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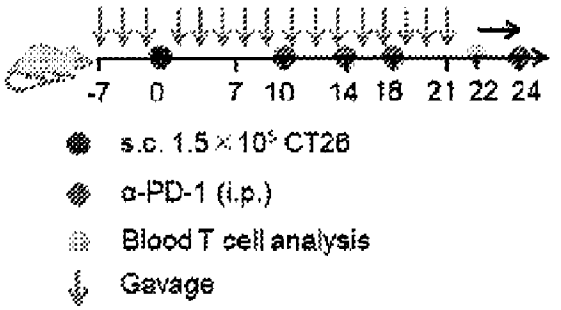
(71) Demandeur/Applicant:
THE REGENTS OF THE UNIVERSITY OF MICHIGAN, US

(72) Inventeurs/Inventors:

(54) Titre : COMPOSITIONS ET METHODES POUR ACCROITRE L'EFFICACITE D'IMMUNOTHERAPIES ET DE VACCINS

(54) Title: COMPOSITIONS AND METHODS FOR INCREASING THE EFFICACY OF IMMUNOTHERAPIES AND VACCINES

FIG. 1A



(57) Abrégé/Abstract:
This invention relates generally to compositions and methods for increasing the efficacy of immunotherapies and vaccines. In particular, the present invention relates to elevating the richness and diversity of a subject's gut microbiome through administration of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) with an immunotherapy or vaccine. Such compositions and methods are useful for treating cancer, infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity.

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(72) Inventeurs(suite)/Inventors(continued): MOON, JAMES J., US; HAN, KAI, US; XU, JIN, US; HUANG, XUEHUI, US
(74) Agent: ROBIC

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Abstract:

This invention relates generally to compositions and methods for increasing the efficacy of immunotherapies and vaccines. In particular, the present invention relates to elevating the richness and diversity of a subject's gut microbiome through administration of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) with an immunotherapy or vaccine. Such compositions and methods are useful for treating cancer, infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity.

COMPOSITIONS AND METHODS FOR INCREASING THE EFFICACY OF IMMUNOTHERAPIES AND VACCINES

FIELD OF THE INVENTION

This invention relates generally to compositions and methods for increasing the efficacy of immunotherapies and vaccines. In particular, the present invention relates to elevating the richness and diversity of a subject's gut microbiome through administration of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) with an immunotherapy or vaccine. Such compositions and methods are useful for treating cancer, infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity.

BACKGROUND OF THE INVENTION

Cancer immunotherapy is revolutionizing the field of oncology. However, immune checkpoint therapies work only in a subset of patients (typically 10-30%). There is a great need to improve the efficacy of immune checkpoint blockade. In addition, there has been extensive research interest to improve vaccines.

The present invention addresses these needs.

SUMMARY

Experiments conducted during the course of developing embodiments for the present invention identified new compounds from FDA approved drugs or diet supplements (e.g., prebiotic agents) that can be ingested to improve the efficacy of immune checkpoint therapies. It was shown that oral formulations of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) can alter the gut microbiome so that beneficial bacteria increase in frequency and synergize with immune checkpoint blockers given by the systemic injection. Indeed, it was shown that concurrent administration of prebiotic agents (e.g., inulin) with an immunotherapy (e.g., α-PD-1 therapy) resulted in stronger anti-tumor efficacy, stronger immune response (e.g. AH1-specific $CD8^+$ T cells frequency among PBMCs), inhibition of tumor growth, enhanced intratumoral infiltration of T cells, higher IFN-γ expression in splenoic $CD8^+$ T cells, and

increased abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the subject's gut microbiome.

Accordingly, the present invention relates generally to compositions and methods for increasing the efficacy of immunotherapies and vaccines. In particular, the present invention relates to elevating the richness and diversity of a subject's gut microbiome through administration of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) with an immunotherapy or vaccine. Such compositions and methods are useful for treating cancer, infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity.

In certain embodiments, the present invention provides a method for increasing the efficacy of a cancer immunotherapy or vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) through administration of 1) a cancer immunotherapy or vaccine to a subject, and 2) an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides a method for inhibiting the ability of a cancer cell to induce immune dysfunction, comprising administration of 1) a cancer immunotherapy or cancer vaccine to a subject, and 2) an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides a method for treating or preventing cancer in a subject, comprising administering to the subject 1) a cancer immunotherapy or a cancer vaccine to a subject, and 2) an agent capable of elevating the richness and diversity of the subject's gut microbiome.

Such methods are not limited to particular manner of administering 1) the cancer immunotherapy or vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) to a subject, and 2) the agent capable of elevating the richness and diversity of the subject's gut microbiome. In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy. In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy. In some embodiments, administration of the agent capable of

elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy. In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy.

Such methods are not limited to a particular type of subject. In some embodiments, the subject is a human subject.

Such methods are not limited to particular type or kind of agent capable of elevating the richness and diversity of a subject's gut microbiome. In some embodiments, the agent is a fiber containing prebiotic agent. In some embodiments, the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

In some embodiments, the agent is inulin. Inulin is a polysaccharide belonging to the fructan group. It consists of a beta-2-1-linked chain of fructose molecules, this chain having at its end an alpha-D-glucose unit at the reducing end. Inulin occurs in economically recoverable amounts in various plants such as, for example, chicory roots and dahlia tubers. In addition, inulin has been found for example in Jerusalem artichokes and artichokes. The average chain lengths of the various inulins and their physico-chemical properties differ from plant species to plant species. In some embodiments, the agent is a gel-based inulin formulation. In some embodiments, the agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the agent is a gel-based inulin formulation having an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33) (see, Example XIII showing surprising anti-tumor efficacy with a gel-based inulin formulation having an average degree of polymerization at approximately 28).

In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber. In some embodiments, the agent is melatonin.

Such methods are not limited to a particular type or kind of caner immunotherapy. In some embodiments, the cancer immunotherapy comprises one or more immune checkpoint inhibitor (ICI) inhibitors. In some embodiments, the one or more ICI inhibitors are capable of binding to, blocking, and/or inhibit the activity of one or more of CTLA-4, PDL1, PDL2, PD1, BTLA, HVEM, TIM3, GAL9, LAG3, VISTA, KIR, 2B4, CD160 and CGEN-15049. In some embodiments, the one or more ICI inhibitors are selected from Tremelimumab (CTLA-4 blocking antibody), anti-OX40, PD-L1 monoclonal Antibody (Anti-B7-H1; MEDI4736), MK-3475 (PD-1 blocker), Nivolumab (anti-PD1 antibody), CT-011 (anti-PD1 antibody), BY55 monoclonal antibody, AMP224 (anti-PDL1 antibody), BMS-936559 (anti-PDL1 antibody), MPLDL3280A (anti-PDL1 antibody), MSB0010718C (anti-PDL1 antibody) and Yervoy/ipilimumab (anti-CTLA-4 checkpoint inhibitor).

Such methods are not limited to particular type or kind of cancer. In some embodiments, the cancer is any type of cancer responsive to cancer immunotherapy or cancer vaccine treatment. In some embodiments, the cancer is one or more of breast, ovarian, prostate, lung, kidney, gastric, colon, testicular, head and neck, pancreas, brain, melanoma, and other tumors of tissue organs and hematological tumors, such as lymphomas and leukemias, including acute myelogenous leukemia, chronic myelogenous leukemia, chronic lymphocytic leukemia, T cell lymphocytic leukemia, and B cell lymphomas.

In some embodiments, such methods further comprise administering to the subject one or more chemotherapeutic agents selected from the group consisting of an alkylating agent, an antimetabolite, an anthracycline, an antitumor antibiotic, a monoclonal antibody, a platinum agent, a plant alkaloid, a topoisomerase inhibitor, a vinca alkaloid, a taxane, and an epipodophyllotoxin.

Such methods are not limited to a particular manner of administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome. In some embodiments, the agent is administered orally. In some embodiments, the agent is administered by oral gavage.

In some embodiments for such methods, the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

In some embodiments for such methods, administration of 1) a cancer immunotherapy or vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome, results in one or more of an increased anti-tumor efficacy of the cancer immunotherapy or vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens), a stronger immune response (e.g., increased anti-tumor T cell frequency among PBMCs), and enhanced inhibition of tumor growth.

In certain embodiments, the present invention provides a composition comprising a gel-based inulin formulation. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33).

In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a resistant potato starch, guar gum, bean gum, gelatin,glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In certain embodiments, the present invention provides methods for treating or preventing a condition characterized with dysregulated gut microbiome activity, comprising administering to the subject an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In some embodiments, the subject is a human subject.

In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent. In some embodiments, the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin. In some embodiments, the fiber containing prebiotic agent is a gel-based inulin formulation. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33). In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-

oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber. In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

In some embodiments, the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

In some embodiments, the condition characterized with dysregulated gut microbiome activity is an autoimmune disease, a neurological disorder, diabetes, and/or obesity.

In some embodiments, the condition characterized with dysregulated gut microbiome activity is selected from rheumatoid arthritis, multiple sclerosis diabetes (e.g., type 1 diabetes mellitus), autoimmune diseases of the thyroid (e.g., Hashimoto's thyroiditis, Graves' disease), thyroid-associated ophthalmopathy and dermopathy, hypoparathyroidism, Addison's disease, premature ovarian failure, autoimmune hypophysitis, pituitary autoimmune disease, immunogastritis, pernicious angemis, celiac disease, vitiligo, myasthenia gravis, pemphigus vulgaris and variants, bullous pemphigoid, dermatitis herpetiformis Duhring, epidermolysis bullosa acquisita, systemic sclerosis, mixed connective tissue disease, Sjogren's syndrome, systemic lupus erythematosus, Goodpasture's syndrome, rheumatic heart disease, autoimmune polyglandular syndrome type 1, Aicardi–Goutières syndrome, Acute pancreatitis Age-dependent macular degeneration, Alcoholic liver disease, Liver fibrosis, Metastasis, Myocardial infarction, Nonalcoholic steatohepatitis (NASH), Parkinson's disease, Polyarthritis/fetal and neonatal anemia, Sepsis, and inflammatory bowel disease.

In some embodiments, the method further comprises administering to the subject one or more of the following additional therapeutic agents: disease-modifying antirheumatic drugs (e.g., leflunomide, methotrexate, sulfasalazine, hydroxychloroquine), biologic agents (e.g., rituximab, infliximab, etanercept, adalimumab, golimumab), nonsteroidal anti-inflammatory drugs (e.g., ibuprofen, celecoxib, ketoprofen, naproxen, piroxicam, diclofenac), analgesics (e.g.,

acetaminophen, tramadol), immunomodulators (e.g., anakinra, abatacept), glucocorticoids (e.g., prednisone, methylprednisone), TNF-α inhibitors (e.g., adalimumab, certolizumab pegol, etanercept, golimumab, infliximab), IL-1 inhibitors, and metalloprotease inhibitors. In some embodiments, the therapeutic agents include, but are not limited to, infliximab, adalimumab, etanercept, parenteral gold or oral gold.

In certain embodiments, the present invention provides a method for increasing the efficacy of a vaccine through administration of 1) a vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the vaccine.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine; or administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine. In some embodiments, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine.

In some embodiments, the vaccine is a vaccine for treating cancer, and/or a vaccine for treating and/or protecting from infectious pathogens.

In some embodiments, the subject is a human subject.

In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent. In some embodiments, the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin. In some embodiments, the fiber containing prebiotic agent is a gel-based inulin formulation. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33). In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a

polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber. In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

In some embodiments, the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

The present invention also provides kits comprising an agent capable of elevating the richness and diversity of the subject's gut microbiome (e.g., a fiber based pre-biotic), and one or more of a vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens), and a cancer immunotherapy (e.g., an ICI inhibitor). The kits may optionally contain other therapeutic agents.

In certain embodiments, the present invention provides compositions comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) bacteria.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the prebiotic compound is gel-based. In some embodiments, the prebiotic compound is gel-based inulin.

In some embodiments, the bacteria is E. coli. In some embodiments, the bacteria is able to alter the gut microbiome of a subject upon administration to the subject.

In some embodiments, the composition is configured for oral administration to a subject.

In certain embodiments, the present invention provides methods for colonic delivery of bacteria to a subject, comprising administering to a subject such a comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) bacteria (e.g., gel-based inulin).

In certain embodiments, the present invention provides compositions comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) one or more probiotic cells. In certain embodiments, the present invention provides methods for increasing the growth of probiotic organisms in the digestive system of a subject, comprising administering to the subject (e.g., mammalian subject; human subject) such a composition.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the prebiotic compound is gel-based. In some embodiments, the prebiotic compound is gel-based inulin.

In some embodiments, the one or more probiotic cells are able to alter the gut microbiome of a subject upon administration to the subject.

In some embodiments, the composition is configured for oral administration to a subject.

In some embodiments, the one or more probiotic cells comprise beneficial bacteria. In some embodiments, the beneficial bacteria comprises one or more of: Saccharomyces cereviseae, Bacillus coagulans, Bacillus licheniformis, Bacillus subtilis, Bifidobacterium angulatum, Bifidobacterium animalis, Bifidobacterium bifidum, Bifidobacterium breve, Bifidobacterium infantis, Bifidobacterium lactis, Bifidobacterium longum, Enterococcus faecium, Enterococcus faecalis, Lactobacillus acidophilus, Lactobacillus amylovorus, Lactobacillus alimentarius, Lactobacillus bulgaricus, Lactobacillus casei subsp. casei, Lactobacillus casei Shirota, Lactobacillus curvatus, Lactobacillus delbrueckii subsp. lactis, Lactobacillus fermentum, Lactobacillus farciminus, Lactobacillus gasseri, Lactobacillus helveticus, Lactobacillus johnsonii, Lactobacillus lacti, Lactobacillus paracasei, Lactobacillus pentosaceus, Lactobacillus plantarum, Lactobacillus reuteri, Lactobacillus rhamnosus (Lactobacillus GG), Lactobacillus sake, Lactobacillus salivarius, Lactococcus lactis, Lactobacillus thermotolerans, Lactobacillus mucosae, Micrococcus varians, Pediococcus acidilactici, Pediococcus pentosaceus, Pediococcus acidilactici, Pediococcus halophilus, Streptococcus faecalis, Streptococcus thermophilus, Staphylococcus carnosus, and Staphylococcus xylosus.

In some embodiments, the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

In certain embodiments, the present invention provides a composition comprising a gel-based prebiotic formulation. In some embodiments, the composition is formulated for oral ingestion. In some embodiments, the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the gel-based prebiotic formulation is associated with one or more probiotic organisms. In some embodiments, the one or more probiotic organisms are chosen from Lactobacillus species and Bifidobacterium species. In some embodiments, the gel-based prebiotic formulation is associated with one or more bacteriophages specific to Bordetella, Borrelia, Brucella, Campylobacter, Chlamydia and Chlamydophila, Clostridium, Corynebacterium, Enterococcus, Escherichia, Francisella, Haemophilus, Helicobacter, Legionella, Leptospira, Listeria, Mycobacterium, Mycoplasma, Neisseria, Pseudomonas, Rickettsia, Salmonella, Shigella, Staphylococcus, Streptococcus, Treponema, Vibrio and Yersinia. In some embodiments, the one or more probiotic organisms are selected from L. acidophilus, L. amylovorus, L. brevis, L. casei, L. casei subsp. rhamnosus (Lactobacillus GG), L. caucasicus, L. crispatus, L. delbrueckii subsp. bulgaricus (L. bulgaricus), L. fermentum (L. fermenti), L. gasseri, L. helveticus, L. johnsonii, L. lactis, L. leichmannii, L. paracasei, L. plantarum, L. reuteri, or L. rhamnosus.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A-F: In vivo screening of the candidate materials to prophylactically improve the anti-tumor efficacy of α-PD-1. (A) Mice were prophylactically gavaged various samples on day -7 for three times. Then 1.5×10^5 CT26 cells were inoculated in BALB/c mice subcutaneously

(s.c.) on day 0. Mice were gavaged three times again in the first week post tumor inoculation and 5 times per week from day 7. α-PD-1 was i.p. injected on days 10, 14, 18 and 24 at 100 μg/dose. (B) Individual tumor growth curves and (C) average tumor growth curves for mice gavaged with various compounds. (D) Survival rate curves of various groups. (E) The average frequency of AH1-specific $CD8^+$ T cells in peripheral blood on day 22. (F) The representative scatter plots were measured via flow cytometry. Data represent mean ± SEM. $^*p<0.05$, $^{**}p<0.01$, analyzed by two-way ANOVA (B), or t-test (E), log-rank (Mantel-Cox) test (D).

FIG. 2A-G: In vivo screening of the candidate materials to improve the anti-tumor efficacy of α-PD-1. (A) 1.5×10^5 CT26 cells were inoculated in BALB/c mice subcutaneously (sc) on day 0. Mice were gavaged from day 7 (5 times per week). On days 11, 15, 19 and 23, α-PD-1 was injected intraperitoneally (ip) at 100 μg per dose. (B) The average tumor growth curves for mice gavaged with various compounds. Data represent mean ± SEM. (C) Individual tumor growth curves and (D) survival rate curves of various groups. On day 18 and 24, peripheral blood was collected. The average frequency of AH1-specific $CD8^+$ T cells at (E) day 18, (F) day 24 and (G) the representative scatter plots were measured via flow cytometry. Data represent mean ± SD. All the data are from 2-3 independent experiments; n = 10 (B, C, D), n = 7-10 (E, F) $^*p<0.05$, $^{**}p<0.01$, analysed by two-way ANOVA (B), one-way ANOVA (E, F) or log-rank (Mantel-Cox) test.

FIG. 3A-H: In vivo assessment of the dosage effect of melatonin and inulin combined with α-PD-1. 1.5×10^5 CT26 cells were s.c. inoculated in BALB/c mice on day 0. Mice were gavaged from day 7 (5 times per week). On days 11, 15, 19 and 23, α-PD-1 was i.p. injected at 100 μg per dose. The average tumor growth curves for mice gavaged with (A) melatonin and (B) inulin at different dosages. The average frequency of AH1-specific $CD8^+$ T cells on day 18 after treatment with (C) melatonin and (D) inulin at different dosages. On day 24, the percentage of $CD45^+CD8^+$ T cells in whole tumor tissue after treatment with (E) melatonin and (F) inulin at different dosages. On day 24, the percentage of $CD45^+CD4^+$ T cells in all cells after treatment with (G) melatonin and (H) inulin at different dosages. Data represent mean ± SEM (n=5). $^*p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$, analyzed by two-way ANOVA (A, B) or two tails, unpaired t-test (D), one-way ANOVA (E, F, G, H).

FIG. 4A-H: Responses of the diversity, richness, and structure of the gut microbiota. 1.5×10^5 CT26 cells were inoculated in BALB/c mice subcutaneously and gavaged from day 7 (5 times per week). α-PD-1 (100 μg per dose) was ip injected on days 11, 15, 19 and 23. The fecal

pellets were collected on day 21 for 16s RNA analysis. (A) OTU number, (B) inverse Simposon diversity and (C) nonmetric multidimensional scaling (NMDS) score plot (based on Bray-Curtis) of gut microbiota in various groups. (D) Relative abundances of the gut microbiota at family level and (I) genus level. (F) The relative abundances of lactobacillus, akkermansia, roseburia and Ruminococcus_1 in various groups. (G) The relationship of between the tumor sizes and the relative abundances of lactobacillus, akkermansia, roseburia and Ruminococcus_1. (H) The heatmap of SCFAs (lactate, propionate and butyrate) levels of various groups in fecal pellets. Data represent mean ± SEM. $^{*}p<0.05$, $^{**}p<0.01$, $^{****}p<0.0001$, analysed by one-way ANOVA (A, B, F).

FIG. 5A-C: Gut microbiota analysis. 1.5×10^5 CT26 cells were inoculated in BALB/c mice subcutaneously and gavaged from day 7 (5 times per week). α-PD-1 (100 μg per dose) was ip injected on days 11, 15, 19 and 23. The fecal pellets were collected on day 21 for 16s RNA analysis. (A) OTU number, (B) NMDS score plot of gut microbiota in various groups. (C) Relative abundances of the gut microbiota at genus level. Data represent mean ± SEM.

FIG. 6A-I: Inulin gel further enhance the therapeutic efficacy of α-PD-1. (A) Image of inulin gel and the SEM image. (B) The average tumor growth curves and individual tumor growth curve for mice gavaged with inulin or inulin gel (60mg/dosage). 1.5×10^5 CT26 cells were inoculated in BALB/c mice subcutaneously. Gavage started from day 7 (5 times per week) and 100 μg of α-PD-1 was ip injected on days 11, 15, 19, 23 and 27. (C) The survival rate curves of various groups. (D) Tumor-eradicated mice in inulin gel combined with α-PD-1 group was injected with 1.5×10^5 CT26 cells and tumor size was monitored. PBS was used as a control. (E) The average frequency and representative scatter plots of AH1-specific $CD8^+$ T cells at day 23. (F) Tumor microenvironment analysis: the percentage of $CD45^+CD8^+$ T cells in whole tumor; AH1-tetramer positive in $DAPI^-CD45^+CD8^+$ T cells; matured DC cells ($CD11c^+CD86^+$ T cells in $DAPI^-CD45^+$ cells) and $CD45^+CD4^+$ T cells in whole tumor. (G, H) On day 23, spleen were obtained for IFN-γ ELISPOT test. (I) CT26 tumor-bearing BALB/c mice were injected with 200 μg of antibodies targeted against $CD8^+$ T cells (αCD8), $CD4^+$ T cells (αCD4) and NK cells (αAsialo GM1) on day 8, 11 and 16. α-PD-1 injection as well as sample gavage employed the same regime mentioned above. Shown are the average and individual tumor growth curves for tumor-bearing mice. IgG antibody was used as a control group. Data represent mean ± SEM. All the data are from 2-3 independent experiments; n = 10 (B, C), n = 5 (D, I), n = 10-15 (E), n = 4-7

(G, F), *p<0.05, **p<0.01, ***p<0.001, analysed by one-way ANOVA (E, F), two-way ANOVA (B, I), or log-rank (Mantel-Cox) test (C).

FIG. 7A-B: (A) Inulin gel was injected through syringe (1 mL) into DI water. Image of inulin gel shows the stability in water. (B) The stability of inulin gel when inulin gel was incubated under a strong acid environment (pH 2) for 2 and 24 h, respectively. DNS reagent was used at probe and the absorbance was measured to verify the content of reduced sugar. Inulin gel without acidic treatment was used as a standard and inulin was used as a control.

FIG. 8A-I: Inulin gel exhibited prolonged colon retention. (A) IVIS imaging of intestinal retention of inulin gel at different time point (white box indicated colon region) and (B) the corresponding mean fluorescence intensity in colon region. Inulin was label with FITC. (C) The fluorescence intensity of inulin-FITC in fecal pellet at different time points post gavage. (D) The inulin content in colon digesta determined by commercial inulin kit. Arrow indicated the area under curve (AUC) value of inulin. The fecal pellets were collected on day 21 and the 16s RNA analysis was performed. (E) OTU number, inverse Simposon diversity and (F) NMDS score plot (based on Bray-Curtis) of gut microbiota in various groups. (G) Relative abundances of the gut microbiota genus level and (H). (I) Naïve mice were fed with broad-spectrum antibiotics (ampicillin + colistin + streptomycin) for one week. Then 1.5× 105 CT26 cells were inoculated in BALB/c mice subcutaneously, mice were fed with normal drinking water for 5 days, followed with continuous broad-spectrum antibiotics treatment. α-PD-1 injection as well as sample gavage employed the same regime mentioned above. Shown are the average tumor growth curves. Data represent mean ± SEM. Data are from 2-3 independent experiments (A-D); *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001, analysed by one-way ANOVA (C, E, H) or two-way ANOVA (I)

FIG. 9A-E: (A) MC38 tumor model was established on C57BL/6 mice and received α-PD-1 injection and sample gavage. (B) On day 20, PBMCs were obtained for IFN-γ ELISPOT assay. (D) The survival rate curves and (E) average and individual tumor growth curves of various groups. Data represent mean ± SEM. *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001, analyzed by one-way ANOVA (A, B, G).

