J. Harmsen, K.N. Faber, M.A. Hermoso, Short chain fatty acids (SCFAs)-mediated gut epithelial and immune regulation and its relevance for inflammatory bowel diseases, Front. Immunol. 10 (2019), https://doi.org/10.3389/fimmu.2019.00277.

[45] D.J. Morrison, T. Preston, Formation of short chain fatty acids by the gut microbiota and their impact on human metabolism, Gut Microbes 7 (2016) 189–200, https://doi.org/10.1080/19490976.2015.1134082.

[46] V. Sencio, A. Barthelemy, L.P. Tavares, M.G. Machado, D. Soulard, C. Cuinat, C. M. Queiroz-Junior, M.-L. Noordine, S. Salomé-Desnoulez, L. Deryuter, Gut Dysbiosis during influenza contributes to pulmonary pneumococcal superinfection through altered short-chain fatty acid production, Cell Rep. 30 (2020) 2934–2947, e2936, https://doi.org/10.1016/j.celrep.2020.02.013.

[47] R.P. Dickson, J.R. Erb-Downward, F.J. Martinez, G.B. Huffnagle, The microbiome and the respiratory tract, Annu. Rev. Physiol. 78 (2016) 481–504, https://doi.org/10.1146/annurev-physiol-021115-105238.

[48] S.V. Lynch, The lung microbiome and airway disease, Ann. Am. Thorac. Soc. 13 (2016) S462–S465, https://doi.org/10.1513/AnnalsATS.201605-356AW.

[49] G. Huffnagle, R. Dickson, N. Lukacs, The respiratory tract microbiome and lung inflammation: a two-way street, Mucosal Immunol. 10 (2017) 299–306, https://doi.org/10.1038/mi.2016.108.

[50] K.-j. Li, Z.-l. Chen, Y. Huang, R. Zhang, X.-q. Luan, T.-t. Lei, L. Chen, Dysbiosis of lower respiratory tract microbiome are associated with inflammation and microbial function variety, Respir. Res. 20 (2019) 1–16, https://doi.org/10.1186/s12931-019-1246-0.

[51] C.I. Vardavas, K. Nikitara, COVID-19 and smoking: a systematic review of the evidence, Tob. Induc. Dis. 18 (20) (2020) 1–4, https://doi.org/10.18332/tid/119324.

[52] N.D. Ubags, B.J. Marsland, Mechanistic insight into the function of the microbiome in lung diseases, Eur. Respir. J. 50 (2017) 1602467, https://doi.org/10.1183/13993003.02467-2016.

[53] B.J. Marsland, A. Trompette, E.S. Gollwitzer, The gut-lung Axis in respiratory disease, Ann. Am. Thorac. Soc. 12 (2015) S150–S156, https://doi.org/10.1513/AnnalsATS.201503-133AW.

[54] K.F. Budden, S.L. Gellatly, D.L. Wood, M.A. Cooper, M. Morrison, P. Hugenholtz, P.M. Hansbro, Emerging pathogenic links between microbiota and the gut-lung axis, Nat. Rev. Microbiol. 15 (2017) 55–63, https://doi.org/10.1038/nrmicro.2016.142.

[55] T. Ichinohe, I.K. Pang, Y. Kumamoto, D.R. Peaper, J.H. Ho, T.S. Murray, A. Iwasaki, Microbiota regulates immune defense against respiratory tract influenza A virus infection, Proc. Natl. Acad. Sci. U. S. A. 108 (2011) 5354–5359, https://doi.org/10.1073/pnas.1019378108.

[56] T.J. Schuijt, J.M. Lankelma, B.P. Scicluna, F.D.S.E. Melo, J.J. Roelofs, J.D. de Boer, A.J. Hoogendijk, R. de Beer, A. de Vos, C. Belzer, The gut microbiota plays a protective role in the host defence against pneumococcal pneumonia, Gut 65 (2016) 575–583, https://doi.org/10.1136/gutjnl-2015-309728.

[57] E.S. Gollwitzer, S. Saglani, A. Trompette, K. Yadava, R. Sherburn, K.D. McCoy, L. P. Nicod, C.M. Lloyd, B.J. Marsland, Lung microbiota promotes tolerance to allergens in neonates via PD-L1, Nat. Med. 20 (2014) 642, https://doi.org/10.1038/nm.3568.

[58] D. Zhang, S. Li, N. Wang, H.-Y. Tan, Z. Zhang, Y. Feng, The cross-talk between gut microbiota and lungs in common lung diseases, Front. Microbiol. 11 (2020) 301, https://doi.org/10.3389/fmicb.2020.00301.