FIG. 10A-C: Biosafety study of inulin gel combined with α-PD-1. (A) The complete blood count panel including eosinophils, lymphocytes, monocytes, platelet count, red blood cell count, RDW, hemoglobin, MCH and mean platelet volume. (B) The biochemistry panel including ALP, ALT, AST, BUN, CPK, total protein, cholesterol and glucose. (C) H&E staining

of heart, liver, spleen, lung, kidneys after treatment of inulin gel combined with α-PD-1 on day 29.

FIG. 11: E. coli growth curve and GFP expression. E. coli was culture in 250 mL Erlenmeyer flask. Culture was sampled at different intervals. OD_{600} and relative fluorescence intensity were measured.

FIG. 12: Cell Viability determined by fluorescence Intensity after 24hrs incubation in PBS and encapsulation in inulin gel respectively.

FIG. 13A-E: Validation of the anti-tumor efficacy of inulin gel plus α-PD-1 combo-therapy in other models. (A) Treatment regimen of CT26 tumor-bearing BALB/c mice from Taconic Farm or Charles River. Shown are the tumor growth among BALB/c mice from (B) Taconic Farm or (C) Charles River. D-E) C57BL/6 mice bearing (D) MC-38 colon carcinoma and (E) B16F10 melanoma were treated as shown (inulin: 60 mg/dose), and tumor growth was monitored.

FIG. 14: ^{1}H NMR spectra of various inulin samples.

FIG. 15: MALDI-TOF mass spectrum of inulin samples.

FIG. 16: Impact of inulin concentration and average DP on inulin gel formation. Various inulin gel formulations were formed using inulin of different DPs. Inulin with the average DP of 7, 10, 23, 26, and 28 were dissolved in water in various concentrations. After inducing gelation via heating and cooling, inulin gel formation was observed with high inulin concentration and high DPs.

FIG. 17: Gel rheological properties of inulin gel formulations formed with varying average DP were measured by frequency sweeps. G' represents elastic modulus, G'' represents viscous modulus. Inulin gel sample #1 had the average DP≈7. Inulin gel sample #3 had the average DP≈23. Inulin gel sample #5 had the average DP≈28.

FIG. 18: Naïve mice were orally gavaged with inulin gel with various average DPs, and inulin content in fecal samples were determined over time. Data shows mean ± SEM.

FIG. 19: Balb/c mice bearing s.c. flank CT26 tumors were treated with oral gavage of inulin gels formed with various DPs (60 mg/dose) plus intraperitoneal administration of α-PD-1 (100 ug/dose). Animals were monitored for tumor growth. Data shows mean ± SEM.

FIG. 20: Balb/c mice bearing s.c. flank CT26 tumors were treated with oral gavage of inulin gels formed with various DPs (60 mg/dose) plus intraperitoneal administration of α-PD-1 (100 ug/dose). Animals were monitored for body weight changes. Data shows mean ± SEM.

FIG. 21: Concentration and temperature dependency of inulin gel formation. Inulin with DP 23 was mixed with water, giving desired concentrations of 15, 20, 25, and 30% w/v. Mixtures were heated to 40, 50, 60, 70 °C respectively for 5 minutes, followed by cooling. Gel formation was examined.

FIG. 22: Food grade potato starch was pre-hydrated at concentrations of 0.1, 0.5, 2.5, and 5% w/v in water, followed by gentle stirring at 70 °C. After cooling, gel formation was examined.

FIG. 23: The gelation process for new fiber gels. #1 inulin gel, #2, inulin gel containing resistant potato starch, #3 inulin gel containing guar gum, #4 inulin gel containing pectin, and #5 inulin gel containing bean gum. The ingredients were first mixed in water (top panel), heated at 70°C for 5 minutes (middle panel), followed by cooling at room temperature overnight, leading to the formation of fiber gels (bottom panel).

FIG. 24: Inulin gel was formed after adding various amounts of natural fibers or excipients. The values shown are the maximum amount of each ingredient that could be added to 23% w/w inulin gel without disrupting the gel formation.

FIG. 25: Gel rheological properties of different fiber gel formulations. Viscoelasticity measured by frequency sweeps (Left) and flow curves for the viscosity (Right).

DEFINITIONS

For the purposes of promoting an understanding of the principles of the present disclosure, reference will now be made to preferred embodiments and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended, such alteration and further modifications of the disclosure as illustrated herein, being contemplated as would normally occur to one skilled in the art to which the disclosure relates.

Articles “a” and “an” are used herein to refer to one or to more than one (i.e. at least one) of the grammatical object of the article. By way of example, “an element” means at least one element and can include more than one element.

“About” is used to provide flexibility to a numerical range endpoint by providing that a given value may be “slightly above” or “slightly below” the endpoint without affecting the desired result.

The use herein of the terms "including," "comprising," or "having," and variations thereof, is meant to encompass the elements listed thereafter and equivalents thereof as well as

additional elements. Embodiments recited as "including," "comprising/* or "having" certain elements are also contemplated as "consisting essentially of and "consisting of those certain elements.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise-Indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. For example, if a concentration range is stated as 1% to 50%, it is intended that values such as 2% to 40%, 10% to 30%, or 1% to 3%, etc., are expressly enumerated in this specification. These are only examples of what is specifically intended, and all possible combinations of numerical values between and including the lowest value and the highest value enumerated are to be considered to be expressly stated in this disclosure.

The transitional term "comprising," which is synonymous with "including," "containing," or "characterized by," is inclusive or open-ended and does not exclude additional, unrecited elements or method steps. By contrast, the transitional phrase "consisting of excludes any element, step, or ingredient not specified in the claim. The transitional phrase "consisting essentially of limits the scope of a claim to the specified materials or steps "and those that do not materially affect the basic and novel characteristic(s)" of the claimed invention.

As used herein, the terms "immune checkpoint inhibitors" (ICIs), "checkpoint inhibitors," and the like refer to compounds that inhibit the activity of control mechanisms of the immune system. Immune system checkpoints, or immune checkpoints, are inhibitory pathways in the immune system that generally act to maintain self-tolerance or modulate the duration and amplitude of physiological immune responses to minimize collateral tissue damage. ICIs can inhibit an immune system checkpoint by inhibiting the activity of a protein in the pathway. ICI proteins include, but are not limited to, CD80, CD28, CD86, cytotoxic T-lymphocyte-associated protein 4 (CTLA-4), PD-L1, PD-L2, PD-1, Ligand of Inducible T-cell costimulator (L-ICOS), Inducible T-cell co-stimulator (ICOS), CD276, and V-set domain containing T cell activation inhibitor 1 (VTCN1). As such, ICI inhibitors include antagonists of, for example, ICIs such as CTLA4, PD1, or PD-L1. For example, antibodies that bind to CTLA4, PD-1, or PD-L1 and

antagonize their function are ICI inhibitors. Moreover, any molecule (e.g., peptide, nucleic acid, small molecule, etc.) that inhibits the inhibitory function of an ICI is an ICI inhibitor.

A "subject" can be a vertebrate, a mammal, or a human. Mammals include, but are not limited to, farm animals, sport animals, pets, primates, mice and rats. In one aspect, a subject is a human.

Unless otherwise defined, all technical terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs.

DETAILED DESCRIPTION

Emerging research suggest that the gut microbiome has a crucial role in modulating immune responses. Indeed, there have been efforts to use fecal microbiomta transfer or probiotics to boost the effiacy of immune checkpoint blockade.

Immune checkpoint therapy, which targets regulatory pathways in T cells to enhance antitumor immune responses, has led to important clinical advances and provides a new weapon against cancer. This therapy has elicited durable clinical responses and, in a fraction of patients, long-term remissions where patients exhibit no clinical signs of cancer for many years.

A number of these immune checkpoints, such as CTLA-4 (cytotoxic T-lymphocyte antigen 4), and PD-1 (programmed death 1) are known to prevent T cells from attacking tumor cells. Therapies comprising antibodies that target CTLA-4 (e.g., ipilimumab) and PD-1 (e.g., nivolumab and pembrolizumab) are known to boost the immune response against cancer cells and have shown efficacy in treating certain cancers. However, the cost and required route of administration (IV), coupled with deleterious side effects, are a hurdle to patient compliance.

Experiments conducted during the course of developing embodiments for the present invention identified new compounds from FDA approved drugs or diet supplements (e.g., prebiotic agents) that can be ingested to improve the efficacy of immune checkpoint therapies. It was shown that oral formulations of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) can alter the gut microbiome so that beneficial bacteria increase in frequency and synergize with immune checkpoint blockers given by the systemic injection. Indeed, it was shown that concurrent administration of prebiotic agents (e.g., inulin) with an immunotherapy (e.g., α-PD-1 therapy) resulted in stronger anti-tumor efficacy, stronger immune response (e.g. AH1-specific $CD8^+$ T cells frequency among PBMCs), inhibition of tumor growth, enhanced

intratumoral infiltration of T cells, higher IFN-γ expression in splenoic $CD8^+$ T cells, and increased abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the subject's gut microbiome.

Accordingly, the present invention relates generally to compositions and methods for increasing the efficacy of immunotherapies and vaccines. In particular, the present invention relates to elevating the richness and diversity of a subject's gut microbiome through administration of an agent (e.g., fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin)) (e.g., melatonin) with administering an immunotherapy or vaccine. Such compositions and methods are useful for treating cancer, infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity.

In certain embodiments, the present invention provides a method for increasing the efficacy of a cancer immunotherapy through administration of 1) a cancer immunotherapy to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides methods of inhibiting the ability of a cancer cell to induce immune dysfunction, comprising administration of 1) a cancer immunotherapy to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides a method for increasing the efficacy of a vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) through administration of 1) a vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides methods of inhibiting the ability of a cancer cell to induce immune dysfunction, comprising administration of 1) a cancer vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides methods for treating cancer, comprising administration of 1) a cancer immunotherapy to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides methods for treating cancer, comprising administration of 1) a cancer vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In certain embodiments, the present invention provides methods for treating a condition characterized with dysregulated gut microbiome activity, comprising administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In some embodiments, such administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, or after administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy. In some embodiments, such administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy. In some embodiments, such administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and after administration of the vaccine (e.g., cancer vaccine) (e.g., vaccines against infectious pathogens) or cancer immunotherapy.

Such methods are not limited to a particular subject. In some embodiments, the subject is a mammal. In some embodiments, the subject is a human subject. In some embodiments, the subject is a human subject diagnosed with cancer. In some embodiments, the subject is a human subject at risk for developing cancer. In some embodiments, the subject is a human subject having a condition characterized with dysregulated gut microbiome activity.

Such methods are not limited to a particular agent capable of elevating the richness and diversity of a subject's gut microbiome. In some embodiments, the agent is a fiber containing prebiotic agent (e.g., epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin). In some embodiments, the agent is melatonin. In some embodiments, the agent is capable of inducing increased abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the subject's gut microbiome. In some embodiments, the fiber containing prebiotic agent is a gel-based fiber containing prebiotic agent (e.g., gel based inulin).

Indeed, among the prebiotics suitable for treatment, as either part of any food or as supplement, are included the following components: 1,4-dihydroxy-2-naphthoic acid (DHNA), Inulin, trans-Galactooligosaccharides (GOS), Lactulose, Mannan oligosaccharides (MOS), Fructooligosaccharides (FOS), Neoagaro-oligosaccharides (NAOS), Pyrodextrins, Xylo-oligosaccharides (XOS), Isomalto-oligosaccharides (IMOS), Amylose-resistant starch, Soybean oligosaccharide (SBOS), Lactitol, Lactosucrose (LS), Isomaltulose (including Palatinose),

Arabinoxylooligosaccharides (AXOS), Raffinose oligosaccharides (RFO), Arabinoxylans (AX), Polyphenols or any another compound capable of changing the microbiota composition with a desirable effect.

Such methods are not limited to a specific cancer immunotherapy.

In some embodiments, the cancer immunotherapy is one or more immune checkpoint inhibitor (ICI) inhibitors.

ICIs include any agent that blocks or inhibits in a statistically significant manner, the inhibitory pathways of the immune system. Illustrative ICIs that may be targeted for blocking or inhibition include, but are not limited to, CTLA-4, PDL1, PDL2, PD1, B7-H3, B7-H4, BTLA, HVEM, GAL9, LAG3, TIM3, VISTA, KIR, 2B4 (belongs to the CD2 family of molecules and is expressed on all NK, γδ, and memory CD8+ (αβ) T cells), CD160 (also referred to as BY55), CGEN-15049, CHK 1 and CHK2 kinases, A2aR and various B-7 family ligands. B7 family ligands include, but are not limited to, B7-1, B7-2, B7-DC, B7-H1, B7-H2, B7-H3, B7-H4, B7-H5, B7-H6 and B7-H7. ICIs include antibodies, or antigen binding fragments thereof, other binding proteins, biologic therapeutics or small molecules, that bind to and block or inhibit the activity of one or more of CTLA-4, PDL1, PDL2, PD1, BTLA, HVEM, TIM3, GAL9, LAG3, VISTA, KIR, 2B4, CD160 and CGEN-15049. Illustrative ICIs include Tremelimumab (CTLA-4 blocking antibody), anti-OX40, PD-L1 monoclonal Antibody (Anti-B7-H1; MEDI4736), MK-3475 (PD-1 blocker), Nivolumab (anti-PD1 antibody), CT-011 (anti-PD1 antibody), BY55 monoclonal antibody, AMP224 (anti-PDL1 antibody), BMS-936559 (anti-PDL1 antibody), MPLDL3280A (anti-PDL1 antibody), MSB0010718C (anti-PDL1 antibody) and Yervoy/ipilimumab (anti-CTLA-4 checkpoint inhibitor). Checkpoint protein ligands include, but are not limited to PD-L1, PD-L2, B7-H3, B7-H4, CD28, CD86 and TIM-3.

In some embodiments, the present invention covers the use of a specific class of ICIs are drugs that block the interaction between immune checkpoint receptor programmed cell death protein 1 (PD-1) and its ligand PD-L1 (see, Mullard, Nature Reviews: Drug Discovery (2013)), 12:489-492. PD-1 is expressed on and regulates the activity of T-cells. Specifically, when PD-1 is unbound to PDL-1, the T-cells can engage and kill target cells. However, when PD-1 is bound to PDL-1 it causes the T-cells to cease engaging and killing target cells. Furthermore, unlike other checkpoints, PD-1 acts proximately such the PDLs are overexpressed directly on cancer cells which leads to increased binding to the PD-1 expressing T-cells.

In some embodiments, ICIs which are antibodies are provided that can act as agonists of PD-1, thereby modulating immune responses regulated by PD-1. In one embodiment, the anti-PD-1 antibodies can be antigen-binding fragments. Anti-PD-1 antibodies disclosed herein are able to bind to human PD-1 and agonize the activity of PD-1, thereby inhibiting the function of immune cells expressing PD-1.

In some embodiments, the present invention covers the use of a specific class of ICIs that are drugs that inhibit CTLA-4. Suitable anti-CTLA4 antagonist agents for use in the methods of the invention, include, without limitation, anti-CTLA4 antibodies, human anti-CTLA4 antibodies, mouse anti-CTLA4 antibodies, mammalian anti-CTLA4 antibodies, humanized anti-CTLA4 antibodies, monoclonal anti-CTLA4 antibodies, polyclonal anti-CTLA4 antibodies, chimeric anti-CTLA4 antibodies, MDX-010 (ipilimumab), tremelimumab, anti-CD28 antibodies, anti-CTLA4 adnectins, anti-CTLA4 domain antibodies, single chain anti-CTLA4 fragments, heavy chain anti-CTLA4 fragments, light chain anti-CTLA4 fragments, inhibitors of CTLA4 that agonize the co-stimulatory pathway, the antibodies disclosed in PCT Publication No. WO 2001/014424, the antibodies disclosed in PCT Publication No. WO 2004/035607, the antibodies disclosed in U.S. Publication No. 2005/0201994, and the antibodies disclosed in granted European Patent No. EP 1212422 B1. Additional CTLA-4 antibodies are described in U.S. Pat. Nos. 5,811,097, 5,855,887, 6,051,227, and 6,984,720; in PCT Publication Nos. WO 01/14424 and WO 00/37504; and in U.S. Publication Nos. 2002/0039581 and 2002/086014. Other anti-CTLA-4 antibodies that can be used in a method of the present invention include, for example, those disclosed in: WO 98/42752; U.S. Pat. Nos. 6,682,736 and 6,207,156; Hurwitz et al., Proc. Natl. Acad. Sci. USA, 95(17):10067-10071 (1998); Camacho et al., J. Clin. Oncology, 22(145):Abstract No. 2505 (2004) (antibody CP-675206); Mokyr et al., Cancer Res., 58:5301-5304 (1998), and U.S. Pat. Nos. 5,977,318, 6,682,736, 7,109,003, and 7,132,281.

Additional anti-CTLA4 antagonists include, but are not limited to, the following: any inhibitor that is capable of disrupting the ability of CD28 antigen to bind to its cognate ligand, to inhibit the ability of CTLA4 to bind to its cognate ligand, to augment T cell responses via the co-stimulatory pathway, to disrupt the ability of B7 to bind to CD28 and/or CTLA4, to disrupt the ability of B7 to activate the co-stimulatory pathway, to disrupt the ability of CD80 to bind to CD28 and/or CTLA4, to disrupt the ability of CD80 to activate the co-stimulatory pathway, to disrupt the ability of CD86 to bind to CD28 and/or CTLA4, to disrupt the ability of CD86 to activate the co-stimulatory pathway, and to disrupt the co-stimulatory pathway, in general from

being activated. This necessarily includes small molecule inhibitors of CD28, CD80, CD86, CTLA4, among other members of the co-stimulatory pathway; antibodies directed to CD28, CD80, CD86, CTLA4, among other members of the co-stimulatory pathway; antisense molecules directed against CD28, CD80, CD86, CTLA4, among other members of the co-stimulatory pathway; adnectins directed against CD28, CD80, CD86, CTLA4, among other members of the co-stimulatory pathway, RNAi inhibitors (both single and double stranded) of CD28, CD80, CD86, CTLA4, among other members of the co-stimulatory pathway, among other anti-CTLA4 antagonists.

In one embodiment, the present invention covers the use of a specific class of ICI are drugs that inhibit TIM-3. Blocking the activation of TIM-3 by a ligand, results in an increase in Th1 cell activation. Furthermore, TIM-3 has been identified as an important inhibitory receptor expressed by exhausted CD8+ T cells. TIM-3 has also been reported as a key regulator of nucleic acid mediated antitumor immunity. In one example, TIM-3 has been shown to be upregulated on tumor-associated dendritic cells (TADCs).

Such methods are not limited to the use of a particular cancer vaccine. Indeed, one approach that has been pursued for cancer immunotherapy is the area covered by the term "tumor vaccines" or "cancer vaccines" which includes immunization with tumor specific or overexpressed antigens. In this approach, an antigen or antigens specific for, or overexpressed in, tumor cells are injected alone, with adjuvants, as part of a microorganism that delivers the antigen (for example, Listeria Monocytogenes), or after incubation ex-vivo with immune cells (including but not limited to dendritic cells) in order to elicit cellular and/or humoral immune responses.

In some embodiments, the cancer is carcinoma. Carcinomas are cancers of epithelial origin. In some embodiments, the carcinoma is selected from the group consisting of acinar carcinoma, acinous carcinoma, alveolar adenocarcinoma, carcinoma adenomatosum, adenocarcinoma, carcinoma of adrenal cortex, alveolar carcinoma, alveolar cell carcinoma, basal cell carcinoma, carcinoma basocellular, basaloid carcinoma, basosquamous cell carcinoma, breast carcinoma, bronchioalveolar carcinoma, bronchiolar carcinoma, cerebriform carcinoma, cholangiocellular carcinoma, chorionic carcinoma, colloid carcinoma, comedocarcinoma, corpus carcinoma, cribriform carcinoma, carcinoma en cuirasse, carcinoma cutaneum, cylindrical carcinoma, cylindrical cell carcinoma, duct carcinoma, carcinoma durum, embryonal carcinoma, encephaloid carcinoma, epibulbar carcinoma, epidermoid carcinoma,

carcinoma epitheliate adenoids, carcinoma exulcere, carcinoma fibrosum, gelatinform carcinoma, gelatinous carcinoma, giant cell carcinoma, gigantocellulare, glandular carcinoma, granulose cell carcinoma, hair matrix carcinoma, hematoid carcinoma, hepatocellular carcinoma, Hurthle cell carcinoma, hyaline carcinoma, hypernephroid carcinoma, infantile embryonal carcinoma, carcinoma in situ, intraepidermal carcinoma, intraepithelial carcinoma, Krompecher's carcinoma, Kulchitzky-cell carcinoma, lentivular carcinoma, carcinoma lenticulare, lipomatous carcinoma, lymphoepithelial carcinoma, carcinoma mastotoids, carcinoma medullare, medullary carcinoma, carcinoma melanodes, melanotonic carcinoma, mucinous carcinoma, carcinoma muciparum, carcinoma mucocullare, mucoepidermoid carcinoma, mucous carcinoma, carcinoma myxomatodes, masopharyngeal carcinoma, carcinoma nigrum, oat cell carcinoma, carcinoma ossificans, osteroid carcinoma, ovarian carcinoma, papillary carcinoma, periportal carcinoma, preinvasive carcinoma, prostate carcinoma, renal cell carcinoma of kidney, reserve cell carcinoma, carcinoma sarcomatodes, scheinderian carcinoma, scirrhous carcinoma, carcinoma scrota, signet-ring cell carcinoma, carcinoma simplex, small cell carcinoma, solandoid carcinoma, spheroidal cell carcinoma, spindle cell carcinoma, carcinoma spongiosum, squamous carcinoma, squamous cell carcinoma, string carcinoma, carcinoma telangiectaticum, carcinoma telangiectodes, transitional cell carcinoma, carcinoma tuberrosum, tuberous carcinoma, verrucous carcinoma, carcinoma vilosum.

In some embodiments, the cancer is a sarcoma. Sarcomas are mesenchymal neoplasms that arise in bone and soft tissues. In some embodiments, the sarcoma is selected from liposarcomas (including myxoid liposarcomas and pleomorphic liposarcomas), leiomyosarcomas, rhabdomyosarcomas, neurofibrosarcomas, malignant peripheral nerve sheath tumors, Ewing's tumors (including Ewing's sarcoma of bone, extraskeletal or non-bone) and primitive neuroectodermal tumors (PNET), synovial sarcoma, hemangioendothelioma, fibrosarcoma, desmoids tumors, dermatofibrosarcoma protuberance (DFSP), malignant fibrous histiocytoma (MFH), hemangiopericytoma, malignant mesenchymoma, alveolar soft-part sarcoma, epithelioid sarcoma, clear cell sarcoma, desmoplastic small cell tumor, gastrointestinal stromal tumor (GIST) and osteosarcoma (also known as osteogenic sarcoma-skeletal and extra-skeletal, and chondrosarcoma.

In some embodiments, the cancer is a refractory or a responding cancer. As used herein, a refractory cancer is a cancer that is resistant to the ordinary standards of care prescribed. These

cancers, although initially responsive to treatment, recur and/or may be completely non responsive to the treatment.

In some embodiments, the cancer is an immunogenic cancer. Examples of immunogenic cancers include malignant melanoma and renal cell carcinoma, Mantel cell lymphoma, follicular lymphoma, diffuse large B-cell lymphoma, T-cell acute lymphoblastic leukemia, Burkitt Lymphoma, myeloma, immunocytoma, acute promyelocyte leukemia, chronic myeloid/acute lymphoblastic leukemia, acute leukemia, B-cell acute lymphoblastic leukemia, anaplastic large cell leukemia, myelodysplasia syndrome/acute myeloid leukemia, non-Hodgkin's lymphoma, chronic lymphocytic leukemia, acute myelogenous leukemia (AML), common (pre-B) acute lymphocytic leukemia, malignant melanoma, T-cell lymphoma, leukemia, B-cell lymphoma, epithelial malignancies, lymphoid malignancies, gynecologic carcinoma, biliary adenocarcinomas and ductal adenocarcinomas of the pancreas.