[59] J. Wilks, T. Golovkina, Influence of microbiota on viral infections, PLoS Pathog. 8 (2012), https://doi.org/10.1371/journal.ppat.1002681.

[60] V. Monedero, M.C. Collado, J. Rodríguez-Díaz, Therapeutic opportunities in intestinal microbiota–virus interactions, Trends Biotechnol. 36 (2018) 645–648, https://doi.org/10.1016/j.tibtech.2017.12.009.

[61] R.R. Garg, S.M. Karst, Chapter 5.2 - interactions between enteric viruses and the gut microbiota, in: L. Svensson, U. Desselberger, H.B. Greenberg, M.K. Estes (Eds.), Viral Gastroenteritis, Academic Press, Boston, 2016, pp. 535–544.

[62] R. Vignesh, C.R. Swathirajan, Z.H. Tun, M.R. Rameshkumar, S.S. Solomon, P. Balakrishnan, Could perturbation of gut microbiota possibly exacerbate the severity of COVID-19 via cytokine storm? Front. Immunol. 11 (2020) 607734, https://doi.org/10.3389/fimmu.2020.607734.

[63] K. Venema, Foreword - the importance of a healthy microbiota in the era of COVID-19, Benefic. Microbes 12 (2021) 1–3, https://doi.org/10.3920/BM2021.x001.

[64] J. Luo, S. Liang, F. Jin, Gut microbiota in antiviral strategy from bats to humans: a missing link in COVID-19, Sci. China Life Sci. (2021), https://doi.org/10.1007/s11427-020-1847-7.

[65] P. Littlejohn, B.B. Finlay, When a pandemic and an epidemic collide: COVID-19, gut microbiota, and the double burden of malnutrition, BMC Med. 19 (2021) 31, https://doi.org/10.1186/s12916-021-01910-z.

[66] H.S. Kim, Do an altered gut microbiota and an associated leaky gut affect COVID-19 severity? mBio 12 (2021) https://doi.org/10.1128/mBio.03022-20 e03022–03020.

[67] K.C. Bradley, K. Finsterbusch, D. Schnepf, S. Crotta, M. Llorian, S. Davidson, S. Y. Fuchs, P. Staeheli, A. Wack, Microbiota-driven tonic interferon signals in lung stromal cells protect from influenza virus infection, Cell Rep. 28 (2019) 245–256, e244, https://doi.org/10.1016/j.celrep.2019.05.105.

[68] J. Wang, F. Li, R. Sun, X. Gao, H. Wei, L.-J. Li, Z. Tian, Bacterial colonization dampens influenza-mediated acute lung injury via induction of M2 alveolar macrophages, Nat. Commun. 4 (2013) 1–10, https://doi.org/10.1038/ncomms3106.

[69] P. Kanmani, P. Clua, M.G. Vizoso-Pinto, C. Rodriguez, S. Alvarez, V. Melnikov, H. Takahashi, H. Kitazawa, J. Villena, Respiratory commensal bacteria Corynebacterium pseudodiphtheriticum improves resistance of infant mice to respiratory syncytial virus and Streptococcus pneumoniae superinfection, Front. Microbiol. 8 (2017) 1613, https://doi.org/10.3389/fmicb.2017.01613.

[70] S. Wu, Z.-Y. Jiang, Y.-F. Sun, B. Yu, J. Chen, C.-Q. Dai, X.-L. Wu, X.-L. Tang, X.-Y. Chen, Microbiota regulates the TLR7 signaling pathway against respiratory tract influenza A virus infection, Curr. Microbiol. 67 (2013) 414–422, https://doi.org/10.1007/s00284-013-0380-z.

[71] A. Trompette, E.S. Gollwitzer, C. Pattaroni, I.C. Lopez-Mejia, E. Riva, J. Pernot, N. Ubags, L. Fajas, L.P. Nicod, B.J. Marsland, Dietary fiber confers protection against flu by shaping Ly6c− patrolling monocyte hematopoiesis and CD8+ T cell metabolism, Immunity 48 (2018) 992–1005, e1008, https://doi.org/10.1016/j.immuni.2018.04.022.

[72] M. Moriyama, T. Ichinohe, High ambient temperature dampens adaptive immune responses to influenza A virus infection, Proc. Natl. Acad. Sci. U. S. A. 116 (2019) 3118–3125, https://doi.org/10.1073/pnas.1815029116.