In some embodiments, such methods further comprise administering other therapies such as, for example, radiation therapy, surgery, conventional chemotherapy or with a combination of one or more additional therapies. Such other active ingredient includes, but is not limited to glutathione antagonists, angiogenesis inhibitors, chemotherapeutic agent(s) and antibodies (e.g., cancer antibodies). The agents described in this invention may be administered simultaneously or sequentially. The separation in time between administrations may be minutes, hours, days or it may be longer.

For example, the agent capable of elevating the richness and diversity of the subject's gut microbiome and the cancer immunotherapy or cancer vaccine can be administered before, after, or simultaneously with an additional chemotherapeutic and/or cytotoxic agents such as alkylating agents (e.g., chlorambucil, cyclophosphamide, ccnu, melphalan, procarbazine, thiotepa, bcnu, and busulfan), antimetabolites (e.g., 6-mercaptopurine and 5-fluorouracil), anthracyclines (e.g., daunorubicin, doxorubicin, idarubicin, epirubicin, and mitoxantrone), antitumor antibiotics (e.g., bleomycin), monoclonal antibodies (e.g., alemtuzumab, bevacizumab, cetuximab, gemtuzumab, ibritumomab, panitumumab, rituximab, tositumomab, and trastuzumab), platinums (e.g., cisplatin, oxaliplatin, and carboplatin), plant alkaloids (e.g., vincristine), topoisomerase I or II inhibitors (e.g., irinotecan, topotecan, amsacrine, etoposide, etoposide phosphate, and teniposide), vinca alkaloids (e.g., vincristine, vinblastine, vinorelbine, and vindesine), taxanes (e.g., paclitaxel and docetaxel), epipodophyllotoxins (e.g., etoposide

and teniposide), nucleoside analogs, and angiogenesis inhibitors (e.g., Avastin (beracizumab), a humanized monoclonal antibody specific for VEGF-A).

Examples of glutathione antagonists include but are not limited to buthionine sulfoximine, cyclophosphamide, ifosphamide, actinomycin-d and N-(4-hydroxyphenyl) retinamide (4-HPR). Examples of angiogenesis inhibitors include but are not limited to 2-methoxyestradiol(2-ME), AG3340, Angiostatin, antithrombin-III, Anti-VEGF antibody, Batimastat, bevacizumab (Avastin), BMS-275291, CA1, Canstatin, combretastatin, Combretastatin-A4 phosphate, CC-5013, captopril, celecoxib, Dalteparin, EMD121974, Endostatin, Erlotinib, Gefitinib, Genistein, Halofuginone, ID 1, ID3, IM862, Imatinib mesylate, Inducible protein-10, Interferon-alpha, Interleukin-12, Lavendustin-a, LY317615, or AE-941, Marimastat, Mapsin, Medroxyprogesterone acetate, Meth-1, Meth-2, Neovastat, Osteopontin cleaved product, PEX, Pigment epithelium growth factor (PEGF), platelet growth factor 4, prolactin fragment, proliferin-related protein (PRP), PTK787/ZK222584, recombinant human platelet factor-4(rPF4), restin, squalamine, SU5416, SU6668, Suramin, Taxol, Tecogalan, Thalidomide, Tetrathiomolybdate (TM), Thrombospondin, TNP-470, Troponin I, Vasostatin, VEGF1, VEGF-TPvAP and ZD6474. In some embodiment the angiogenesis inhibitor is a VRGF antagonist. The VEGF antagonist may be a VEGF binding molecule. VEGF binding molecule include VEGF antibodies, or antigen binding fragment (s) thereof. One example of a VEGF antagonist is NeXstar.

Examples of categories of chemotherapeutic agents that may be used in any of the methods or agents disclosed herein include, but are not limited to, DNA damaging agents and these include topoisomerase inhibitors (e.g., etoposide, camptothecin, topotecan, irinotecan, teniposide, mitoxantrone), anti-microtubule agents (e.g., vincristine, vinblastine), antimetabolite agents (e.g., cytarabine, methotrexate, hydroxyurea, 5-fluorouracil, flouridine, 6-thioguanine, 6-mercaptompurine, fludarabine, pentostatin, chlorodeoxyadenosine), DNA alkylating agents (e.g., cisplatin, mecholorethamine, cyclophosphamide, ifosphamide, melphalan, chlorambucil, busulfan, thiotepa, carmustine, lomustine, carboplatin, dacarbazine, procarbazine) and DNA strand break inducing agents (e.g., bleomycin, doxorubicin, daunorubicin, idarubicin, mitomycin C).

Chemotherapeutic agents include synthetic, semisynthetic and naturally derived agents. Important chemotherapeutic agents include, but are not limited to, Avicine, Aclarubicin, Acodazole, Acronine, Adozelesin, Adriamycin, aldesleukin, Alitretinoin, AUopurinol sodium,

Altretamine, Ambomycin, Ametantrone acetate, Aminoglutethimide, Amsacrine, Anastrazole, Annonaceous Acetogenins, Anthramycin, Asimicin, Asparaginase, asperlin, Azacitidine, azetepa, Azotomycin, batimastat, benzodepa, bexarotene, Bicalutamide, Bisantrene, Bisnafide, Bizelesin, Bleomycin, Brequinar, Bropirimine, Bullatacin, Busulfan, Cabergoline, cactinomycin, calusterone, caracemide, carbetimer, carboplatin, carmustine, carubicin, carzelesin, cedefingol, chlorambucil, celecoxib, cirolemycin, cisplatin, cladribine, crisnatol, cyclophosphamide, cytarabine, dacarbazine, DACA, dactinomycin, Daunorubicin, daunomycin, Decitabine, denileukin, Dexormaplatin, Dezaguanine, Diaziquone, Docetaxel, Doxorubicin, Droloxifene, Dromostalone, Duazomycin, Edatrexate, Eflornithine, Elsamitrucin, Estramustine, Etanidazole, Etoposide, Etoprine, Fadrozole, Fazarabine, Fenretinide, Floxuridine, Fludarabine, Fluorouracil, Flurocitabine, 5-FdUMP, Fosquidone, Fosteuecine, FK-317, FK-973, FR-66979, FR-900482, Gemcitabine, Gemtuzumab, Ozogamicin, Gold Aul 98, Goserelin, Guanacone, Hydroxyurea, Idarubicin, Ilmofosine, Interferon alpha and analogs, Iproplatin, irinotecan, Lanreotide, Letrozole, Leuprolide, Liarozole, Lometrexol, Lomustine, Losoxantrone, masoprocol, Maytansine, Mechlorethamine, Megestrol, Melengestrol, Melphalan, Menogaril, Metoprine, maturedepa, mitindomide, Mitocarcin, Mitogillin, Mitomalacin, Mitomycin, Mitomycin C, Mitosper, Mitotane, Mitoxantrone, Mycophenolic acid, Nocodazole, Nogalamycin, Oprelvekin, ormaplatin, Oxisuran, Paclitaxel, pamidronate, pegaspargase, Peliomycin, Pentamustine, Peplomycin, Perfosfamide, Pipobroman, Piposulfan, Piroxantrone, Plicamycin, Plomestane, Porfimer, Porfiromycin, Prednimustine, procarbazine, Puromycin, Pyrazofurin, Riboprine, Rituximab, Rogletimide, Rolliniastatin, safingol, Samarium, Semustine, Simtrazene, Sparfosate, Sparsomycin, spirogermanium, Spiromustine, Spiroplatin, Squamocin, Squamotacin, streptonigrin, streptozocin, SrC12, Sulphofenur, Talisomycin, Taxane, Toxoid, Tecoglan, Tegafur, teloxantrone, Temoporfin, teniposide, Teroxirone, Testolactone, Thiamiprine, Thiotepa, Thymitaq, Tiazofurin, Tirapazamine, Tomudex, Top-53, Topotecan, Toremixifme, Trastuzumab, Trestolone, triciribine, Triciribine, Trimetrexate, trimetrexate glucuronate, Triptorelin, Tubulozole, uracil mustard, Uredepa, valrubicin, vapreotide, Vinblastine, Vincristine, Vindesine, Vinepidine, Vinglycinate, Vinleurosine, Vinorelbine, Vinrosidine, Vinzolidine, Vorozole, Zeniplatin, Zinostatin, Zorubicin, 2-cholrodeoxyrubicine, 2'-deoxyformycin, 9-aminocamptothecin, raltitrexed, N-propargyl-5,8-didezafolic acid, 2-cholo-2'arabinofluoro-2' deoxyadenosine, 2-cholo-2'-deoxyadenosine, anisomycin, Trichostatin, hPRL-G129R, CEP-751, Linomide, Sulfur mustard, nitrogen mustard, N-methyl-N-nitrosourea,

fotemustine, Streptozotocin, dacarbazine, mitozolomide, temozolomide, AZQ, ormaplatin, CI-973, DWA21 14R, JM216, JM335, Bisplatinum, Tomudex, azacitidine, cytrabincine, gemcitabine, 6-mercaptopurine, Hypoxanthine, Teniposide, CPT-11, Doxorubicin, Daunorubicin, Epirubicin, darubicin, losoxantrone, amsacrine, pyrazoloacridine, all trans retinol, 14-hydroxy-retro-retinol, all-trans retinoic acid, N-(4-hydroxyphenyl) retinamide, 13-cisretinoic acid, 3-methyl TTNEB, 9-cisretenoic acid, fludarabine, and 2-Cda.

Other chemotherapeutic agent include: 20-epi1,25-dihydroxyvitamin-D3, 5-ethynyl uracil, abiraterone, aclarubicin, acylfulvene, adecylpenol, adozelesin, aldesleukin, ALL-TK antagonists, altretamine, ambumastine, amidox, amifostine, amino levulinic acid, anagrelide, anastrozole, andrographolide, angiogenesis inhibitors, antagonist D, antagonists D, antarelix, anti-dorsalizing morphogenetic protein-1, antiandrogen, antiestrogen, antineoplastone, antisense oligonucleotides, aphidicolin, apoptosis gene modulators, apoptosis regulators, apurinic acid, ara-cdp-dl-PTBA, arginine aminase, asulacrine, atamestine, atrimustine, axinamastine 1 and axinamastine 2, axinamastine 3, azasetron, azatoxin, azatyrosine, baccatin III derivatives, balanol, BCR/ABL antagonist, benzochlorins, benzoylsaurosporine, beta lactam derivatives, beta-alethine, perillyl alcohol, phenozenomyein, phenyl acetate, phosphatase inhibitors, picibanil, pilocarbine and salts or analogs thereof, pirarubucin, piritrexim, placetin A, placetin B, plasminogen activator inhibitor, platinum complex, phenyl ethyl isothiocyanate and analogs thereof, platinum compounds, platinum triamine complex, podophylotoxin, porfimer sodium, porphyromycin, propyl bis acridones, prostaglnadins J2, protease inhibitors, protein A based immune modulators, PKC inhibitors, microalgal, protein tyrosine phosphatase inhibitors, purine nucleoside phosphorylase inhibitors, purpurins, pyrazoloacridines, pyridoxylated hemoglobin polyoxyethylene conjugate, raf antagonists, raltitrexed, ramosetron, ras farnesyl protein tranferase inhibitors, rasinhibitors, ras-GAP inhibitors, ratellitptine demethylated, Rhenium Re 186 etidronate, rhizoxine, ribozyme, RII retinide, rogletimide, rosagliatazone and analogs and derivatives thereof, rohitukine, romurtide, roquinimex, rubiginone B1, ruboxyl, safingol, saintopin, SarCNU, sarcophytol A, sargrmostim, sdi 1 mimetics, semustine, senescence derived inhibitor 1, sense oligonucleotide, signal transduction inhibitors, signal transduction modulators, single chain antigen binding protein, sizofiran, sobuzoxane, sodium borocaptate, sodium phenyl acetate, solverol, somatomedin binding protein, sonermin, sparfosic acid, spicamycin D, spiromustin, splenopentine, spongistatin 1, squalamine, stem cell inhibitor, stem cell division inhibitor, stipiamide, stromelysin, sulfinosine, superactive vasoactive intestinal peptide

antagonists, suradista, siramin, swainsonine, synthetic glycosaminoglycans, tallimustine, tamoxifen methiodide, tauromustine, tazarotene, tacogalan sodium, tegafur, tellurapyrilium, telomerase inhibitors, temoporfin, tmeozolomide, teniposide, tetrachlorodecaoxide, tetrazomine, thaliblastine, thalidomide, thiocoraline, thrombopoetin and mimetics thereof, thymalfasin, thymopoetin receptor agonist, thymotrinan, thyroid stimulating harmone, tin ethyl etiopurpin, tirapazamine, titanocene and salts thereof, topotecan, topsentin, toremifene, totipotent stem cell factors, translation inhibitors, tretinoin, triacetyluridine, tricribine, trimetrexate, triptorelin, tropisetron, turosteride, tyrosine kinase inhibitors, tyrphostins, UBC inhibitors, ubenimex, urogenital sinus derived growth inhibitory factor, urokinase receptor antagonists, vapreotide, variolin B, vector system, erythrocyte gene therapy, velaresol, veramine, verdins, verteporfin, vinorelbine, vinxaltine, vitaxin, vorozol, zanoterone, zeniplatin, zilascorb and zinostatin.

Other chemotherapeutic agents include: antiproliferative agents (e.g., piritrexim isothiocyanate), antiprostatic hypertrophy agents (sitogluside), Benign prostatic hyperplasia therapy agents (e.g., tomsulosine, RBX2258), prostate growth inhibitory agents (pentomone) and radioactive agents: Fibrinogen 1125, fludeoxyglucose F18, Flurodopa F18, Insulin 1125, Iobenguane 1123, Iodipamide sodium 1131, Iodoantipyrine 1131, Iodocholesterol 1131, Iodopyracet 1125, Iofetamine HCL 1123, Iomethin 1131, Iomethin 1131, Iothalamate sodium 1125, Iothalamate 1131, Iotyrosine 1131, Liothyronine 1125, Merosproprol Hgl 97, Methyl iodobenzo guanine (MIBG-I131 or MIBGI 123) selenomethionine Se75, Technetium Tc99m furifosmin, technetium Tc99m gluceptate, Tc99m Biscisate, Tc99m disofenin, TC99m gluceptate, Tc99m lidofenin, Tc99m mebrofenin, Tc99m medronate and sodium salts thereof, Tc99m mertiatide, Tc99m oxidronate, Tc99m pentetate and salts thereof, Tc99m sestambi, Tc99m siboroxime, Tc99m succimer, Tc99m sulfur colloid, Tc 99m teboroxime, Tc 99m Tetrofosmin, Tc99m Tiatide, Thyroxine 1125, Thyroxine 1131, Tolpovidone 1131, Triolein 1125 and Treoline 1125, and Treoline 131, MIBG-I123 and MIBG 1131 are especially preferred chemotherapeutic agents for co-administration with the nitrofuran containing pharmaceutical composition of invention.

Another category of chemotherapeutic agents are anticancer supplementary potentiating agents, e.g., antidepressant drugs (Imipramine, desipramine, amitriptyline, clomipramine, trimipramine, doxepin, nortriptyline, protriptyline, amoxapine, and maprotiline), or no-trycyclic anti-depressant drugs (sertraline, trazodone and citalopram), Ca++ antagonists (verapamil, nifedipine, nitrendipine and caroverine), calmodulin inhibitors (prenylamine, trifluoperazine

and clomipramine), Amphotericin B, Triparanol analogs (e.g., Tamoxifen), antiarrhythmic drugs (e.g., quinidine), antihypertensive drugs (e.g., reserpine), thiol depleters (e.g., buthionine and sulfoximine) and multiple drug resistance reducing agents such as Cremophor EL.

In some embodiments, the condition characterized with dysregulated gut microbiome activity is an autoimmune disease, a neurological disorder, diabetes, and/or obesity. Examples of such conditions include, but are not limited to, rheumatoid arthritis, multiple sclerosis diabetes (e.g., type 1 diabetes mellitus), autoimmune diseases of the thyroid (e.g., Hashimoto's thyroiditis, Graves' disease), thyroid-associated ophthalmopathy and dermopathy, hypoparathyroidism, Addison's disease, premature ovarian failure, autoimmune hypophysitis, pituitary autoimmune disease, immunogastritis, pernicious angemis, celiac disease, vitiligo, myasthenia gravis, pemphigus vulgaris and variants, bullous pemphigoid, dermatitis herpetiformis Duhring, epidermolysis bullosa acquisita, systemic sclerosis, mixed connective tissue disease, Sjogren's syndrome, systemic lupus erythematosus, Goodpasture's syndrome, rheumatic heart disease, autoimmune polyglandular syndrome type 1, Aicardi–Goutières syndrome, Acute pancreatitis Age-dependent macular degeneration, Alcoholic liver disease, Liver fibrosis, Metastasis, Myocardial infarction, Nonalcoholic steatohepatitis (NASH), Parkinson's disease, Polyarthritis/fetal and neonatal anemia, Sepsis, and inflammatory bowel disease.

In some embodiments, such methods for treating or preventing conditions characterized with dysregulated gut microbiome activity disorders further comprise administering (e.g., simultaneously or at different times) additional therapeutic agents. Examples of such therapeutic agents include, but are not limited to, disease-modifying antirheumatic drugs (e.g., leflunomide, methotrexate, sulfasalazine, hydroxychloroquine), biologic agents (e.g., rituximab, infliximab, etanercept, adalimumab, golimumab), nonsteroidal anti-inflammatory drugs (e.g., ibuprofen, celecoxib, ketoprofen, naproxen, piroxicam, diclofenac), analgesics (e.g., acetaminophen, tramadol), immunomodulators (e.g., anakinra, abatacept), glucocorticoids (e.g., prednisone, methylprednisone), TNF-α inhibitors (e.g., adalimumab, certolizumab pegol, etanercept, golimumab, infliximab), IL-1 inhibitors, and metalloprotease inhibitors. In some embodiments, the therapeutic agents include, but are not limited to, infliximab, adalimumab, etanercept, parenteral gold or oral gold.

In certain embodiments, the present invention provides a composition comprising a gel-based inulin formulation. In some embodiments, the gel-based inulin formulation has an average

degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33). In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In certain embodiments, the present invention provides a method for increasing the efficacy of a vaccine through administration of 1) a vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the vaccine.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine; or administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine. In some embodiments, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine.

In some embodiments, the vaccine is a vaccine for treating cancer, and/or a vaccine for treating and/or protecting from infectious pathogens.

In some embodiments, the subject is a human subject.

In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent. In some embodiments, the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin. In some embodiments, the fiber containing prebiotic agent is a gel-based inulin formulation. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at or higher than 20 and at or less than 47. In some embodiments, the gel-based inulin formulation has an average degree of polymerization at approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33). In some embodiments, the gel-based inulin formluation comprises one or more prebiotic compounds selected from a fructo-

oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber. In some embodiments, the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

In some embodiments, the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

In some embodiments, administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

In certain embodiments, the present invention provides compositions comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) bacteria.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the prebiotic compound is gel-based. In some embodiments, the prebiotic compound is gel-based inulin.

In some embodiments, the bacteria is E. coli. In some embodiments, the bacteria is able to alter the gut microbiome of a subject upon administration to the subject.

In some embodiments, the composition is configured for oral administration to a subject.

In certain embodiments, the present invention provides methods for colonic delivery of bacteria to a subject, comprising administering to a subject such a comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) bacteria (e.g., gel-based inulin).

In certain embodiments, the present invention provides compositions comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed,

adsorbed, admixed) one or more probiotic cells. In certain embodiments, the present invention provides methods for increasing the growth of probiotic organisms in the digestive system of a subject, comprising administering to the subject (e.g., mammalian subject; human subject) such a composition.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the prebiotic compound is gel-based. In some embodiments, the prebiotic compound is gel-based inulin.

In some embodiments, the one or more probiotic cells are able to alter the gut microbiome of a subject upon administration to the subject.

In some embodiments, the composition is configured for oral administration to a subject.

In some embodiments, the one or more probiotic cells comprise beneficial bacteria. In some embodiments, the beneficial bacteria comprises one or more of: Saccharomyces cereviseae, Bacillus coagulans, Bacillus licheniformis, Bacillus subtilis, Bifidobacterium angulatum, Bifidobacterium animalis, Bifidobacterium bifidum, Bifidobacterium breve, Bifidobacterium infantis, Bifidobacterium lactis, Bifidobacterium longum, Enterococcus faecium, Enterococcus faecalis, Lactobacillus acidophilus, Lactobacillus amylovorus, Lactobacillus alimentarius, Lactobacillus bulgaricus, Lactobacillus casei subsp. casei, Lactobacillus casei Shirota, Lactobacillus curvatus, Lactobacillus delbrueckii subsp. lactis, Lactobacillus fermentum, Lactobacillus farciminus, Lactobacillus gasseri, Lactobacillus helveticus, Lactobacillus johnsonii, Lactobacillus lacti, Lactobacillus paracasei, Lactobacillus pentosaceus, Lactobacillus plantarum, Lactobacillus reuteri, Lactobacillus rhamnosus (Lactobacillus GG), Lactobacillus sake, Lactobacillus salivarius, Lactococcus lactis, Lactobacillus thermotolerans, Lactobacillus mucosae, Micrococcus varians, Pediococcus acidilactici, Pediococcus pentosaceus, Pediococcus acidilactici, Pediococcus halophilus, Streptococcus faecalis, Streptococcus thermophilus, Staphylococcus carnosus, and Staphylococcus xylosus.

In some embodiments, the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

In certain embodiments, the present invention provides a composition comprising a gel-based prebiotic formulation. In some embodiments, the composition is formulated for oral ingestion. In some embodiments, the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

In some embodiments, the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

In some embodiments, the gel-based prebiotic formulation is associated with one or more probiotic organisms. In some embodiments, the one or more probiotic organisms are chosen from Lactobacillus species and Bifidobacterium species. In some embodiments, the gel-based prebiotic formulation is associated with one or more bacteriophages specific to Bordetella, Borrelia, Brucella, Campylobacter, Chlamydia and Chlamydophila, Clostridium, Corynebacterium, Enterococcus, Escherichia, Francisella, Haemophilus, Helicobacter, Legionella, Leptospira, Listeria, Mycobacterium, Mycoplasma, Neisseria, Pseudomonas, Rickettsia, Salmonella, Shigella, Staphylococcus, Streptococcus, Treponema, Vibrio and Yersinia. In some embodiments, the one or more probiotic organisms are selected from L. acidophilus, L. amylovorus, L. brevis, L. casei, L. casei subsp. rhamnosus (Lactobacillus GG), L. caucasicus, L. crispatus, L. delbrueckii subsp. bulgaricus (L. bulgaricus), L. fermentum (L. fermenti), L. gasseri, L. helveticus, L. johnsonii, L. lactis, L. leichmannii, L. paracasei, L. plantarum, L. reuteri, or L. rhamnosus.

Such methods are not limited to a particular manner of administering the agent capable of elevating the richness and diversity of a subject's gut microbiome. In some embodiments, the agent is preferably administered orally (e.g., by oral gavage). However, administration can be by any suitable route of administration including buccal, dental, endocervical, intramuscular, inhalation, intracranial, intralymphatic, intramuscular, intraocular, intraperitoneal, intrapleural,

intrathecal, intratracheal, intrauterine, intravascular, intravenous, intravesical, intranasal, ophthalmic, otic, biliary perfusion, cardiac perfusion, priodontal, rectal, spinal subcutaneous, sublingual, topical, intravaginal, transermal, ureteral, or urethral. Dosage forms can be aerosol including metered aerosol, chewable bar, capsule, capsule containing coated pellets, capsule containing delayed release pellets, capsule containing extended release pellets, concentrate, cream, augmented cream, suppository cream, disc, dressing, elixer, emulsion, enema, extended release fiber, extended release film, gas, gel, metered gel, granule, delayed release granule, effervescent granule, chewing gum, implant, inhalant, injectable, injectable lipid complex, injectable liposomes, insert, extended release insert, intrauterine device, jelly, liquid, extended release liquid, lotion, augmented lotion, shampoo lotion, oil, ointment, augmented ointment, paste, pastille, pellet, powder, extended release powder, metered powder, ring, shampoo, soap solution, solution for slush, solution/drops, concentrate solution, gel forming solution/drops, sponge, spray, metered spray, suppository, suspension, suspension/drops, extended release suspension, swab, syrup, tablet, chewable tablet, tablet containing coated particles, delayed release tablet, dispersible tablet, effervescent tablet, extended release tablet, orally disintegrating tablet, tampon, tape or troche/lozenge.

Intraocular administration can include administration by injection including intravitreal injection, by eyedrops and by trans-scleral delivery.

Administration can also be by inclusion in the diet of the mammal such as in a functional food for humans or companion animals.

As noted, it is preferable that such agents capable of elevating the richness and diversity of a subject's gut microbiome are to be administered orally. Such formulations are preferably encapsulated and formulated with suitable carriers in solid dosage forms. Some examples of suitable carriers, excipients, and diluents include lactose, dextrose, sucrose, sorbitol, mannitol, starches, gum acacia, calcium phosphate, alginates, calcium silicate, microcrystalline cellulose, polyvinylpyrrolidone, cellulose, gelatin, syrup, methylcellulose, methyl- and propylhydroxybenzoates, talc, magnesium, stearate, water, mineral oil, and the like. The formulations can additionally include lubricating agents, wetting agents, emulsifying and suspending agents, preserving agents, sweetening agents or flavoring agents. The compositions may be formulated such as to provide rapid, sustained, or delayed release of the active ingredients after administration to the patient by employing procedures well known in the art.

The formulations can also contain substances that diminish proteolytic degradation and promote absorption such as, for example, surface-active agents.

The specific dose can be calculated according to the approximate body weight or body surface area of the patient or the volume of body space to be occupied. The dose will also depend upon the particular route of administration selected. Further refinement of the calculations necessary to determine the appropriate dosage for treatment is routinely made by those of ordinary skill in the art. Such calculations can be made without undue experimentation by one skilled in the art in light of the activity in assay preparations such as has been described elsewhere for certain compounds (see for example, Howitz et al., Nature 425:191-196, 2003 and supplementary information that accompanies the paper). Exact dosages can be determined in conjunction with standard dose-response studies. It will be understood that the amount of the composition actually administered will be determined by a practitioner, in the light of the relevant circumstances including the condition or conditions to be treated, the choice of composition to be administered, the age, weight, and response of the individual patient, the severity of the patient's symptoms, and the chosen route of administration.

The present invention also provides kits comprising an agent capable of elevating the richness and diversity of the subject's gut microbiome (e.g., a fiber based pre-biotic), and one or more of a vaccine (e.g., a cancer vaccine) (e.g., a vaccine for treating and/or protecting from infectious pathogens), and a cancer immunotherapy (e.g., an ICI inhibitor). The kits may optionally contain other therapeutic agents.

EXPERIMENTAL

The following examples are provided to demonstrate and further illustrate certain preferred embodiments of the present invention and are not to be construed as limiting the scope thereof.

Example I.

This example demonstrates efficacy improvement for immune checkpoint blockers with prebiotics in a prophylatic setting.

Among the FDA's list, five candidate materials were selected for the initial screening. Melatonin, found in pineal gland and gastrointestinal tracta, regulates sleep cycle and circadian rhythm. Epigallocatechin gallate (EGCG) is a natural antioxidant in plants. Fucoidan,

oligofructose and inulin are plant polysaccharides that are widely used in food products and diet supplements. These candidate materials were first tested for their ability to improve the anti-tumor efficacy of α-PD-1 therapy in a prophylactic manner. WT Balb/c mice were treated with these materials via oral gavage one week before tumor inoculation **(Fig. 1A)**. All these agents combined with α-PD-1 therapy exhibited stronger anti-tumor efficacy, compared with α-PD-1 alone, and inulin exhibited the best efficacy **(Fig. 1B and C)**. Inulin combined with α-PD-1 prolonged the survival of animals with 60% mice still surviving on day 50 **(Fig. 1D)**.

The effect of these materials were next tested on systemic immune responses. The surrogate marker of tumor specific antigen, MHC-I minimal epitope of CT-26 gp70 (AH1) (H-2L^d–restricted SPSYVYHQF (SEQ ID NO.: 1)), was employed to quantitate the frequency of AH1-specific CD8$^+$ T cells among peripheral blood mononuclear cells (PBMCs). Mice orally gavaged with inulin and melatonin combined with α-PD-1 IgG induced 1.7-fold and 1.8-fold greater frequencies of AH1-specific CD8$^+$ T cells, compared with α-PD-1 treatment alone **(Fig. 1E and F)**.

Example II.

This example describes improvement in the efficacy of immune checkpoint blockers with prebiotics in a therapeutic setting.

Having identified inulin as a promising candidate, these agents were next tested in a therapeutic setting. After Balb/c mice were inoculated with CT-26 cells, tumor-bearing mice were treated with oral gavage starting day 7 **(Fig. 2A)**. Consistent with the prophylactic treatment, inulin combined with α-PD-1 IgG therapy exhibited the strongest anti-tumor efficacy **(Fig. 2B and C)** with an extended animal survival **(Fig. 2D)**. Inulin also elicited significantly higher AH1-specific CD8$^+$ T cells among PBMCs on day 18 and 24 **(Fig. 2E-G)**.

Example III.

This example describes dosage effects of inulin and melanotinin.

The dosage effect of inulin and melatonin were next examined, which were the top 2 candidates identified above. Reducing the dosage of inulin and melatonin by half (i.e., 60 mg for inulin and 50 mg/Kg for melatonin) did not compromise their combination efficacy with α-PD-1 against tumor growth **(Fig. 3A, B)**, suggesting a relatively wide therapeutic window of inulin and melatonin. Similar results were also found in the frequency of AH1-specific CD8$^+$ T cells among

PBMCs (**Fig. 3C, D**). Since tumor-infiltrating lymphocytes play pivotal roles in the outcome of immunotherapy, T lymphocytes in the tumor microenvironment were examined. Inulin or melatonin treatment combined with α-PD-1 IgG significantly enhanced intratumoral infiltration of T cells, compared α-PD-1 IgG alone (**Fig. 3E-H**).

Example IV.

This example describes changes in the gut microbiome.

The composition of the gut microbiome during the treatment was examined via 16S rDNA sequencing analysis. Oral gavage of these materials increased the operational taxonomic unit (OUT, **Fig. 4A**) as well as inverse Simpson diversity value (**Fig. 4B**), compared with PBS group, indicating that the treatments elevated the richness and diversity of gut microbiome. Nonmetric multidimensional scaling analysis (NMDS) clearly showed that oral gavage of these materials led to a distinct clustering of microbial community structure compared with PBS or free α-PD-1, especially for inulin (**Fig. 4C**). Further analysis in the family/genus level showed that oral administration of inulin, followed by α-PD-1 treatment increased the relative abundance of Akkermansia, Lactobacillus, Ruminococcus, and Butyricicoccus post, compared with α-PD-1 alone or PBS group (**Fig. 4D-F, Fig. 5A**). Recent studies have shown that Lactobacillus and Akkermansia can improve the anti-tumor efficacy of immune checkpoint blockade in tumor-bearing mice, while Butyricicoccus and Ruminococcus are known to generate short chain fatty acids (SCFAs) including butyrate as metabolites. Microbiome metabolite SCFAs, especially butyrate, are known to improve immune response as well as inhibit inflammation. Surprisingly, it was also found that free α-PD-1 treatment dramatically decreased the abundance of Roseburia (another crucial butyrate-producing bacteria) to almost 0%, compared to PBS group (**Fig. 4F**). Oral gavage of the candidate agents, especially inulin, increased the abundance of Roseburia in the gut. Analysis of SCFAs in fecal pellets further confirmed that oral gavage of inulin increased the concentration of lactate, propionate and butyrate (**Fig. 4G**). In contrast, free α-PD-1 group had lower propionate and butyrate, compared with the PBS group. Furthermore, the fitting curves and Spearman's correlation coefficients analysis showed that the tumor sizes were negatively correlated with the relative abundance of Akkermansia, Lactobacillus, Roseburia, Ruminococcus, and Butyricicoccus (**Fig. 4H**), suggesting beneficial roles of these commensal bacteria for cancer treatment. NMDS and microbiome composition results further clearly demonstrated that free

inulin and melatonin, but not α-PD-1, played the dominated role in manipulating the microbial community structure during the combined therapy with α-PD-1 **(Fig. 5)**.

Example V.

This example demonstrates that inulin gel further improves the efficacy of immune checkpoint blockade.

Given that inulin showed the best efficacy among these candidate materials with α-PD-1 and the reduced dosage (60 mg/dosage) didn't compromise the efficacy obviously, a 60 mg/dosage was chosen for inulin in the following study. Inulin gel via was prepared via a heating-cooling method, which ensured a large scale production with ease **(Fig 6A)**. This gel is injectable for oral gavage **(Fig. 7A)**. Scanning electron microscope (SEM) revealed that inulin gel exhibited fabric-like surface morphology **(Fig. 6A)**. Reduced sugar assay verified stability of inulin gel at stomach-like acidic environment for 2 h **(Fig. 7B)**. The antitumor effect of combining α-PD-1 was compared with either free inulin or inulin gel. Strikingly, inulin gel exhibited significantly higher tumor inhibition efficacy than free inulin **(Fig. 7B)**. The survival rate in inulin gel group was signifcantly prolonged, and 60% mice completely eradicated established tumors **(Fig 6C)**. These survivors were protected against tumor re-challenge with 1.5×10^5 CT26 tumor cells **(Fig 6D)**, demonstrating long-term immunity against tumor replase. Tetramer staining assay revealed that the frequency of AH1-specific $CD8^+$ T cells among PBMCs was significantly elavated after gavage of inulin gel, compared with free inulin **(Fig 6E)**. Meanwhile, the amount of tumor infiltrating $CD45^+CD8^+$ T cells, $CD45^+CD4^+$ T cells, as well as matured DC cells ($CD86^+CD11C^+$) were significantly increased **(Fig. 6F)**. Note that these tumor infiltrating $CD8^+$ T cells in inulin gel group exhibited better functionality against tumor in terms of improved AH1-tetramer$^+$ and decreased PD-1^+ biomarkers on cell surfaces, compared with inulin group. IFN-γ ELISPOT assay in spleen further revealed that inulin gel combined with α-PD-1 elicited robust IFN-γ expression among $CD8^+$ T cells **(Fig 6G and H)**, which was 3.5 and 4.6-fold higher than the inulin+α-PD-1 group and α-PD-1 group, respectively. Besides, the administration of α-CD8 depletion antibody completely abrogated the antitumor efficacy of inulin gel + α-PD-1. In sharp contrast, administration of α-Asialo GM1 or α-CD4 antibody did not affect the therapeutic efficacy of inulin gel + α-PD-1 therapy **(Fig 6I)**, revealing that $CD8^+$ T cells, but not $CD4^+$ T cells or NK cells, are the key lymphocytes for tumor inhibition and eradication.

Example VI.

This example demonstrates that inulin gel with improved retention in colon alters the gut microbiome.

FITC-inulin was employed to synthesize FITC-labeled inulin gel. In vivo gastrointestinal retetion imaging showed that the inulin gel group exhibited improved accumulation and retention in cecum and colon at 4.5 h post gavage, compared with free inulin group (**Fig 8A,B**). Fecal pellets were collected at preset time points post gavage of FITC-inulin or FITC-inulin gel and confirmed increased retention of FITC-inulin gel, compared with inulin (**Fig 8C**). These results were confirmed using an inulin detection kit, and the area under curve value clearly domonstrated the better retention of inulin gel in colon, compared with inulin (**Fig 8D**).

This prolonged retention of inulin gel resulted in increased OTU and inverse Simpson diversity values (**Fig 8E**). NMDS result and microbiome analysis in family level showed that there was a shift in microbial community structure to some extent between inulin and inulin gel groups (**Fig 8F**). The microbiome composition in genera level revealed that the relative abundance of Akkermansia, Ruminococcus, and Roseburia were significantly increased post gavage of inulin gel, compared with inulin group (**Fig 8G,H**), while the abundance of Lactobacillus and Butyricicoccus were comparable between these two groups.

To confirm the role of gut microbiome in antitumor efficacy, mice in specific pathogen-free (SPF) housing condition were given broad-spectrum antibiotics (ampicillin + colistin + streptomycin) for 7 days before tumor inoculation and continuous antibiotics treatment from day 5 post tumor inoculation. Broad-spectrum antibiotics treatment dramatically compromised the antitumor effects of inulin gel combined with α-PD-1 (**Fig. 8I**), demonstrating the crucial role of gut microbiome in the combination inulin gel plus α-PD-1 therapy.

Example VII.

This exmaple demonstrates the therapeutic efficacy of inulin gel in a second tumor model.

The inulin gel system was evaluated in MC38 tumor model using C57BL/6 mice as another mouse strain (**Fig 9A**). Previous study showed that MC38 cells had mutated neo-epitope within the Adpgk protein (ASMTNRELM (SEQ ID NO.: 2)→ASMTNMELM (SEQ ID NO.: 3) mutation) in the context of H-2Db molecules. Inulin gel combined with α-PD-1 induced higher IFN-γ expression in splenoic $CD8^+$ T cells via IFN-γ ELISPOT assay (**Fig 9B,C**), compared with

either α-PD-1, inulin gel, or free inulin + α-PD-1. As a result, inulin gel significantly slowed down the tumor growth and prolonged the survival of tumor-bearing mice (**Fig 9D,E**).

Example VIII.

This example demonstrates the safety of inulin gel plus α-PD-1 therapy.

The safety of inulin gel system was evaluated. Mice treated with inuline gel plus α-PD-1 therapy did not exhibit any changes in the complete blood counts and blood chemistry panels, compared with PBS treated mice. In addition, H&E staining of major organs did not show any signs of overt inflammation or tissue damage after inuline gel plus α-PD-1, indicating the safety of the combination therapy.

Example IX.

This example provides the materials and methods utilized in Exmaples I-VIII.

Inulin hydrogel preparation and characterization

300 mg of inulin (Sigma-Aldrich) was dissolved in 1.2 mL DI water. Then inulin solution was heated at 70°C for 5 min and kept at room temperature for 12 h to obtain inulin gel. For SEM observation, inulin gel was flash-frozen in liquid nitrogen and lyophilized. The samples were then sputter-coated with gold for 30s. The samples were visualized with MIRA3 TESCAN (voltage 15 kV). To simulate the potential degradation of inulin gel in stomach acid environment, inulin gel was incubated at strong acidic water (pH 2) for 2 or 24 h with gentle agitation. Samples were centrifuged and supernatant was collected. The dinitrosalicylic acid (DNS) method (Miller, 1959) was used for the quantitative analysis of the reducing sugar in supernatant. The intensity of developed color was measured at 540 nm using a microplate reader.

In vivo cancer immunotherapy

Mice were cared for under the guidelines from federal, state and local. All experimental animal procedures were approved by the University Committee on Use and Care of Animals (UCUCA) at University of Michigan, Ann Arbor. Female C57BL/6 or BALB/c mice of 6-8-week old were obtained from Jackson Laboratory. BALB/c mice were inoculated with 1.5×10^5 CT26 cells per mouse, while C57BL/6 mice were inoculated with 1.2×10^6 MC38 cells per mouse on the right flank by subcutaneous injection on day 0. Tumor-bearing mice were randomly assigned

to different groups on day 5. For prophylactic antitumor study, mice were received oral gavage with melatonin (100 mg/Kg bodyweight/dosage), EGCG (100 mg/Kg bodyweight /dosage), fucoidan (200 mg/Kg bodyweight /dosage), oligofructose (120 mg/dosage), or inulin (120 mg/dosage) three times for one week prior to tumor inoculation. After tumor inoculation, mice received oral gavage three times in the first week, followed by five times per week. Mice were injected *i.p.* with α-PD-1 antibody (100 μg/dosage) on days 10, 14, 18 and 22 post tumor inoculation. For the therapeutic therapy, mice were inoculated with tumor cells on day 0 as indicated above and treated with the indicated samples by oral gavage starting day 7 post tumor inoculation. Mice received oral gavage of the indicated samples (same dosage with the prophylactic antitumor study) five times per week while α-PD-1 antibody (100 μg/dose) was injected on days 11, 15, 19 and 23 post-tumor inoculation. Tumor size was measured at preset time, and tumor volume was calculated as length × width^2. For anti-tumor studies with inulin gel, the dosage of inulin gel or inulin was 60 mg/dosage. For the survival study, tumor-bearing mice were euthanized when the tumor size reached 1.5 cm in diameter or when animals became moribund with severe weight loss (> 20%) or had tumor ulceration exceeding 50% of the tumor volume. In the antibody depletion studies, CT26 tumor-bearing mice received oral gavage with inulin gel (60 mg/dosage) and α-PD-1 treatment as indicated above. CD8 T-cells, CD4 T-cells, and NK cells were depleted by i.p. administration days 8, 11 and 16 with 200 μg/dosage of anti-CD8 (Bioxcell, clone 2.43, #BP0061), anti-CD4 (Bioxcell, clone GK1.5, #BP0003-1), or anti-Asialo GM1 (Wako chemicals USA, Inc, #986-10001), respectively.

Tetramer analysis in PBMCs

Peripheral blood mononuclear cells (PBMCs) were collected at preset times to analyze tumor antigen-specific CD8$^+$ T cells in the systemic circulation. Red blood cells were lysed, and the remaining cells were blocked with anti-CD16/32 antibody for 10 min and stained with peptide-MHC tetramer, including H-2L^d-restricted SPSYVYHQF (SEQ ID NO.: 1) or H-2D^b-restricted ASMTNMELM (SEQ ID NO.: 3). Both the tetramers were provided by NIH Tetramer Core Facility. Cells were also stained anti-CD8-APC (BD Biosciences, #553035) and DAPI for flow cytometric analysis.

Tumor microenvironment analysis

After treatment with various samples, tumor tissues were excised at preset time points for analysis of tumor-infiltrating T cells. Tumor tissues were excised, cut into small pieces, and incubated with collagenase type IV (1 mg/ml) and of DNase I (0.1 mg/ml) with gentle shaking. After 30 min, cell suspension was filtered through a 70-μm strainer. Cells were washed with FACS buffer and blocked with anti-CD16/32 antibody. Cells were then stained with various antibodies (CD4 Monoclonal Antibody (GK1.5)-PE (eBioscience), APC-Anti-CD45 Rat Monoclonal Antibody (clone: 30-F11), FITC-Anti-CD45 Rat Monoclonal Antibody (clone: 30-F11), FITC-Rat Anti-Mouse CD8a Clone 53-6.7 (BD Biosciences), PE labeled H-2L^d-restricted SPSYVYHQF (SEQ ID NO.: 1), FITC-Anti-CD86 Rat Monoclonal Antibody (clone: GL-1, BioLegend), PE-CD11c Armenian Hamster anti Mouse (Clone: N418, eBioscience), PE-Cy7-Anti-mouse PD-1 (clone: 29F.1A12, BioLegend), FITC-CD44 Rat anti-Human/Mouse (clone: IM7, eBioscience), PE-Cy7-CD62L Monoclonal Antibody (MEL-14) (eBioscience), PE-Tcf1/Tcf7 (C63D9) Rabbit mAb (Cell Signaling Technology, #14456), PE-Cy7-Anti-mouse CD86 (Clone: GL1, BD Bioscience), FITC anti-mouse/human CD11b (M1/70, BioLegend), PE-anti-mouse F4/80 (BM8, BioLegend), or APC anti-mouse CD206 (MMR, BioLegend)). The cells were washed and stained with DAPI, or 7-AAD, or efluor 450 for flow cytometric analysis.

Gut microbiome analysis

Tumor-bearing mice received treatments as indicated above. On day 20, the fecal pellets were collected and stored at -80°C before the gut microbial analysis. Both microbiome DNA isolation and 16S rRNA Sequencing were completed by The University of Michigan Microbial Systems Molecular Biology Laboratory. Isolation of microbial DNA from mice fecal samples was performed using Qiagen MagAttract Power Microbiome kit. The V4 region of the 16S rRNA-encoding gene was amplified from the extracted DNA using the barcoded dual-index primers developed by Kozich et al. (1). Briefly, barcoded dual-index primers specific to the V4 region of the 16S rRNA gene amplified the DNA. The conditions for PCR were as follows: 2 min at 95°C, 30 cycles of 95°C for 20 s, 55°C for 15 s, 72°C for 5 min, and 72°C for 10 min. The size of the amplicon library (~399 bp) was confirmed by Agilent Bioanalyzer. Pooled amplicon library was then sequenced on the Illumina MiSeq platform using the 500 cycle MiSeq V2 Reagent kit (catalog no. MS-102-2003) according to the manufacturer's instructions with modifications of the primer set with custom read 1/read 2 and index primers added to the reagent cartridge. The "Preparing Libraries for Sequencing on the MiSeq" (part 15039740, Rev. D)

protocol was used to prepare libraries with a final load concentration of 5.5 pM and spiked with 15% PhiX to create diversity within the run. The microbial 16S rRNA gene sequencing data from mice fecal collections were processed by Mothur. Silva reference files (release 132) were used to align sequences, and the open reference OTU picking protocol was used at 97% sequence identity.

Fecal pH and SCFAs measurement

Fresh fecal pellets of mice were collected and weighted on day 20 post tumor inoculation and treatments. Fecal pellets were homogenized in DI water and centrifuged at 3000 X g for 5 min. The pH of the supernatant was detected by pH meter. For SCFAs measurement, SCFAs were extracted from the fecal pellets using Milli-Q water. The solution was centrifuged for 5 min at 10000 X g (4°C) to pellet bacteria and other solids. The supernatant was collected, and SCFAs were measured via ion chromatography in University of Michigan Biological Station. The concentration of SCFAs was determined using an external standard method.

IFN-γ ELISPOT assay

CT26 tumor-bearing BALB/c mice received the indicated samples via oral gavage for five times per week starting day 7 of tumor inoculation. The animals were also administered i.p. with α-PD-1 antibody (100 μg) on days 11, 15, and 19. On day 23, the animals were euthanized, and their spleens were analyzed for anti-tumor T-cell responses using IFN-γ ELISPOT assay. ELISPOT plate was coated with capture antibody for 24 h and blocked with DMEM + 10% FBS for 2 h. These splenocytes were added to 96-well plate with a density of 2×10^5 alive cells/well. Meanwhile, AH1 peptide (SPSYVYHQF (SEQ ID NO.: 1), 20 μg/mL) was added to stimulate splenocytes. Ionomycin and PMA were employed as the positive control. After 18 h, IFN-γ spots were detected with biotinylated detection antibody, followed by streptavidin-HRP and AEC substrate kit. The number of IFN-γ spots were measured in the Cancer Center Immunology Core of University of Michigan. For IFN-γ ELISPOT assay in MC38 tumor-bearing C57BL/6 mice was conducted in a similar way. PBMCs obtained on day 20 were used for IFN-γ ELISPOT assay.