[73] R.D.S. Vieira, A. Castoldi, P.J. Basso, M.I. Hiyane, N.O.S. Câmara, R.R. Almeida, Butyrate attenuates lung inflammation by negatively modulating Th9 cells, Front. Immunol. 10 (2019) 67, https://doi.org/10.3389/fimmu.2019.00067.

[74] B.W. Haak, E.R. Littmann, J.-L. Chaubard, A.J. Pickard, E. Fontana, F. Adhi, Y. Gyaltshen, L. Ling, S.M. Morjaria, J.U. Peled, Impact of gut colonization with butyrate-producing microbiota on respiratory viral infection following allo-HCT, Blood 131 (2018) 2978–2986, https://doi.org/10.1182/blood-2018-01-828996.

[75] H. Kim, M. Jang, Y. Kim, J. Choi, J. Jeon, J. Kim, Y.I. Hwang, J.S. Kang, W.J. Lee, Red ginseng and vitamin C increase immune cell activity and decrease lung

inflammation induced by influenza A virus/H1N1 infection, J. Pharm. Pharmacol. 68 (2016) 406–420, https://doi.org/10.1111/jphp.12529.
[76] H. Hemilä, Vitamin C and SARS coronavirus, J. Antimicrob. Chemother. 52 (2003) 1049–1050, https://doi.org/10.1093/jac/dkh002.
[77] S. Hansdottir, M.M. Monick, N. Lovan, L. Powers, A. Gerke, G.W. Hunninghake, Vitamin D decreases respiratory syncytial virus induction of NF-κB–linked chemokines and cytokines in airway epithelium while maintaining the antiviral state, J. Immunol. 184 (2010) 965–974, https://doi.org/10.4049/jimmunol.0902840.
[78] D. Hughes, R. Norton, Vitamin D and respiratory health, Clin. Exp. Immunol. 158 (2009) 20–25, https://doi.org/10.1111/j.1365-2249.2009.04001.x.
[79] A.S. Prasad, Clinical, immunological, anti-inflammatory and antioxidant roles of zinc, Exp. Gerontol. 43 (2008) 370–377, https://doi.org/10.1016/j.exger.2007.10.013.
[80] S.A. Read, S. Obeid, C. Ahlenstiel, G. Ahlenstiel, The role of zinc in antiviral immunity, Adv. Nutr. 10 (2019) 696–710, https://doi.org/10.1093/advances/nmz013.
[81] Y. Li, Z. Lin, M. Guo, Y. Xia, M. Zhao, C. Wang, T. Xu, T. Chen, B. Zhu, Inhibitory activity of selenium nanoparticles functionalized with oseltamivir on H1N1 influenza virus, Int. J. Nanomedicine 12 (2017) 5733, https://doi.org/10.2147/IJN.S140939.
[82] A. Gasmi, T. Tippairote, P.K. Mujawdiya, M. Peana, A. Menzel, M. Dadar, A. Gasmi Benahmed, G. Bjorklund, Micronutrients as immunomodulatory tools for COVID-19 management, Clin. Immunol. 220 (2020) 108545, https://doi.org/10.1016/j.clim.2020.108545.
[83] H. Cory, S. Passarelli, J. Szeto, M. Tamez, J. Mattei, The role of polyphenols in human health and food systems: a mini-review, Front. Nutr. 5 (2018) 87, https://doi.org/10.3389/fnut.2018.00087.
[84] S.-C. Lin, C.-T. Ho, W.-H. Chuo, S. Li, T.T. Wang, C.-C. Lin, Effective inhibition of MERS-CoV infection by resveratrol, BMC Infect. Dis. 17 (2017) 144, https://doi.org/10.1186/s12879-017-2253-8.
[85] D. Davani-Davari, M. Negahdaripour, I. Karimzadeh, M. Seifan, M. Mohkam, S. J. Masoumi, A. Berenjian, Y. Ghasemi, Prebiotics: definition, types, sources, mechanisms, and clinical applications, Foods 8 (2019) 92, https://doi.org/10.3390/foods8030092.
[86] I. Visan, Fiber against flu, Nat. Immunol. 19 (2018) 647, https://doi.org/10.1038/s41590-018-0147-6.
[87] R. Luoto, O. Ruuskanen, M. Waris, M. Kalliomäki, S. Salminen, E. Isolauri, Prebiotic and probiotic supplementation prevents rhinovirus infections in preterm infants: a randomized, placebo-controlled trial, J. Allergy Clin. Immunol. 133 (2014) 405–413, https://doi.org/10.1016/j.jaci.2013.08.020.