Inulin hydrogel retention in the gastrointestinal system

Retention of inulin gel in the gastrointestinal system was measured using FITC-inulin gel. To prepare FITC-tagged inulin hydrogel, 47.5 mg inulin and 12.5 mg FITC-inulin (Sigma-Aldrich) were mixed in 200 μL DI water. For in vivo imaging of inulin, mice received oral gavage with FITC-tagged inulin or inulin gel and euthanized at preset time points. The stomach, small intestine, cecum, colon and rectum were harvested and washed with PBS before fluorescence imaging with the IVIS optical imaging system. For detection of inulin content in fecal pellets, FITC-tagged inulin or inulin gel was orally gavaged into mice, and the fecal pellets were collected at preset time points. The fecal pellets were weighted and resuspended in DI water. The sample solution was then centrifuged, and the fluorescence intensity of supernatants was measured using a microplate reader. The fluorescence intensity was normalized to 1 mg/mL fecal sample. For detection of inulin content in colon, mice were gavaged with inulin or inulin gel (60 mg/dose) and euthanized at preset time points post gavage. The fecal pellets in colon was harvested, weighted, homogenized, and centrifuged. The supernatants were diluted 20 times and used for detection of inulin. Inulin was detected via PicoProbe™ Inulin Assay Kit (BioVision) according to the manufacturer's protocol.

Antibiotic water treatment

Mice received sterile drinking water containing antibiotics for one week before tumor inoculation. After tumor inoculation, the animals received normal drinking water for 5 days to avoid the direct effect of antibiotics on tumor engraftment and formation. After 5 days, tumor-bearing mice received drinking water with antibiotics for the reminder of the studies. The antibiotic drinking water containing ampicillin (0.3 mg/ml), streptomycin (2.5 mg/ml), and colistin (0.3 mg/ml) was replaced twice every week.

Biosafety evaluation

CT26 tumor-bearing mice were treated with the regimen as described above. On day 29, blood samples were collected for complete blood count (CBC) (including eosinophils, lymphocytes, monocytes, platelets, red blood cells, hemoglobin, mean platelet volume, red cell distribution width (RDW) and mean corpuscular hemoglobin (MCH)). Serum samples were used for biochemistry analysis, including alanine transaminase (ALT), aspartate aminotransferase (AST), blood urea nitrogen (BUN), glucose, cholesterol, and creatine phosphokinase (CPK).

Mice were euthanized on day 29, and lung, liver, spleen, heart and kidney were collected for H&E staining.

Statistical analysis

Animal studies were performed after randomization. Data were analyzed by paired or unpaired t-tests or one- or two-way analysis of variance (ANOVA), followed by multiple comparison test with Prism 8.0 (GraphPad Software). $p < 0.05$ was considered statistically significant.

EXAMPLE X.

This example demonstrates a method of delivering bacteria and probiotics using inulin-gel formulation.

There is intense research interest for colon-targeted delivery of probiotics for improving health benefits. A new strategy of using prebiotic-based gel formulations for co-delivery of bacteria (probiotics) was developed. As a proof-of-concept, E. coli was used as a model bacteria organism and used inulin-gel formulation described earlier to encapsulate and deliver E. coli.

E. coli expressing GFP was used to assess entrapment and growth of E. coli in inulin-gel formulation. E. coli entrapped in inulin gel demonstrated a typical bacteria growth pattern of four phases (**Figure 10**). The cell density was proportional to the GFP expression before reaching the stationary phase. The cell number stayed constant in stationary phase and collapsed in lag phase due to the exhaustion of nutrient and generation of metabolites, while the fluorescence accumulated gradually. This demonstrated that inulin-gel can be used to entrap E. coli and maintain its viability.

The growth of E. coli in culture dishes was compared versus in inulin-gel. E. coli showed comparable fluorescence intensity between inulin gel-entrapped group and PBS control group (i.e. culture dish). The inulin gel emitted negligible autofluorescence at the wave length of GFP.

When viability of E. coli was compared by CFU counting, it was observed that E. coli entrapped in inulin gel exhibited increased viability (Table 1). The calculated CFU of inulin gel group was 3-fold higher than the number acquired in PBS. This demonstrates that inulin gel can entrap and promote the growth of bacteria. These results, combined with the results shown in prior examples, indicate that inulin gel designed for colon retention can be used for entrapping bacteria (probiotics) and delivering them to colon tissues.

Table 1. Cell Viability determined by CFU counting after 24hrs incubation in PBS and encapsulation in inulin gel respectively.

E. coli@PBS	E. coli@Inulin Gel
1.61×10^8 CFU/mL	5.25×10^8 CFU/mL

Example XI.

This example describes the materials and methods utilized in Example X.

E. coli Culture and CFU Counting E. coli was cultured in Tryptic Soy Broth (TSB) media supplemented with 100 μg/mL ampicillin, 37°C, 200 rpm, overnight. Optical density at 600nm was measured. 10-fold serial dilution was applied to cell culture and dilutions were spread onto TSB agar plate, culturing for 12 hrs, 37°C. CFU was calculated through numbers of each dilution factor.

Inulin Gel Preparation and E. coli Encapsulation Inulin (330 mg/mL) was suspended in sterile PBS buffer using vortex. Suspension was heated to 70°C for 5 mins and then cooled down for 10 mins under room temperature. E. coli culture of 7.5×10^9 CFU/mL density was added to the cooled suspension in a ratio of E.coli : Inulin = 1:9, acquiring the E. coli gel with final concentration of 7.5×10^8 CFU@300 mg/mL.

Example XII.

Figures 1-10 showed results generated in BABL/c mice obtained from Jackson Laboratory. As mice from different animal vendors are known to have distinct gut microbiome, experiments were conducted that sought to validate the therapeutic efficacy of inulin gel plus α-PD-1 combo-therapy in mice obtained from other animal vendors. BABL/c mice obtained from Charles River and Taconic Farm were inoculated with CT26 tumor cells and treated with inulin gel plus α-PD-1 combo-therapy as shown in Figure 13A. Inulin gel plus α-PD-1 combo-therapy exerted anti-tumor efficacy in BABL/c mice obtained from Charles River and Taconic Farm (Figure 13B-C), thus showing that the anti-tumor efficacy of the combo-therapy is not vendor-specific effects.

In addition to CT26 tumor model in BABL/c mice, experiments were conducted that sought to validate these results in other tumor models. Inulin gel (60 mg/dose) plus α-PD-1 combo-therapy also generated strong $CD8^+$ T cell responses with robust anti-tumor efficacy in

C57BL/6 mice (Jackson Laboratory) bearing either MC-38 colon carcinoma or B16F10 melanoma (Figure 13D-E), thus showing utility of this strategy in multiple tumor models in multiple mouse strains.

Example XIII.

In order to understand the impact of the composition of inulin gel on *in vivo* outcomes, experiments were conducted that synthesized various inulin gel formulations using inulin of various degrees of polymerization (DP).

Materials and Methods

Inulin samples were purchased from Now Foods, Swanson Health Products, Sigma-Aldrich, and Orafti.

^{1}H-NMR. Each 5 mg of inulin powder was dissolved in 600 µL D_2O to prepare ^{1}H-NMR samples. Samples were run on Agilent/Varian 400MHz NMR spectrometer with a 5mm ONE probe with multinuclear capabilities, operated by host software VNMRJ 3.2. The DP was calculated through the ^{1}H-NMR spectrum as described previously (T. Barkhatova, M. Nazarenko, M. Kozhukhova, I. Khripko, *Foods and Raw materials* 2015, 3).

MALDI-TOF-MS. Each 10 mg inulin sample was dissolved in 1.00 ml water, 0.25 ml methanol, and 0.25 ml acetonitrile. Then 2 µL sample solution was mixed with the matrix solution, and spotted onto the target plate. The matrix solution was 2,5-DHB, at a concentration of 4 mg/mL, dissolved in 50/50 acetonitrile/water with 0.1% TFA. The samples were run on Bruker Autoflex Speed in linear mode. The instrument was mass calibrated with a mixture on bovine insulin and cytochrome C in a 2,5-DHB matrix.

Preparation of inulin gel. A desired weight of inulin powder was dissolved in 1.0 mL deionized water. Then inulin solution was heated at 70°C for 5 min with 1000 rpm shake and kept at room temperature overnight for gelatinization.

Rheology test. Inulin gel (samples 3 and 5) for rheology test was prepared as described above with a concentration of 300 mg inulin in 1.0 mL deionized water. Inulin (3) suspension was prepared with same concentration but without heating and cooling procedures. Inulin gel (sample 1) was prepared with same gelatinization steps but in a concentration of 700 mg inulin in 1.0 mL deionized water. Measurements were performed at 25°C with MCR702 TwinDrive rheometer manufactured by Anton Paar equipped with parallel PP60 Ti plates with 0.100 mm

gap. All tests were conducted at the strain of 1% which was in the range of the linear viscoelastic region of the studied samples. G' represents elastic modulus, G'' represents viscous modulus.

Inulin content in fecal samples. To detect inulin content in fecal samples, mice were oral gavaged with inulin gel (60 mg/dose). And fresh fecal pellets of mice were collected and weighted at preset time points (0, 2.5, 5, 7.5, 10 and 12.5h) post gavage. Each fecal pellet was homogenized in 800 μL DI water and centrifuged at 20000 RCF for 10 min. Then the supernatants were diluted 25 times for quantifying the inulin content with PicoProbe™ Inulin Assay Kit (BioVision) according to the manufacturer's instructions.

In vivo study. CT26 tumor-bearing BALB/c mice (female, Jackson Laboratory, aged 6-8 weeks) were randomly assigned to different groups for treatments. Mice were gavaged with inulin gel (60 mg/dose) four times in every five days, and α-PD-1 antibody (100 μg/dose) was administrated via intraperitoneal injection once every four days. Starting from day 5 post tumor inoculation, the tumor volume and mouse body weight were measured every other day. Tumor volume was calculated as (length × width^2)/2.

Statistical analysis. GraphPad Prism 8 was used to analyze the statistical data. The results are expressed as means ± SEM. Differences among groups were analyzed by two-way ANOVA with Bonferroni's multiple comparisons test. The differences were considered significant for p values *P < 0.05, **P < 0.01 and ***P < 0.001.

Results

Inulin samples with various degrees of polymerization (DP) were obtained from different companies and analyzed by ^{1}H-NMR (Figure 14). ^{1}H-NMR spectrum analyses revealed the following (Figure 14). Inulin sample #1 had the average DP≈7, Mw≈1314 Da. Inulin sample #2 had the average DP≈10, Mw≈1800 Da. Inulin sample #3 had the average DP≈23, Mw≈3906 Da. Inulin sample #4 had the average DP≈26, Mw≈4392 Da. Inulin sample #5 had the average DP≈28, Mw≈4716 Da.

Furthermore, MALDI-TOF-MS analyses revealed that inulin samples #1, #2, #3, #4 and #5 had molar mass between 990 and 6336 Da (Figure 15). However, the increase in intensity of peaks around 990-2124 Da suggested prevalence of lower DP inulin chain between 5 and 12. It is likely that the inulin chains with low DP are shorter and easier to be excited to be detected, while the long inulin chains with higher DP are tightly entangled with each other and are less likely to be excited off the substrate leading to lower intensity of signal MALDI-TOF-MS analyses.

Experiments were next conducted that examined inulin gel formation using these inulin samples with various DPs. As shown in Figure 16, inulin samples with DP 7 and DP 10 (samples 1 and 2) were more soluble in water before heating, compared with inulin samples with higher DP (samples 3-5). For inulin gel formation under the same condition, much higher concentration (700 mg/g water) of inulin was needed for inulin sample 1 with DP 7, compared with other four inulin samples with higher DPs. Inulin sample 5 with the highest DP 28 was able for form inulin gel with even inulin concentration as low as 100 mg/g in water. These results showed that inulin with higher DP was less soluble in water and requires less concentration for forming inulin gel.

The DP of inulin also has impact on rheological properties of the gel. In Figure 17, with the rise of DP from 7 (sample 1) to 28 (sample 5), both elastic modulus (G') and viscous modulus (G''), increased by ~10-fold. Inulin sample 3 exhibited G' and G'' at intermediate values compared with inulin sample 1 and 5. Compared with free inulin solution, all three inulin gels formed with inulin sample 1, 3, and 5 had greater G' and G'' values. These results indicated that these samples were more solid-like rather than liquid, confirming successful inulin gel formation.

Experiments were next conducted that evaluated the colon retention behavior of various inulin gel formulations *in vivo*. Naïve mice were orally gavaged with inulin gel with various DPs, and fecal samples were analyzed for inulin content over time. As shown in Figure 18, inulin gels with lower DPs had an earlier peak time, with 6.17 h post gavage for inulin sample 1 and 5.38 h post gavage for inulin sample 2. And for inulin gels with higher DPs, longer peak time was observed, with 7.73 h for inulin sample 3 and 10.25 h for inulin sample 5. Furthermore, the relative total inulin content in feces gradually decreased with the rise of the DP regarding the area under the curves. These indicated that inulin gel with higher DP prolonged the retention time of inulin in the gastrointestinal tract, which may further increase the utilization of inulin by the gut microbiota.

Experiments were next conducted that assessed the therapeutic efficacy of various inulin gel formulations, namely inulin gel formed with DP 7, 10, 23, and 28. Balb/c mice bearing s.c. flank CT26 tumors were treated with oral gavage of DP-variable inulin gels (60 mg/dose) plus intraperitoneal administration of α-PD-1 (100 ug/dose). Tumor volume and mouse body weight were recorded every other day. Whereas α-PD-1 alone treatment group exhibited a modest anti-tumor efficacy, α-PD-1 treatment combined with inulin gel formed with either DP 10 or DP 23 exhibited improved anti-tumor efficacy (Figure 19). Notably, inulin gel with DP 28 exhibited

markedly enhanced anti-tumor efficacy, compared with inulin gel with DP 10 or DP23 (Figure 19). It was also observed that inulin gel with low DP of 7 seemed to decrease the anti-tumor efficacy of α-PD-1 therapy. These results suggested that the composition of inulin gel had a major role in the anti-tumor efficacy of α-PD-1 therapy and that inulin gel with longer DP exhibited superior an-tumor efficacy, potentially due to prolonged retention time in the gastrointestinal tract as shown in Figure 18. In all animals treated with various inulin gel formulations plus α-PD-1 therapy, no major toxicity or any negative change in animal body weight was observed (Figure 20), indicating safety of the inulin gel plus α-PD-1 combo-therapy.

Example XIV.

Experiments were next conducted that examined the impact of inulin concentration and temperature on inulin gel formation. Inulin (Sigma) with an average DP 23 was first mixed with water, giving desired concentrations of 15, 20, 25, and 30% w/v. Mixtures were heated to 40, 50, 60, 70 °C respectively for 5 minutes. Gel formation was examined by flipping the Eppendorf tubes after cooling overnight at room temperature. For inulin of given DP 23, higher inulin concentration led to inulin gel formation (Figure 21). Higher temperature applied during the gelation process promote inulin gel formation (Figure 21). These results showed the concentration and temperature dependency of inulin gel formation.

Example XV.

Experiments were next conducted that examined gel formation using potato starch, another prebiotic natural fiber. The impact of potato starch concentration on gel formation was examined. Food grade potato starch (Bob's Red Mill) was pre-hydrated at desired concentrations of 0.1, 0.5, 2.5, and 5% w/v in water, followed by gentle stirring at 70 °C. Figure 22 shows potato starch gels. Potato starch was instantly gelatinized at concentrations above 5% w/v when the swelling was completed.

Example XVI.

Experiments were next conducted involving the formation of new fiber gels by combining inulin with other natural dietary fibers or pharmaceutical excipients. Briefly, inulin gels were manufactured by first mixing 23% w/w inulin together with other excipients, including resistant potato starch, pectin, guar gum, bean gum, gelatin, or glycerol. Other natural fibers would

provide additional nutrient source for commensal microbiome, while other excipients served as thickening reagents in these formulations. The mixtures were then heated at 70°C for 5 minutes, followed by cooling at room temperature overnight. During the manufacturing processes, both pre-dissolving and dry-blending were used in order to add the excipients, based on individual dissolutions in water. Figure 23 shows the gelation process for #1 inulin gel, #2, inulin gel containing resistant potato starch, #3 inulin gel containing guar gum, #4 inulin gel containing pectin, and #5 inulin gel containing bean gum. The ingredients were first mixed in water (top panel), heated at 70°C for 5 minutes (middle panel), followed by cooling at room temperature overnight, leading to the formation of fiber gels (bottom panel) (Figure 23).

Experiments were next conducted that varied the amount of natural fibers and excipients added to inulin gel and determined the ideal composition for forming fiber gels. As shown in Figure 24, for inulin gels containing inulin content of 23% w/w, they could be reliably added with the following amount of natural fibers or pharmaceutical excipients: 5% potato starch, 2% pectin, 0.5% guar gum, 1.0% bean gum, 5.0% gelatin, or 50% glycerol (w/w). The indicated values are the maximum amount of each ingredient that could be added to 23% w/w inulin gel without disrupting gel formation.

Experiments were next conducted that measured rheological properties of these optimized fiber gels. Rheology measurements were conducted at 25°C with MCR702 TwinDrive Rheometer (Anton Paar, USA) equipped with parallel 40 mm plates with 0.100 mm gap. All frequency sweep measurements were performed at the strain of 1% which is in the range of linear viscoelastic region of the studied formulations. G' represents elastic modulus, G'' represents viscous modulus. Flow curve was obtained as a function of shear rate ranging from to 10^{-1} to 10^{2} s^{-1} at 25°C. The reported results are average of at least 3 replications (Figure 25). All tested new fiber gel formulations exhibited weaker gel strength, as shown by the lower values of G' and G'', compared with pure inulin gel. However, inulin gel combined with potato starch demonstrated ~10-fold increase in terms of viscosity.

INCORPORATION BY REFERENCE

The entire disclosure of each of the patent documents and scientific articles referred to herein is incorporated by reference for all purposes.

EQUIVALENTS

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative rather than limiting the invention described herein. Scope of the invention is thus indicated by the appended claims rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are intended to be embraced therein.

CLAIMS

WHAT IS CLAIMED IS:

1. A method for increasing the efficacy of a cancer immunotherapy or vaccine through administration of 1) a cancer immunotherapy or vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

2. The method of claim 1, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the vaccine or cancer immunotherapy.

3. The method of claim1,

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine or cancer immunotherapy; or

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine or cancer immunotherapy.

4. The method of claim 1, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine or cancer immunotherapy.

5. The method of claim 1, wherein the vaccine is a vaccine for treating cancer, and/or a vaccine for treating and/or protecting from infectious pathogens.

6. The method of claim 1, wherein the subject is a human subject.

7. The method of claim 1, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent.

8. The method of claim 7, wherein the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

9. The method of claim 7, wherien the fiber containing prebiotic agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47.

10. The method of claim 9,

wherein the gel-based inulin formulation has an average degree of polymerization of approximately 28,

wherein the gel-based inulin formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

11. The method of claim 1, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

12. The method of claim 1, wherein the cancer immunotherapy comprises one or more immune checkpoint inhibitor (ICI) inhibitors.

13. The method of claim 12, wherein the one or more ICI inhibitors are capable of binding to, blocking, and/or inhibit the activity of one or more of CTLA-4, PDL1, PDL2, PD1, BTLA, HVEM, TIM3, GAL9, LAG3, VISTA, KIR, 2B4, CD160 and CGEN-15049.

14. The method of claim 12, wherein the one or more ICI inhibitors are selected from Tremelimumab (CTLA-4 blocking antibody), anti-OX40, PD-L1 monoclonal Antibody (Anti-B7-H1; MEDI4736), MK-3475 (PD-1 blocker), Nivolumab (anti-PD1 antibody), CT-011 (anti-PD1 antibody), BY55 monoclonal antibody, AMP224 (anti-PDL1 antibody), BMS-936559 (anti-

PDL1 antibody), MPLDL3280A (anti-PDL1 antibody), MSB0010718C (anti-PDL1 antibody) and Yervoy/ipilimumab (anti-CTLA-4 checkpoint inhibitor).

15. The method of claim 1, wherein the cancer is any type of cancer responsive to cancer immunotherapy or cancer vaccine treatment.

16. The method of claim 1, wherein the cancer is one or more of breast, ovarian, prostate, lung, kidney, gastric, colon, testicular, head and neck, pancreas, brain, melanoma, and other tumors of tissue organs and hematological tumors, such as lymphomas and leukemias, including acute myelogenous leukemia, chronic myelogenous leukemia, chronic lymphocytic leukemia, T cell lymphocytic leukemia, and B cell lymphomas.

17. The method of claim 1, further comprising administering to the subject one or more chemotherapeutic agents selected from the group consisting of an alkylating agent, an antimetabolite, an anthracycline, an antitumor antibiotic, a monoclonal antibody, a platinum agent, a plant alkaloid, a topoisomerase inhibitor, a vinca alkaloid, a taxane, and an epipodophyllotoxin.

18. The method of claim 1, wherein the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

19. The method of claim 1, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

20. The method of claim 1, wherein administration of 1) a cancer immunotherapy or a vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome, results in one or more of

an increased anti-tumor efficacy of the cancer immunotherapy or vaccine, and

a stronger immune response (e.g., increased anti-tumor T cell frequency among PBMCs), enhanced inhibition of tumor growth.

21. A method for inhibiting the ability of a cancer cell to induce immune dysfunction, comprising administration of 1) a cancer immunotherapy or vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome;

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine or cancer immunotherapy; or

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine or cancer immunotherapy.

22. The method of claim 21, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the cancer vaccine or cancer immunotherapy.

23. The method of claim 21, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine or cancer immunotherapy.

24. The method of claim 21, wherein the vaccine is a vaccine for treating cancer, and/or a vaccine for treating and/or protecting from infectious pathogens.

25. The method of claim 21, wherein the subject is a human subject.

26. The method of claim 21, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent.

27. The method of claim 26, wherein the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

28. The method of claim 26,

wherien the fiber containing prebiotic agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47 (e.g., approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33)) and/or

wherein the gel-based inulin formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

29. The method of claim 21, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

30. The method of claim 21, wherein the cancer immunotherapy comprises one or more immune checkpoint inhibitor (ICI) inhibitors.

31. The method of claim 30, wherein the one or more ICI inhibitors are capable of binding to, blocking, and/or inhibit the activity of one or more of CTLA-4, PDL1, PDL2, PD1, BTLA, HVEM, TIM3, GAL9, LAG3, VISTA, KIR, 2B4, CD160 and CGEN-15049.

32. The method of claim 30, wherein the one or more ICI inhibitors are selected from Tremelimumab (CTLA-4 blocking antibody), anti-OX40, PD-L1 monoclonal Antibody (Anti-B7-H1; MEDI4736), MK-3475 (PD-1 blocker), Nivolumab (anti-PD1 antibody), CT-011 (anti-PD1 antibody), BY55 monoclonal antibody, AMP224 (anti-PDL1 antibody), BMS-936559 (anti-PDL1 antibody), MPLDL3280A (anti-PDL1 antibody), MSB0010718C (anti-PDL1 antibody) and Yervoy/ipilimumab (anti-CTLA-4 checkpoint inhibitor).

33. The method of claim 21, wherein the cancer is any type of cancer responsive to cancer immunotherapy or cancer vaccine treatment.

34. The method of claim 21, wherein the cancer is one or more of breast, ovarian, prostate, lung, kidney, gastric, colon, testicular, head and neck, pancreas, brain, melanoma, and other

tumors of tissue organs and hematological tumors, such as lymphomas and leukemias, including acute myelogenous leukemia, chronic myelogenous leukemia, chronic lymphocytic leukemia, T cell lymphocytic leukemia, and B cell lymphomas.

35. The method of claim 21, further comprising administering to the subject one or more chemotherapeutic agents selected from the group consisting of an alkylating agent, an antimetabolite, an anthracycline, an antitumor antibiotic, a monoclonal antibody, a platinum agent, a plant alkaloid, a topoisomerase inhibitor, a vinca alkaloid, a taxane, and an epipodophyllotoxin.

36. The method of claim 21, wherein the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

37. The method of claim 21, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

38. The method of claim 21, wherein administration of 1) a cancer immunotherapy or vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome, results in one or more of

an increased anti-tumor efficacy of the cancer immunotherapy or vaccine, and

a stronger immune response (e.g., increased anti-tumor T cell frequency among PBMCs), enhanced inhibition of tumor growth.