[88] B. Langkamp-Henken, B.S. Bender, E.M. Gardner, K.A. Herrlinger-garcia, M. J. Kelley, D.M. Murasko, J.P. Schaller, J.K. Stechmiller, D.J. Thomas, S.M. Wood, Nutritional formula enhanced immune function and reduced days of symptoms of upper respiratory tract infection in seniors, J. Am. Geriatr. Soc. 52 (2004) 3–12, https://doi.org/10.1093/jac/dkh002.
[89] A.N. Olaimat, I. Aolymat, M. Al-Holy, M. Ayyash, M. Abu Ghoush, A.A. Al-Nabulsi, T. Osaili, V. Apostolopoulos, S.Q. Liu, N.P. Shah, The potential application of probiotics and prebiotics for the prevention and treatment of COVID-19, NPJ Sci. Food 4 (2020) 17, https://doi.org/10.1038/s41538-020-00078-9.
[90] H. Zhang, C. Yeh, Z. Jin, L. Ding, B.Y. Liu, L. Zhang, H.K. Dannelly, Prospective study of probiotic supplementation results in immune stimulation and improvement of upper respiratory infection rate, Synth. Syst. Biotechnol. 3 (2018) 113–120, https://doi.org/10.1016/j.synbio.2018.03.001.
[91] M. De Vrese, P. Winkler, P. Rautenberg, T. Harder, C. Noah, C. Laue, S. Ott, J. Hampe, S. Schreiber, K. Heller, Probiotic bacteria reduced duration and severity but not the incidence of common cold episodes in a double blind, randomized, controlled trial, Vaccine 24 (2006) 6670–6674, https://doi.org/10.1016/j.vaccine.2006.05.048.
[92] M.-K. Park, N. Vu, Y.-M. Kwon, Y.-T. Lee, S. Yoo, Y.-H. Cho, S.-M. Hong, H. S. Hwang, E.-J. Ko, Y.-J. Jung, Lactobacillus plantarum DK119 as a probiotic confers protection against influenza virus by modulating innate immunity, PLoS One 8 (2013), https://doi.org/10.1371/journal.pone.0075368.
[93] L.M. Rocha-Ramírez, B. Hernández-Ochoa, S. Gómez-Manzo, J. Marcial-Quino, N. Cárdenas-Rodríguez, S. Centeno-Leija, M. García-Garibay, Evaluation of immunomodulatory activities of the heat-killed probiotic strain lactobacillus casei IMAU60214 on macrophages in vitro, Microorganisms 8 (2020) 79, https://doi.org/10.3390/microorganisms8010079.
[94] E. Guillemard, F. Tondu, F. Lacoin, J. Schrezenmeir, Consumption of a fermented dairy product containing the probiotic lactobacillus casei DN-114 001 reduces the duration of respiratory infections in the elderly in a randomised controlled trial, Br. J. Nutr. 103 (2010) 58–68, https://doi.org/10.1017/S0007114509991395.
[95] J. Hu, L. Zhang, W. Lin, W. Tang, F.K.L. Chan, S.C. Ng, Review article: probiotics, prebiotics and dietary approaches during COVID-19 pandemic, Trends Food Sci. Technol. 108 (2021) 187–196, https://doi.org/10.1016/j.tifs.2020.12.009.
[96] A.E.C. Antunes, G. Vinderola, D. Xavier-Santos, K. Sivieri, Potential contribution of beneficial microbes to face the COVID-19 pandemic, Food Res. Int. 136 (2020) 109577, https://doi.org/10.1016/j.foodres.2020.109577.
[97] B.C. Taylor, F. Lejzerowicz, M. Poirel, J.P. Shaffer, L. Jiang, A. Aksenov, N. Litwin, G. Humphrey, C. Martino, S. Miller-Montgomery, P.C. Dorrestein, P. Veiga, S.J. Song, D. McDonald, M. Derrien, R. Knight, Consumption of fermented foods is associated with systematic differences in the gut microbiome and metabolome, mSystems 5 (2020), https://doi.org/10.1128/mSystems.00901-19 e00901–00919.
[98] M. Chan, H. Baxter, N. Larsen, L. Jespersen, E.I. Ekinci, K. Howell, Impact of botanical fermented foods on metabolic biomarkers and gut microbiota in adults with metabolic syndrome and type 2 diabetes: a systematic review protocol, BMJ Open 9 (2019), e029242, https://doi.org/10.1136/bmjopen-2019-029242.