39. A method of treating cancer in a subject, comprising administering to the subject 1) a cancer immunotherapy or a cancer vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

40. The method of claim 39, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the cancer vaccine or cancer immunotherapy.

41. The method of claim 39, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the cancer vaccine or cancer immunotherapy.

42. The method of claim 39, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the cancer vaccine or cancer immunotherapy.

43. The method of claim 39, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the cancer vaccine or cancer immunotherapy.

44. The method of claim 39, wherein the subject is a human subject.

45. The method of claim 39, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent.

46. The method of claim 45, wherein the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

47. The method of claim 45,

wherien the fiber containing prebiotic agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47 (e.g., approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33)) and/or

wherein the gel-based inulin formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

48. The method of claim 39, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

49. The method of claim 39, wherein the cancer immunotherapy comprises one or more immune checkpoint inhibitor (ICI) inhibitors.

50. The method of claim 49, wherein the one or more ICI inhibitors are capable of binding to, blocking, and/or inhibit the activity of one or more of CTLA-4, PDL1, PDL2, PD1, BTLA, HVEM, TIM3, GAL9, LAG3, VISTA, KIR, 2B4, CD160 and CGEN-15049.

51. The method of claim 49, wherein the one or more ICI inhibitors are selected from Tremelimumab (CTLA-4 blocking antibody), anti-OX40, PD-L1 monoclonal Antibody (Anti-B7-H1; MEDI4736), MK-3475 (PD-1 blocker), Nivolumab (anti-PD1 antibody), CT-011 (anti-PD1 antibody), BY55 monoclonal antibody, AMP224 (anti-PDL1 antibody), BMS-936559 (anti-PDL1 antibody), MPLDL3280A (anti-PDL1 antibody), MSB0010718C (anti-PDL1 antibody) and Yervoy/ipilimumab (anti-CTLA-4 checkpoint inhibitor).

52. The method of claim 39, wherein the cancer is any type of cancer responsive to cancer immunotherapy or cancer vaccine treatment.

53. The method of claim 39, wherein the cancer is one or more of breast, ovarian, prostate, lung, kidney, gastric, colon, testicular, head and neck, pancreas, brain, melanoma, and other tumors of tissue organs and hematological tumors, such as lymphomas and leukemias, including acute myelogenous leukemia, chronic myelogenous leukemia, chronic lymphocytic leukemia, T cell lymphocytic leukemia, and B cell lymphomas.

54. The method of claim 39, further comprising administering to the subject one or more chemotherapeutic agents selected from the group consisting of an alkylating agent, an antimetabolite, an anthracycline, an antitumor antibiotic, a monoclonal antibody, a platinum agent, a plant alkaloid, a topoisomerase inhibitor, a vinca alkaloid, a taxane, and an epipodophyllotoxin.

55. The method of claim 39, wherein the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

56. The method of claim 39, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

57. The method of claim 39, wherein administration of 1) a cancer immunotherapy or cancer vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome, results in one or more of

an increased anti-tumor efficacy of the cancer immunotherapy or cancer vaccine, and

a stronger immune response (e.g., increased anti-tumor T cell frequency among PBMCs),

enhanced inhibition of tumor growth.

58. A method of treating or preventing a condition characterized with dysregulated gut microbiome activity, comprising administering to the subject an agent capable of elevating the richness and diversity of the subject's gut microbiome.

59. The method of claim 58, wherein the subject is a human subject.

60. The method of claim 58, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent.

61. The method of claim 60, wherein the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

62. The method of claim 60,

wherien the fiber containing prebiotic agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47 (e.g., approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33)), and/or

wherein the gel-based inulin formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

63. The method of claim 58, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

64. The method of claim 58, wherein the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

65. The method of claim 58, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

66. The method of claim 58, wherein the condition characterized with dysregulated gut microbiome activity is an autoimmune disease, a neurological disorder, diabetes, and/or obesity.

67. The method of claim 58, wherein the condition characterized with dysregulated gut microbiome activity is selected from rheumatoid arthritis, multiple sclerosis diabetes (e.g., type 1 diabetes mellitus), autoimmune diseases of the thyroid (e.g., Hashimoto's thyroiditis, Graves' disease), thyroid-associated ophthalmopathy and dermopathy, hypoparathyroidism, Addison's disease, premature ovarian failure, autoimmune hypophysitis, pituitary autoimmune disease, immunogastritis, pernicious angemis, celiac disease, vitiligo, myasthenia gravis, pemphigus vulgaris and variants, bullous pemphigoid, dermatitis herpetiformis Duhring, epidermolysis bullosa acquisita, systemic sclerosis, mixed connective tissue disease, Sjogren's syndrome, systemic lupus erythematosus, Goodpasture's syndrome, rheumatic heart disease, autoimmune polyglandular syndrome type 1, Aicardi–Goutières syndrome, Acute pancreatitis Age-dependent macular degeneration, Alcoholic liver disease, Liver fibrosis, Metastasis, Myocardial infarction,

Nonalcoholic steatohepatitis (NASH), Parkinson's disease, Polyarthritis/fetal and neonatal anemia, Sepsis, and inflammatory bowel disease.

68. The method of claim 58, further comprising administering to the subject one or more of the following additional therapeutic agents: disease-modifying antirheumatic drugs (e.g., leflunomide, methotrexate, sulfasalazine, hydroxychloroquine), biologic agents (e.g., rituximab, infliximab, etanercept, adalimumab, golimumab), nonsteroidal anti-inflammatory drugs (e.g., ibuprofen, celecoxib, ketoprofen, naproxen, piroxicam, diclofenac), analgesics (e.g., acetaminophen, tramadol), immunomodulators (e.g., anakinra, abatacept), glucocorticoids (e.g., prednisone, methylprednisone), TNF-α inhibitors (e.g., adalimumab, certolizumab pegol, etanercept, golimumab, infliximab), IL-1 inhibitors, and metalloprotease inhibitors. In some embodiments, the therapeutic agents include, but are not limited to, infliximab, adalimumab, etanercept, parenteral gold or oral gold.

69. A method for increasing the efficacy of a vaccine through administration of 1) a vaccine to a subject, and 2) administration of an agent capable of elevating the richness and diversity of the subject's gut microbiome.

70. The method of claim 69, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to, concurrent with, and/or after administration of the vaccine.

71. The method of claim 69,

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs concurrent with administration of the vaccine; or

wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to administration of the vaccine.

72. The method of claim 69, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome occurs prior to and concurrent with administration of the vaccine.

73. The method of claim 69, wherein the vaccine is a vaccine for treating cancer, and/or a vaccine for treating and/or protecting from infectious pathogens.

74. The method of claim 69, wherein the subject is a human subject.

75. The method of claim 69, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is a fiber containing prebiotic agent.

76. The method of claim 75, wherein the fiber containing prebiotic agent is selected from epigallocatechin gallate (EGCG), fucoidan, potato starch, oligofructose and inulin.

77. The method of claim 75,

wherien the fiber containing prebiotic agent is a gel-based inulin formulation having an average degree of polymerization at or higher than 20 and at or less than 47 (e.g., approximately 28 (e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33)), and/or

wherein the gel-based inulin formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

78. The method of claim 69, wherein the agent capable of elevating the richness and diversity of a subject's gut microbiome is melatonin.

79. The method of claim 69, wherein the agent capable of elevating the richness and diversity of the subject's gut microbiome is administered orally.

80. The method of claim 69, wherein administration of the agent capable of elevating the richness and diversity of the subject's gut microbiome results in increased relative abundance of Akkermansia, Lactobacillus, Ruminococcus, Roseburia, and Butyricicoccus within the gut microbiome of the subject.

81. A composition comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) one or more probiotic cells.

82. The composition of claim 81, wherein the prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

83. The composition of claim 81, wherein the prebiotic compound is gel-based.

84. The composition of claim 83, wherein the prebiotic compound is gel-based inulin.

85. The composition of claim 81, wherein the one or more probiotic cells are able to alter the gut microbiome of a subject upon administration to the subject.

86. The composition of claim 81, wherein the composition is configured for oral administration to a subject.

87. The composition of claim 81, wherein the one or more probiotic cells comprise beneficial bacteria.

88. The composition of claim 87, wherein the beneficial bacteria comprises one or more of: Saccharomyces cereviseae, Bacillus coagulans, Bacillus licheniformis, Bacillus subtilis, Bifidobacterium angulatum, Bifidobacterium animalis, Bifidobacterium bifidum, Bifidobacterium breve, Bifidobacterium infantis, Bifidobacterium lactis, Bifidobacterium longum, Enterococcus faecium, Enterococcus faecalis, Lactobacillus acidophilus, Lactobacillus amylovorus, Lactobacillus alimentarius, Lactobacillus bulgaricus, Lactobacillus casei subsp. casei, Lactobacillus casei Shirota, Lactobacillus curvatus, Lactobacillus delbrueckii subsp. lactis, Lactobacillus fermentum, Lactobacillus farciminus, Lactobacillus gasseri, Lactobacillus

helveticus, Lactobacillus johnsonii, Lactobacillus lacti, Lactobacillus paracasei, Lactobacillus pentosaceus, Lactobacillus plantarum, Lactobacillus reuteri, Lactobacillus rhamnosus (Lactobacillus GG), Lactobacillus sake, Lactobacillus salivarius, Lactococcus lactis, Lactobacillus thermotolerans, Lactobacillus mucosae, Micrococcus varians, Pediococcus acidilactici, Pediococcus pentosaceus, Pediococcus acidilactici, Pediococcus halophilus, Streptococcus faecalis, Streptococcus thermophilus, Staphylococcus carnosus, and Staphylococcus xylosus.

89. The composition of claim 81, wherein the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

90. A method for increasing the growth of probiotic organisms in the digestive system of a subject, comprising administering to the subject a composition of claim 81.

91. The method of claim 90, wherein the subject is a mammalian subject.

92. The method of claim 90, wherein the subject is a human subject.

93. A composition comprising a gel-based prebiotic formulation.

94. The composition of claim 93, wherein the composition is formulated for oral ingestion.

95. The composition of claim 93, wherein the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

96. The composition of claim 93, wherein the gel-based prebiotic formulation is associated with one or more probiotic organisms.

97. The composition of claim 96, wherein the one or more probiotic organisms are chosen from Lactobacillus species and Bifidobacterium species.

98. The composition of claim 96, wherein the gel-based prebiotic formulation is associated with one or more bacteriophages specific to Bordetella, Borrelia, Brucella, Campylobacter, Chlamydia and Chlamydophila, Clostridium, Corynebacterium, Enterococcus, Escherichia, Francisella, Haemophilus, Helicobacter, Legionella, Leptospira, Listeria, Mycobacterium, Mycoplasma, Neisseria, Pseudomonas, Rickettsia, Salmonella, Shigella, Staphylococcus, Streptococcus, Treponema, Vibrio and Yersinia.

99. The method of claim 96, wherein the one or more probiotic organisms are selected from L. acidophilus, L. amylovorus, L. brevis, L. casei, L. casei subsp. rhamnosus (Lactobacillus GG), L. caucasicus, L. crispatus, L. delbrueckii subsp. bulgaricus (L. bulgaricus), L. fermentum (L. fermenti), L. gasseri, L. helveticus, L. johnsonii, L. lactis, L. leichmannii, L. paracasei, L. plantarum, L. reuteri, or L. rhamnosus.

100. The composition of claim 96, wherein the gel-based prebiotic formulation comprises one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

101. A method for treating and/or preventing infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity, comprising administering to a subject a composition of claim 93.

102. A method for treating and/or preventing infectious pathogens, autoimmune diseases, neurological disorders, and/or obesity, comprising administering to a subject a composition of claim 81.

103. A composition comprising a prebiotic formulation associated with (e.g., complexed, conjugated, encapsulated, absorbed, adsorbed, admixed) one or more prebiotic compounds selected from a fructo-oligosaccharide, a short-chain fructo-oligosaccharide, inulin, an isomalt-

oligosaccharide, a transgalacto-oligosaccharide, a pectin, a xylo-oligosaccharide, a chitosan-oligosaccharide, a beta-glucan, an arable gum modified starch, a resistant potato starch, guar gum, bean gum, gelatin, glycerol, a polydextrose, a D-tagatose, an acacia fiber, carob, an oat, and a citrus fiber.

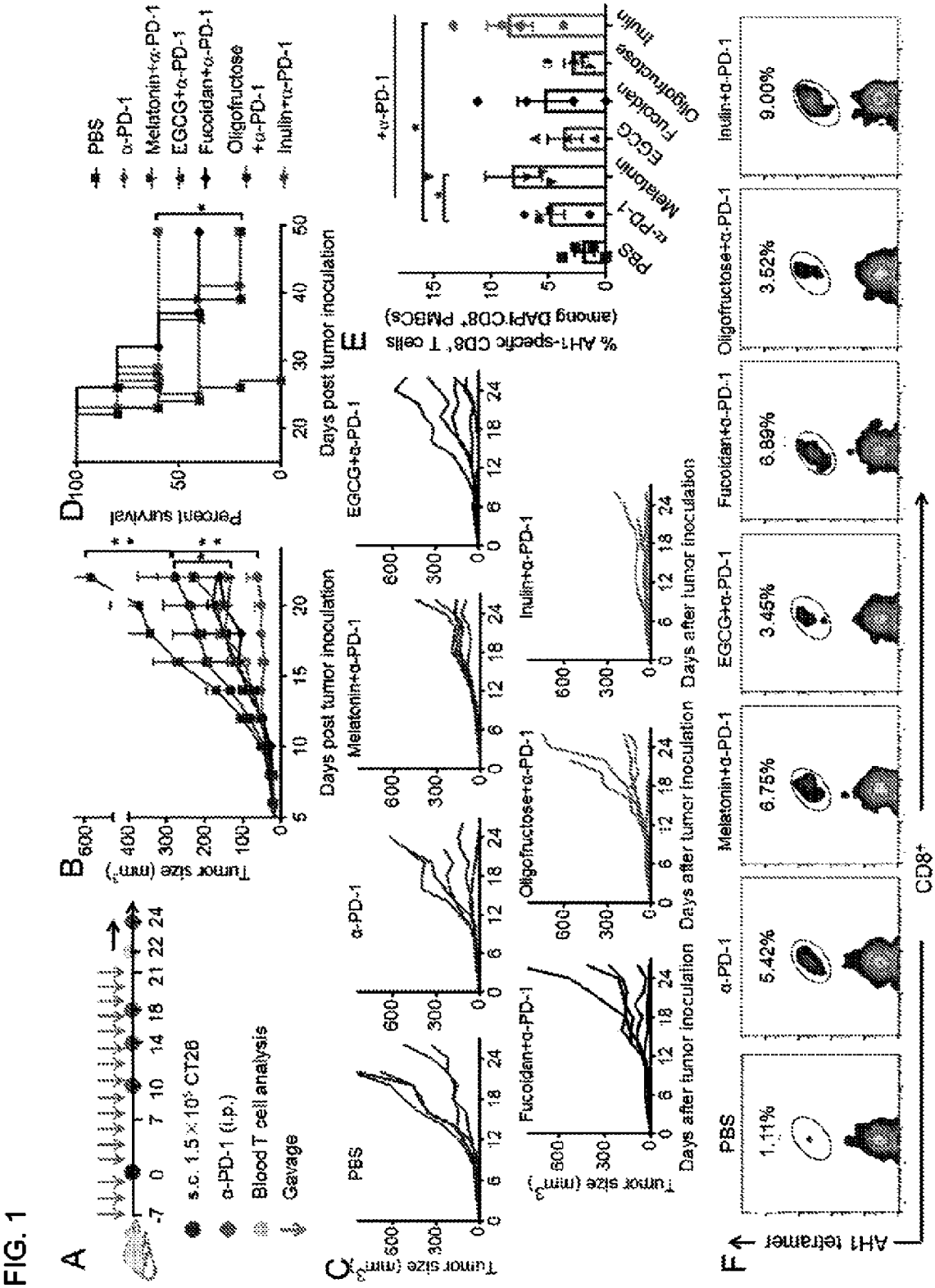
104. The composition of claim 103, wherein the prebiotic compound is gel-based.

105. The composition of claim 104, wherein the prebiotic compound is gel-based inulin.

106. The composition of claim 103, wherein the composition is configured for oral administration to a subject.

107. The composition of claim 103, wherein the composition is a sugar-coated tablet, gel capsule, gel, emulsion, tablet, wafer capsule, hydrogel, nanofiber gel, electrospun fiber, food bar, confectionery, fermented milk, fermented cheese, chewing gum, powder or toothpaste.

FIG. 1


A
s.c. 1.5×10⁵ CT26
α-PD-1 (i.p.)
Blood T cell analysis
Gavage
B
Tumor size (mm³)
Percent survival
Days post tumor inoculation
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose +α-PD-1
Inulin+α-PD-1
C
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1
Days after tumor inoculation
D
E
% AH1-specific CD8⁺ T cells (among DAPI⁻CD8⁺ PMBCs)
+α-PD-1
PBS
α-PD-1
Melatonin
EGCG
Fucoidan
Oligofructose
Inulin
F
AH1 tetramer
CD8⁺
1.11%
5.42%
6.75%
3.45%
6.89%
3.52%
9.00%

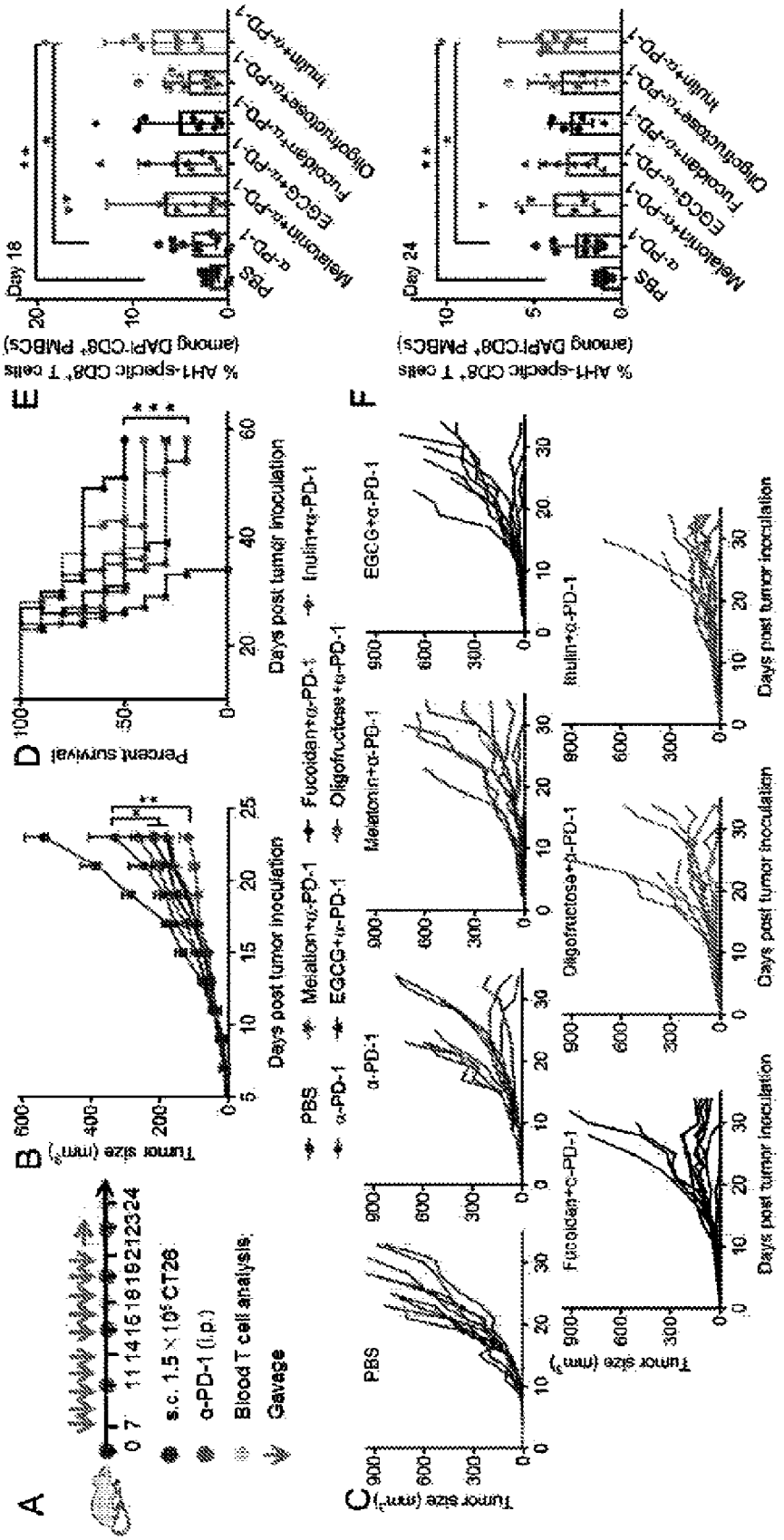

A
0 7 11 14 16 18 19 21 23 24
s.c. 1.5 × 10⁵ CT26
α-PD-1 (i.p.)
Blood T cell analysis
Gavage
B
Tumor size (mm³)
Days post tumor inoculation
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1
C
PBS
α-PD-1
Melatonin+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1
EGCG+α-PD-1
Tumor size (mm³)
Days post tumor inoculation
D
Percent survival
Days post tumor inoculation
E
Day 18
% AH1-specific CD8⁺ T cells (among DAPI⁻CD8⁺ PMBCs)
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1
F
Day 24
% AH1-specific CD8⁺ T cells (among DAPI⁻CD8⁺ PMBCs)
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1

FIG. 2

FIG. 2 (CONT'D)

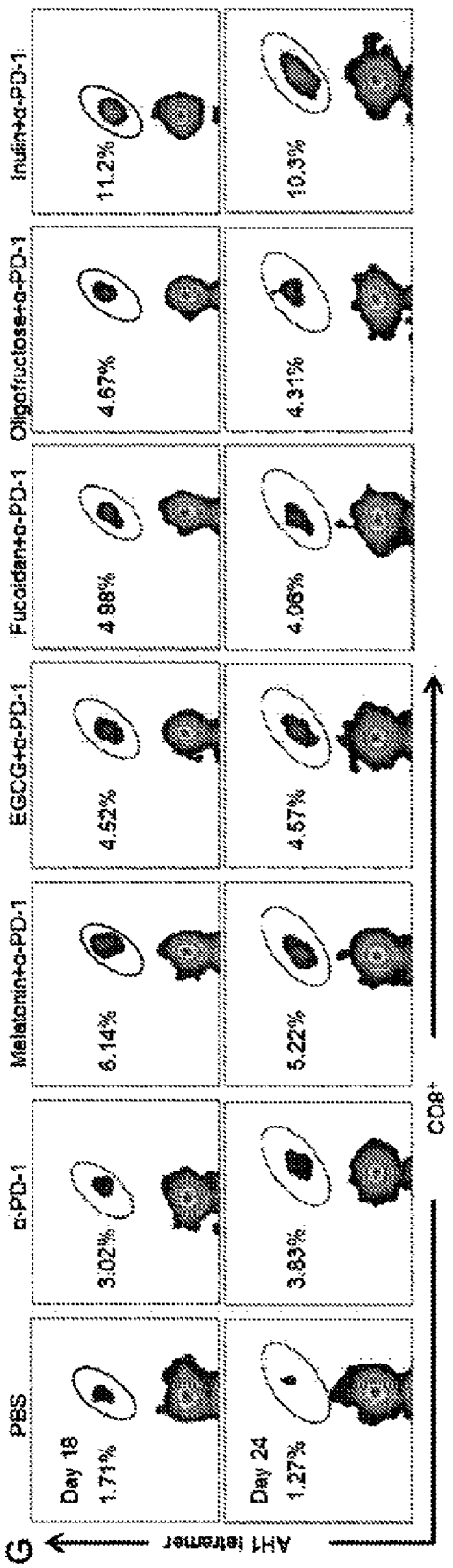

G
PBS
α-PD-1
Melatonin+α-PD-1
EGCG+α-PD-1
Fucoidan+α-PD-1
Oligofructose+α-PD-1
Inulin+α-PD-1
Day 18
1.71%
3.02%
6.14%
4.52%
4.98%
4.67%
11.2%
Day 24
1.27%
3.83%
5.22%
4.57%
4.08%
4.31%
10.3%
AH1 tetramer
CD8+

FIG. 3

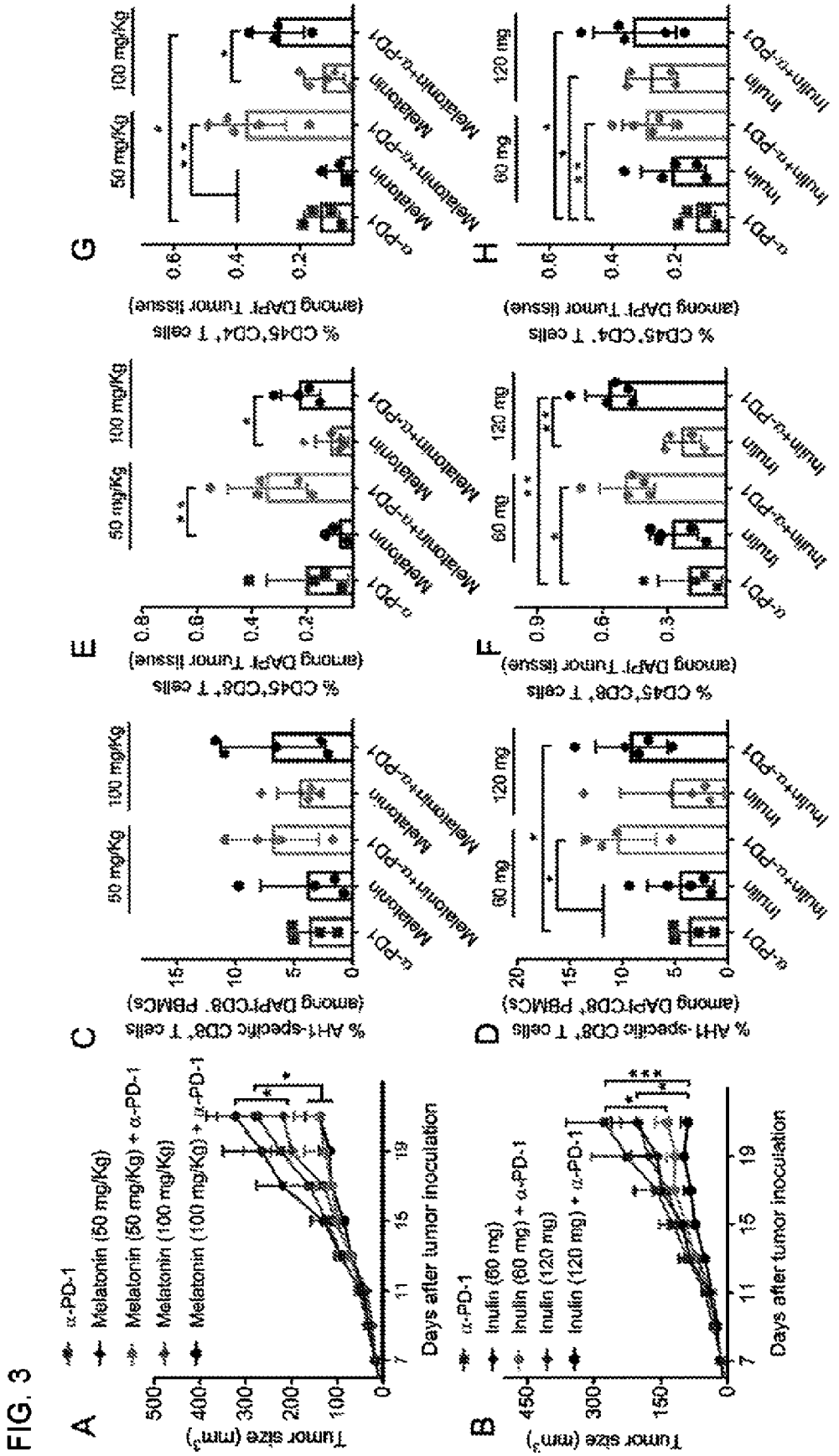

A
α-PD-1
Melatonin (50 mg/Kg) + α-PD-1
Melatonin (100 mg/Kg)
Melatonin (100 mg/Kg) + α-PD-1
Tumor size (mm³)
Days after tumor inoculation
B
α-PD-1
Inulin (60 mg)
Inulin (60 mg) + α-PD-1
Inulin (120 mg)
Inulin (120 mg) + α-PD-1
Tumor size (mm³)
Days after tumor inoculation
C
% AH1-specific CD8⁺ T cells (among DAPI⁻CD8⁺ PBMCs)
50 mg/Kg
100 mg/Kg
α-PD1
Melatonin
Melatonin+α-PD1
Melatonin
Melatonin+α-PD1
D
% AH1-specific CD8⁺ T cells (among DAPI⁻CD8⁺ PBMCs)
60 mg
120 mg
α-PD1
Inulin
Inulin+α-PD1
Inulin
Inulin+α-PD1
E
% CD45⁺CD8⁺ T cells (among DAPI⁻ Tumor tissue)
50 mg/Kg
100 mg/Kg
α-PD1
Melatonin
Melatonin+α-PD1
Melatonin
Melatonin+α-PD1
F
% CD45⁺CD8⁺ T cells (among DAPI⁻ Tumor tissue)
60 mg
120 mg
α-PD1
Inulin
Inulin+α-PD1
Inulin
Inulin+α-PD1
G
% CD45⁺CD4⁺ T cells (among DAPI⁻ Tumor tissue)
50 mg/Kg
100 mg/Kg
α-PD1
Melatonin
Melatonin+α-PD1
Melatonin
Melatonin+α-PD1
H
% CD45⁺CD4⁺ T cells (among DAPI⁻ Tumor tissue)
60 mg
120 mg
α-PD1
Inulin
Inulin+α-PD1
Inulin
Inulin+α-PD1

FIG. 4

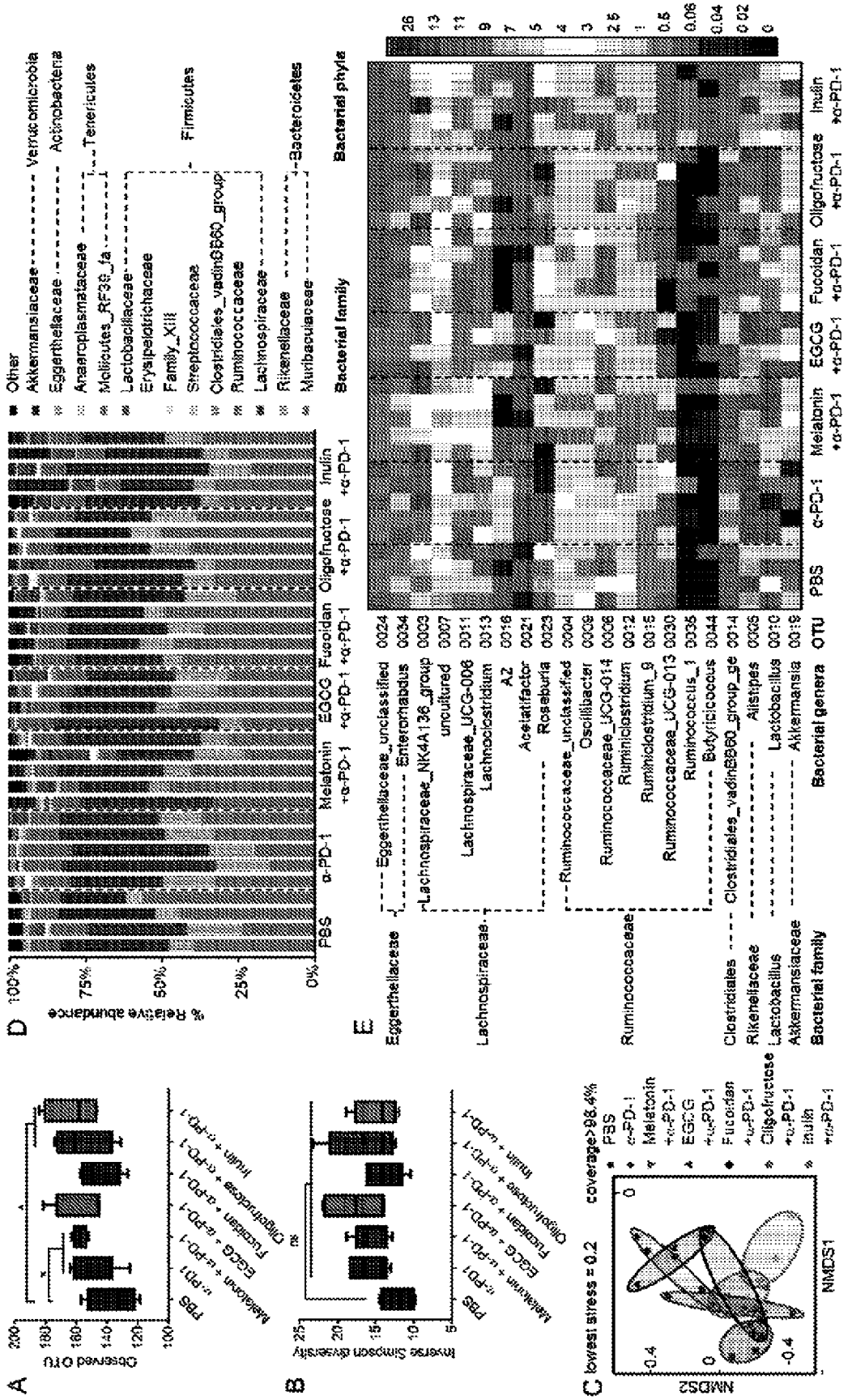

A
Observed OTU
PBS
α-PD-1
Melatonin +α-PD-1
EGCG +α-PD-1
Fucoidan +α-PD-1
Oligofructose +α-PD-1
Inulin +α-PD-1
B
Inverse Simpson diversity
C
Lowest stress = 0.2
coverage>98.4%
NMDS1
NMDS2
D
% Relative abundance
Other
Akkermansiaceae
Eggerthellaceae
Anaeroplasmataceae
Lactobacillaceae
Erysipelotrichaceae
Family_XIII
Streptococcaceae
Clostridiales_vadinBB60_group
Ruminococcaceae
Lachnospiraceae
Rikenellaceae
Muribaculaceae
Verrucomicrobia
Actinobacteria
Tenericutes
Firmicutes
Bacteroidetes
Bacterial family
Bacterial phyla
E
Eggerthellaceae
Lachnospiraceae
Ruminococcaceae
Clostridiales
Rikenellaceae
Lactobacillus
Akkermansiaceae
Bacterial family
Bacterial genera
OTU
Melatonin +α-PD-1
EGCG +α-PD-1
Fucoidan +α-PD-1
Oligofructose +α-PD-1
Inulin +α-PD-1

FIG. 4 (CONT'D)

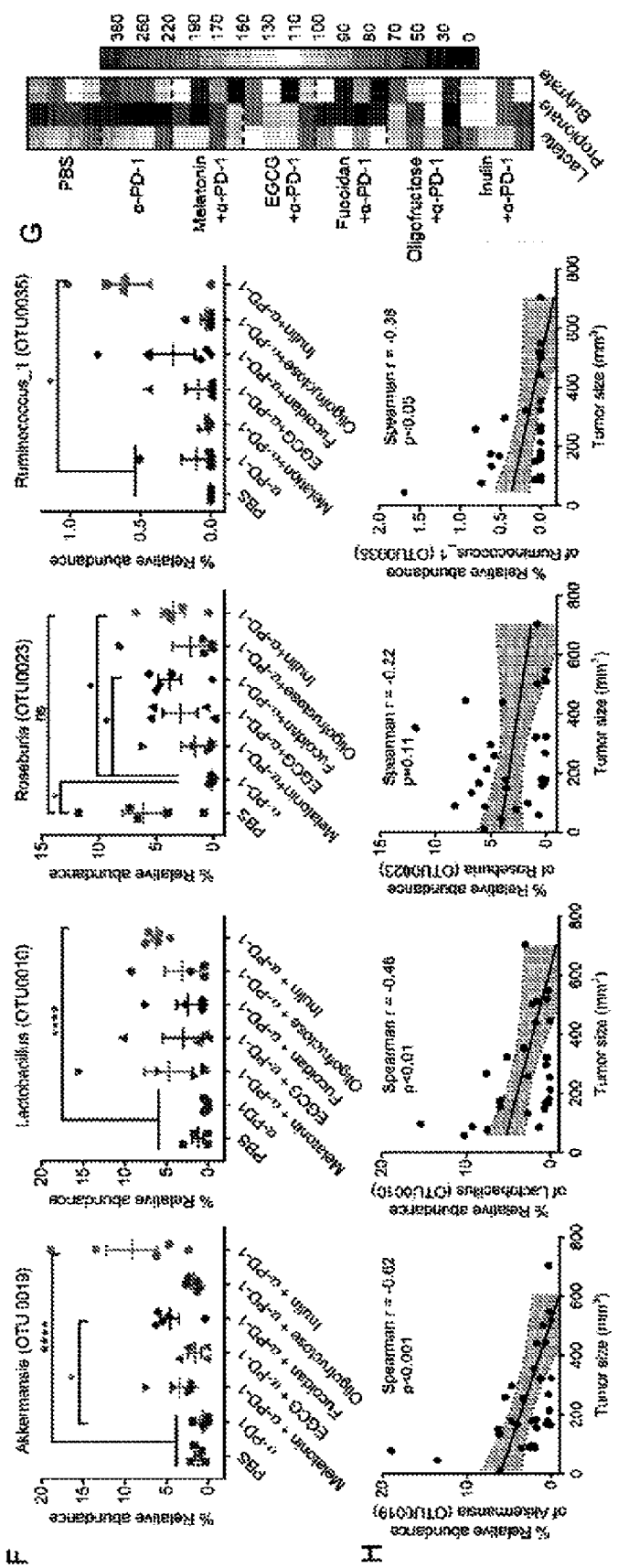

G
PBS
α-PD-1
Melatonin +α-PD-1
EGCG +α-PD-1
Fucoidan +α-PD-1
Oligofructose +α-PD-1
Inulin +α-PD-1
Lactobacillus Johnsonii
Prevotella Ruminicola
Blautia
E
Akkermansia (OTU 0019)
Lactobacillus (OTU0016)
Roseburia (OTU0023)
Ruminococcus_1 (OTU0035)
% Relative abundance
Tumor size (mm³)
Spearman r = -0.62
p<0.001
Spearman r = -0.46
p<0.01
Spearman r = -0.22
p=0.11
Spearman r = -0.38
p<0.05
H
% Relative abundance of Akkermansia (OTU0019)
% Relative abundance of Lactobacillus (OTU0016)
% Relative abundance of Roseburia (OTU0023)
% Relative abundance of Ruminococcus_1 (OTU0035)

FIG. 5

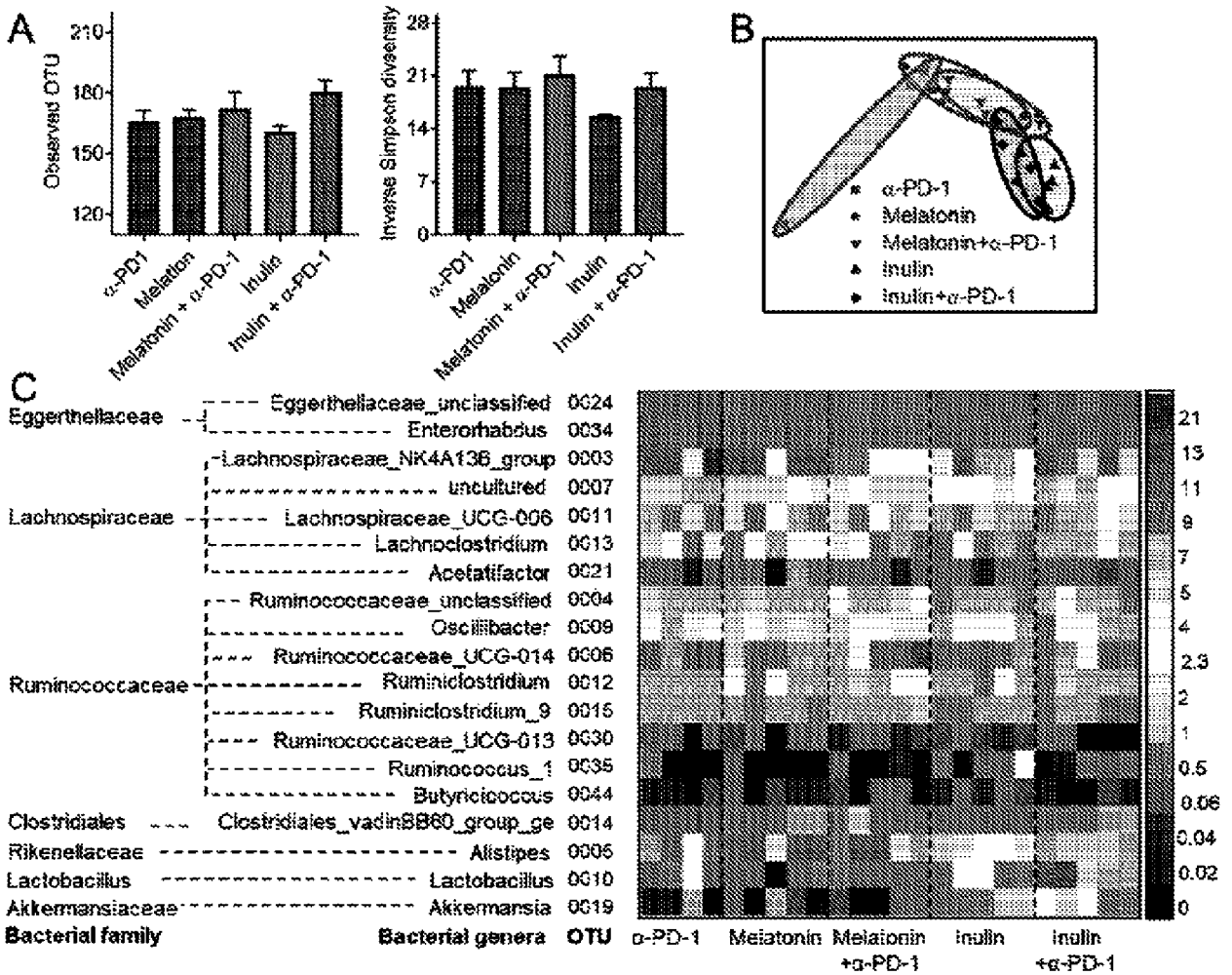
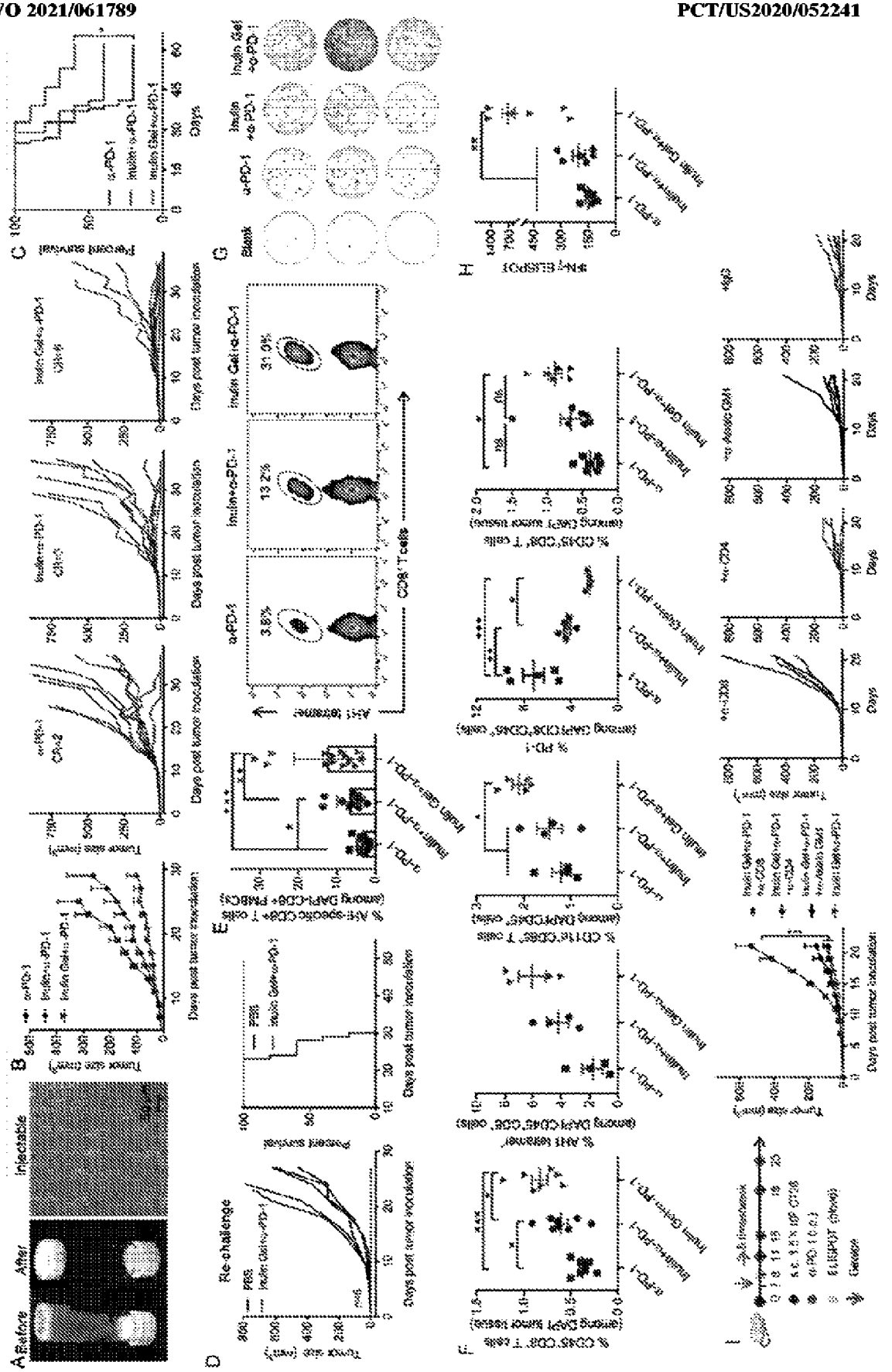

A
Observed OTU
210
180
150
120
α-PD1
Melatonin
Melatonin + α-PD-1
Inulin
Inulin + α-PD-1
Inverse Simpson diversity
28
21
14
7
0
α-PD1
Melatonin
Melatonin + α-PD-1
Inulin
Inulin + α-PD-1
B
α-PD-1
Melatonin
Melatonin+α-PD-1
Inulin
Inulin+α-PD-1
C
Eggerthellaceae
Eggerthellaceae_unclassified 0024
Enterorhabdus 0034
Lachnospiraceae
Lachnospiraceae_NK4A136_group 0003
uncultured 0007
Lachnospiraceae_UCG-006 0011
Lachnoclostridium 0013
Acetatifactor 0021
Ruminococcaceae
Ruminococcaceae_unclassified 0004
Oscillibacter 0009
Ruminococcaceae_UCG-014 0006
Ruminiclostridium 0012
Ruminiclostridium_9 0015
Ruminococcaceae_UCG-013 0030
Ruminococcus_1 0035
Butyricicoccus 0044
Clostridiales
Clostridiales_vadinBB60_group_ge 0014
Rikenellaceae
Alistipes 0005
Lactobacillus
Lactobacillus 0010
Akkermansiaceae
Akkermansia 0019
Bacterial family
Bacterial genera
OTU
21
13
11
9
7
5
4
2.3
2
1
0.5
0.06
0.04
0.02
0
α-PD-1
Melatonin
Melatonin +α-PD-1
Inulin
Inulin +α-PD-1