[99] V. Bell, J. Ferrão, L. Pimentel, M. Pintado, T. Fernandes, One health, fermented foods, and gut microbiota, Foods (Basel, Switzerland) 7 (2018) 195, https://doi.org/10.3390/foods7120195.
[100] B.C. Bourrie, B.P. Willing, P.D. Cotter, The microbiota and health promoting characteristics of the fermented beverage kefir, Front. Microbiol. 7 (2016) 647, https://doi.org/10.3389/fmicb.2016.00647.
[101] A.M. Walsh, F. Crispie, K. Kilcawley, O. O'Sullivan, M.G. O'Sullivan, M. J. Claesson, P.D. Cotter, Microbial succession and flavor production in the fermented dairy beverage kefir, mSystems 1 (2016), https://doi.org/10.1128/mSystems.00052-16 e00052–00016.
[102] D. Rosa, M. Dias, Ł. Grześkowiak, S. Reis, L. Conceição, P. MDCG, Milk kefir: nutritional, microbiological and health benefits, Nutr. Res. Rev. 30 (2017) 82–96, https://doi.org/10.1017/S0954422416000275.
[103] G.R. de Andrade, I.V. Neves, V.D. Marques, M.M. Borges, T.A.M. Broring, M. T. dos Anjos, R.M. Astray, M. de Oliveira, Influence of a Kefir-derived antimicrobial fraction on Zika virus cytopathic effects and lymphocyte proliferation, J. Virol. Curr. Res. 2 (2017) 555584, https://doi.org/10.19080/004JOJIV.2017.02.555584.
[104] M. Ghoneum, N. Felo, S. Agrawal, A. Agrawal, A novel kefir product (PFT) activates dendritic cells to induce CD4+ T and CD8+ T cell responses in vitro, Int. J. Immunopathol. Pharmacol. 28 (2015) 488–496, https://doi.org/10.1177/0394632015599447.
[105] A. Caminero, M. Meisel, B. Jabri, E.F. Verdu, Mechanisms by which gut microorganisms influence food sensitivities, Nat. Rev. Gastroenterol. Hepatol. 16 (2019) 7–18, https://doi.org/10.1038/s41575-018-0064-z.
[106] R. Bouziat, R. Hinterleitner, J.J. Brown, J.E. Stencel-Baerenwald, M. Ikizler, T. Mayassi, M. Meisel, S.M. Kim, V. Discepolo, A.J. Pruijssers, J.D. Ernest, J. A. Iskarpatyoti, L.M. Costes, I. Lawrence, B.A. Palanski, M. Varma, M.A. Zurenski, S. Khomandiak, N. McAllister, P. Aravamudhan, K.W. Boehme, F. Hu, J. N. Samsom, H.C. Reinecker, S.S. Kupfer, S. Guandalini, C.E. Semrad, V. Abadie, C. Khosla, L.B. Barreiro, R.J. Xavier, A. Ng, T.S. Dermody, B. Jabri, Reovirus infection triggers inflammatory responses to dietary antigens and development of celiac disease, Science 356 (2017) 44–50, https://doi.org/10.1126/science.aah5298.
[107] J.A. Tye-Din, H.J. Galipeau, D. Agardh, Celiac disease: a review of current concepts in pathogenesis, prevention, and novel therapies, Front. Pediatr. 6 (2018) 350, https://doi.org/10.3389/fped.2018.00350.
[108] J.J. Brown, B. Jabri, T.S. Dermody, A viral trigger for celiac disease, PLoS Pathog. 14 (2018), e1007181, https://doi.org/10.1371/journal.ppat.1007181.
[109] L. Plot, H. Amital, Infectious associations of celiac disease, Autoimmun. Rev. 8 (2009) 316–319, https://doi.org/10.1016/j.autrev.2008.10.001.
[110] L.C. Stene, M.C. Honeyman, E.J. Hoffenberg, J.E. Haas, R.J. Sokol, L. Emery, I. Taki, J.M. Norris, H.A. Erlich, G.S. Eisenbarth, Rotavirus infection frequency and risk of celiac disease autoimmunity in early childhood: a longitudinal study, Am. J. Gastroenterol. 101 (2006) 2333–2340, https://doi.org/10.1111/j.1572-0241.2006.00741.x.
[111] M.A. Beck, Selenium as an antiviral agent, in: D.L. Hatfield (Ed.), Selenium: Its Molecular Biology and Role in Human Health, Springer US, Boston, MA, 2001, pp. 235–245.