FIG. 6


A
Before
After
Injectable
B
C
D
Re-challenge
E
F
G
Blank
α-PD-1
Insulin
+α-PD-1
Insulin Gel
+α-PD-1
H
I
Days post tumor inoculation
Tumor size (mm³)
Percent survival
Days

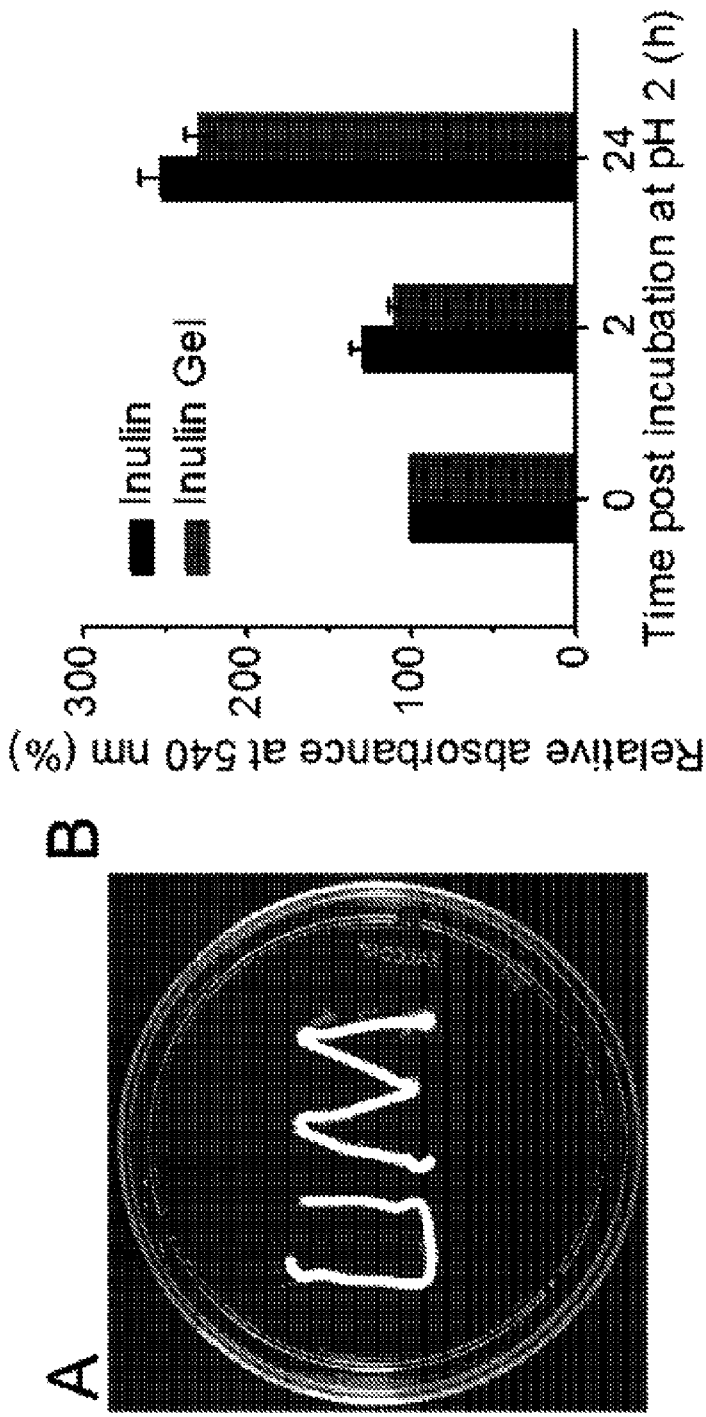

A
B
Relative absorbance at 540 nm (%)
300
200
100
0
Inulin
Inulin Gel
0
2
24
Time post incubation at pH 2 (h)

FIG. 7

FIG. 8

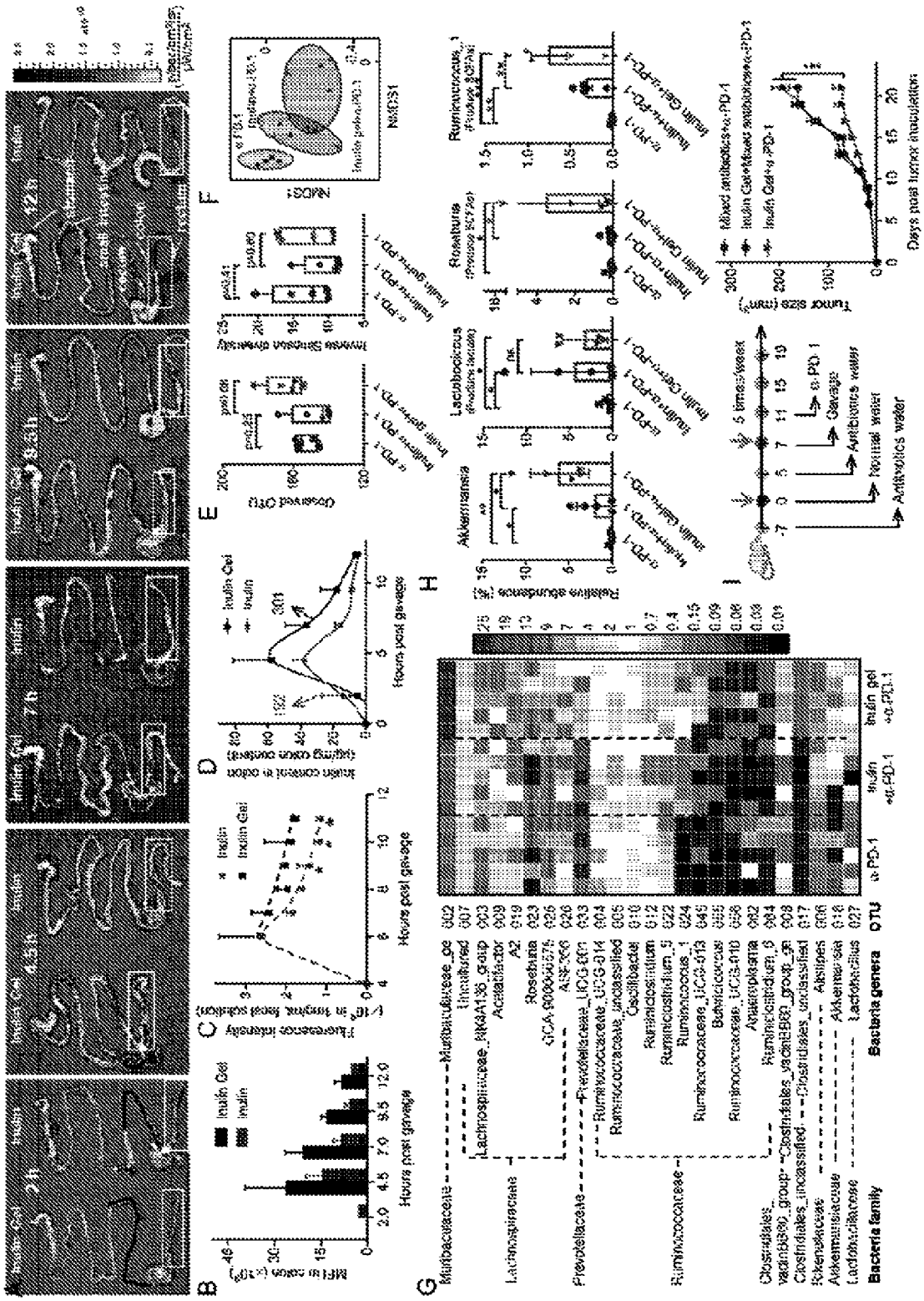

A
Inulin Gel
Inulin
24h
4.5h
7h
12.5
B
Inulin Gel
Inulin
MFI in cecum (x10³)
Hours post gavage
C
Inulin
Inulin Gel
Fluorescence intensity
Hours post gavage
D
Inulin Gel
Inulin
Inulin content in colon (mg/mg fecal content)
Hours post gavage
E
Observed OTUs
Inulin Gel
Inulin
Inulin Gel+α-PD-1
Inulin+α-PD-1
Invasive Streptococcus abundance
F
NMDS1
NMDS2
G
Bacteria family
Bacteria genera
OTU
Inulin
Inulin gel
α-PD-1
H
Akkermansia
Lactobacillus
Roseburia
Ruminococcus_1
Relative abundance (%)
I
5 times/week
α-PD-1
Gavage
Antibiotics water
Normal water
Tumor size (mm³)
Mixed antibiotics+α-PD-1
Inulin Gel+α-PD-1
Days post tumor inoculation

FIG. 9

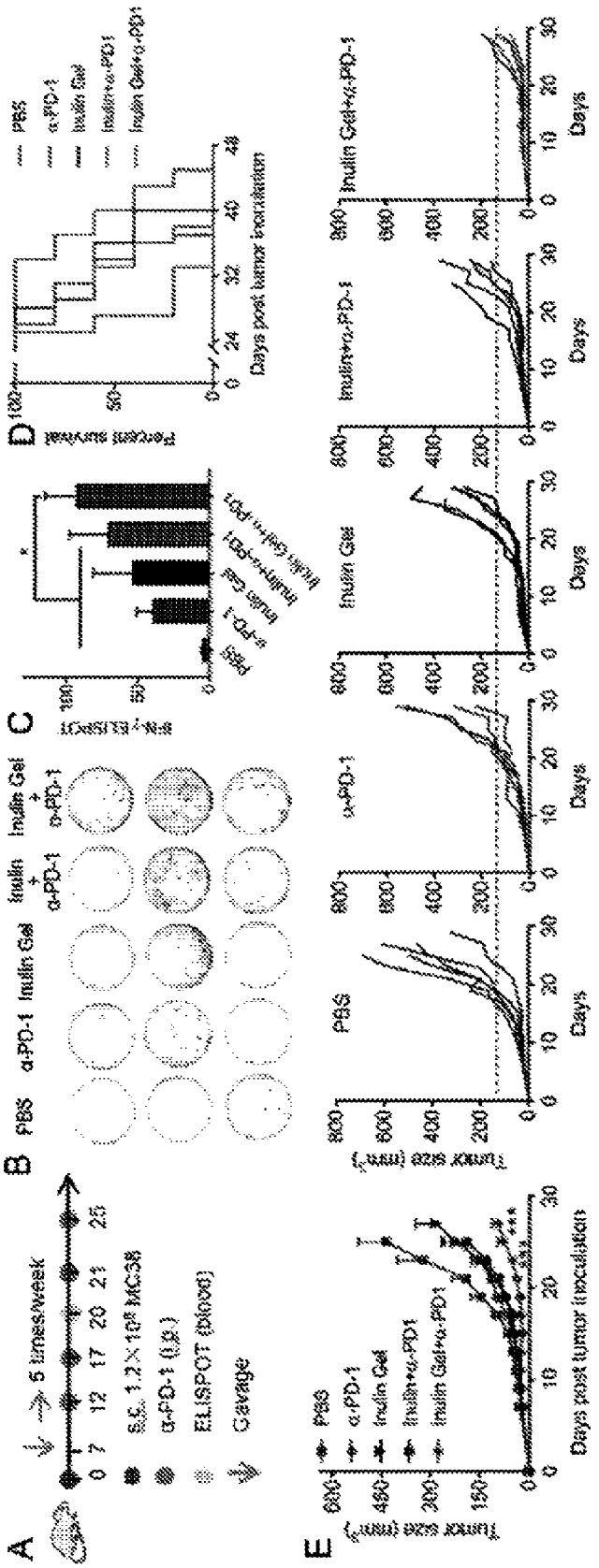
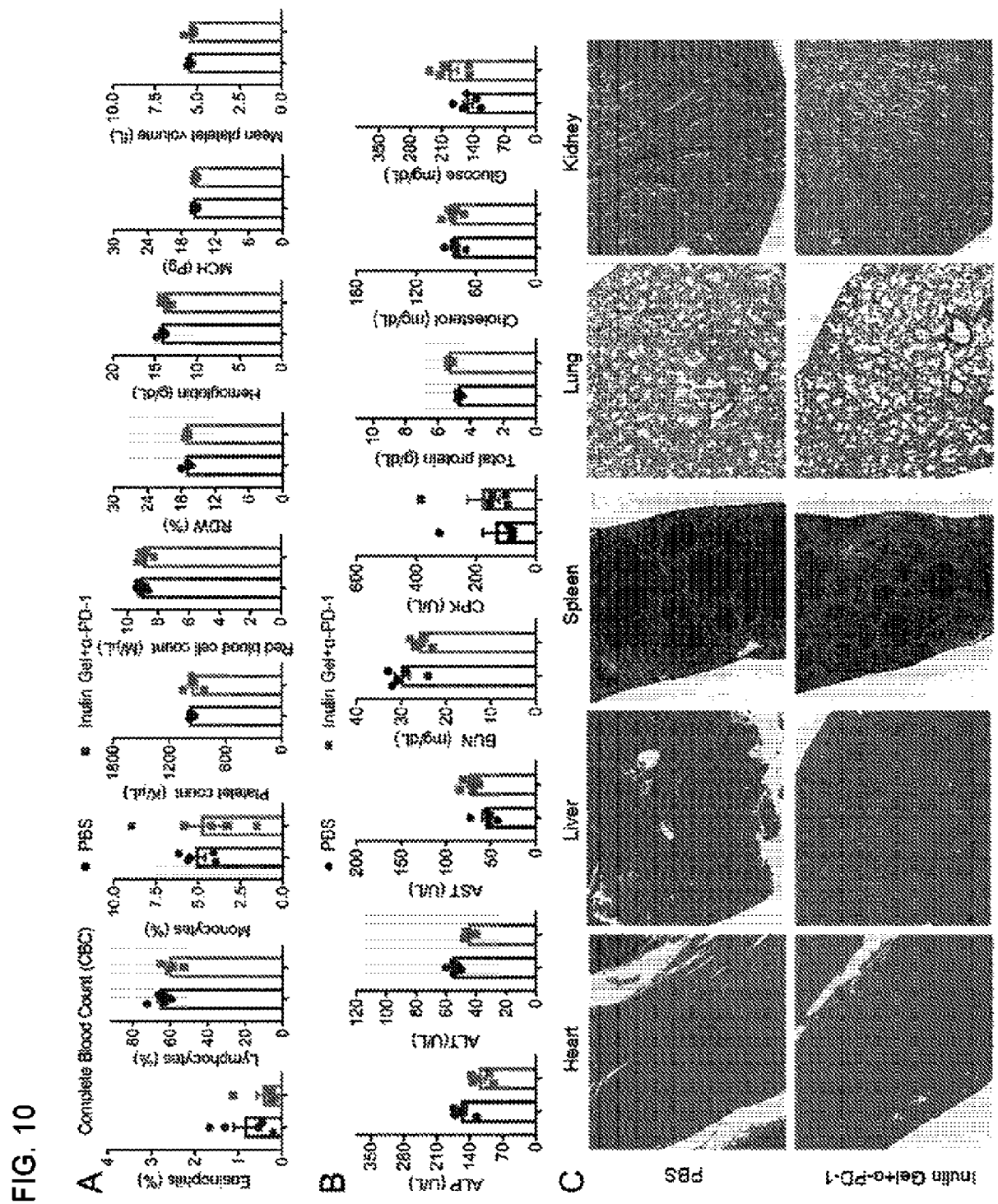

A
B
C
D
E
PBS
α-PD-1
Insulin Gel
Insulin + α-PD-1
Insulin Gel + α-PD-1
5 times/week
S.C. 1.2×10⁶ MC38
α-PD-1 (i.p.)
ELISPOT (blood)
Gavage
Tumor size (mm³)
Days
Days post tumor inoculation
Percent survival

FIG. 10


A
Complete Blood Count (CBC)
PBS
Inulin Gel+α-PD-1
Eosinophils (%)
Lymphocytes (%)
Monocytes (%)
Platelet count (K/μL)
Red blood cell count (M/μL)
RDW (%)
Hemoglobin (g/dL)
MCH (Pg)
Mean platelet volume (fL)
B
PBS
Inulin Gel+α-PD-1
ALP (U/L)
ALT (U/L)
AST (U/L)
BUN (mg/dL)
CPK (U/L)
Total protein (g/dL)
Cholesterol (mg/dL)
Glucose (mg/dL)
C
Heart
Liver
Spleen
Lung
Kidney
PBS
Inulin Gel+α-PD-1

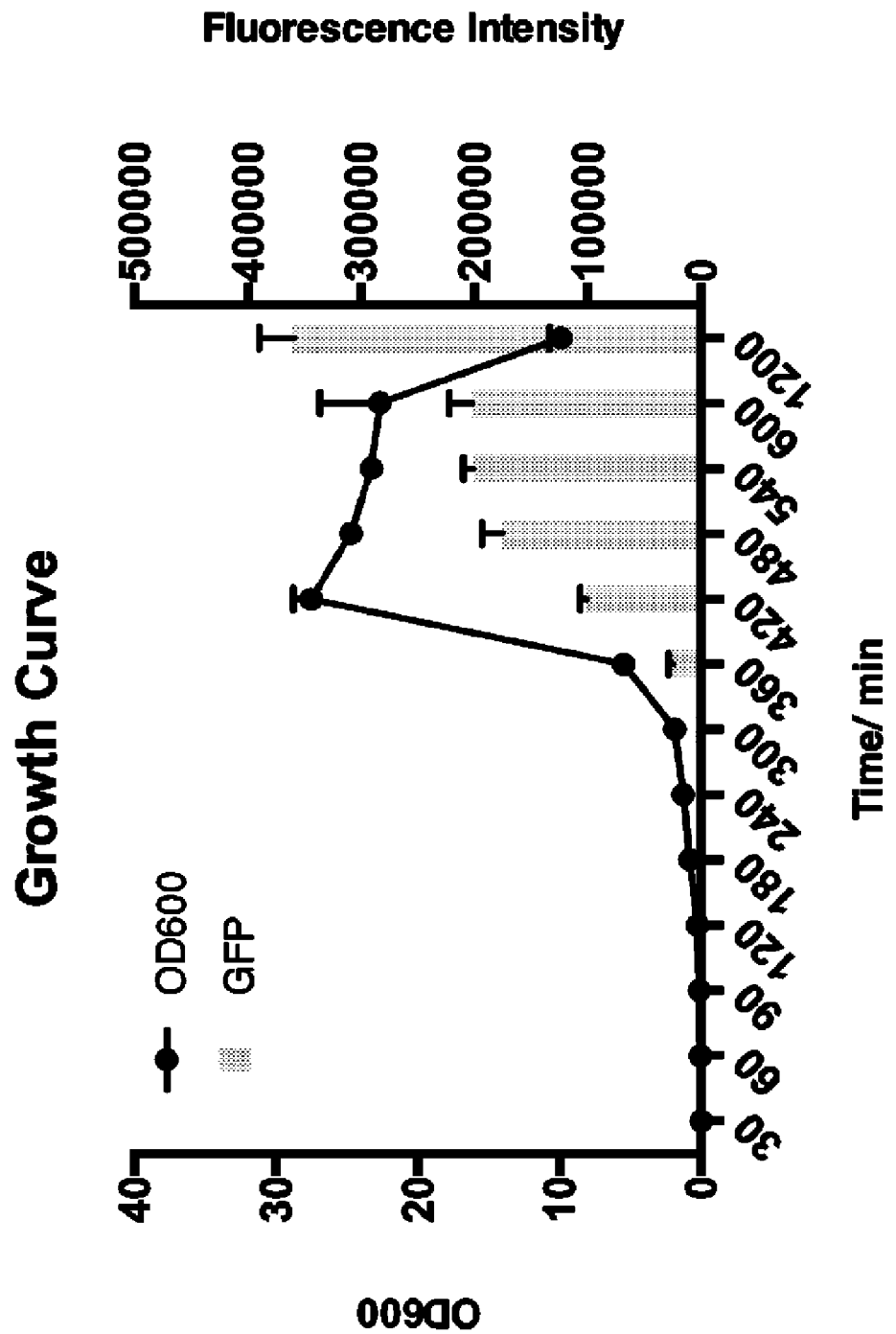

Fluorescence Intensity
500000
400000
300000
200000
100000
0
Growth Curve
OD600
GFP
40
30
20
10
0
OD600
30
60
90
120
180
240
300
360
420
480
540
600
1200
Time/ min

FIG. 11

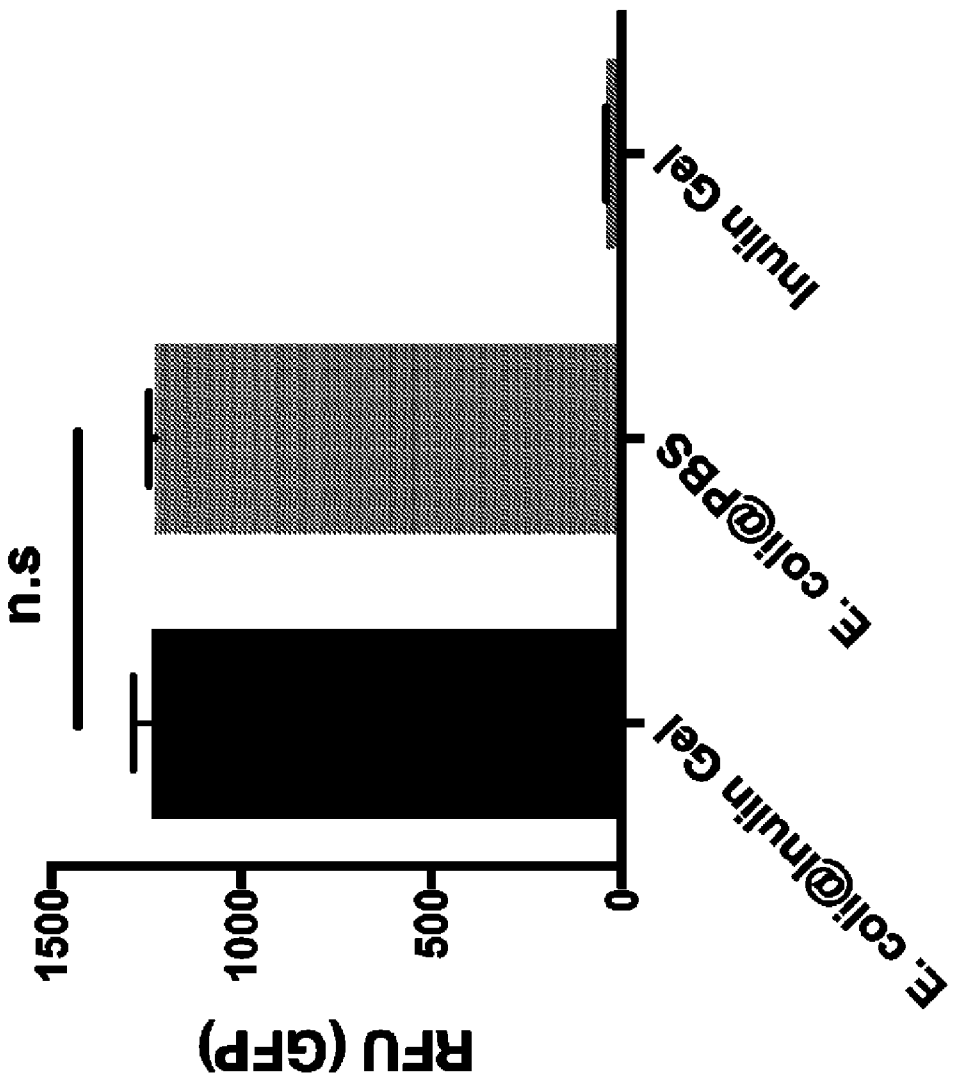

RFU (GFP)
1500
1000
500
0
n.s
E. coli@Inulin Gel
E. coli@PBS
Inulin Gel

FIG. 12

FIG. 13

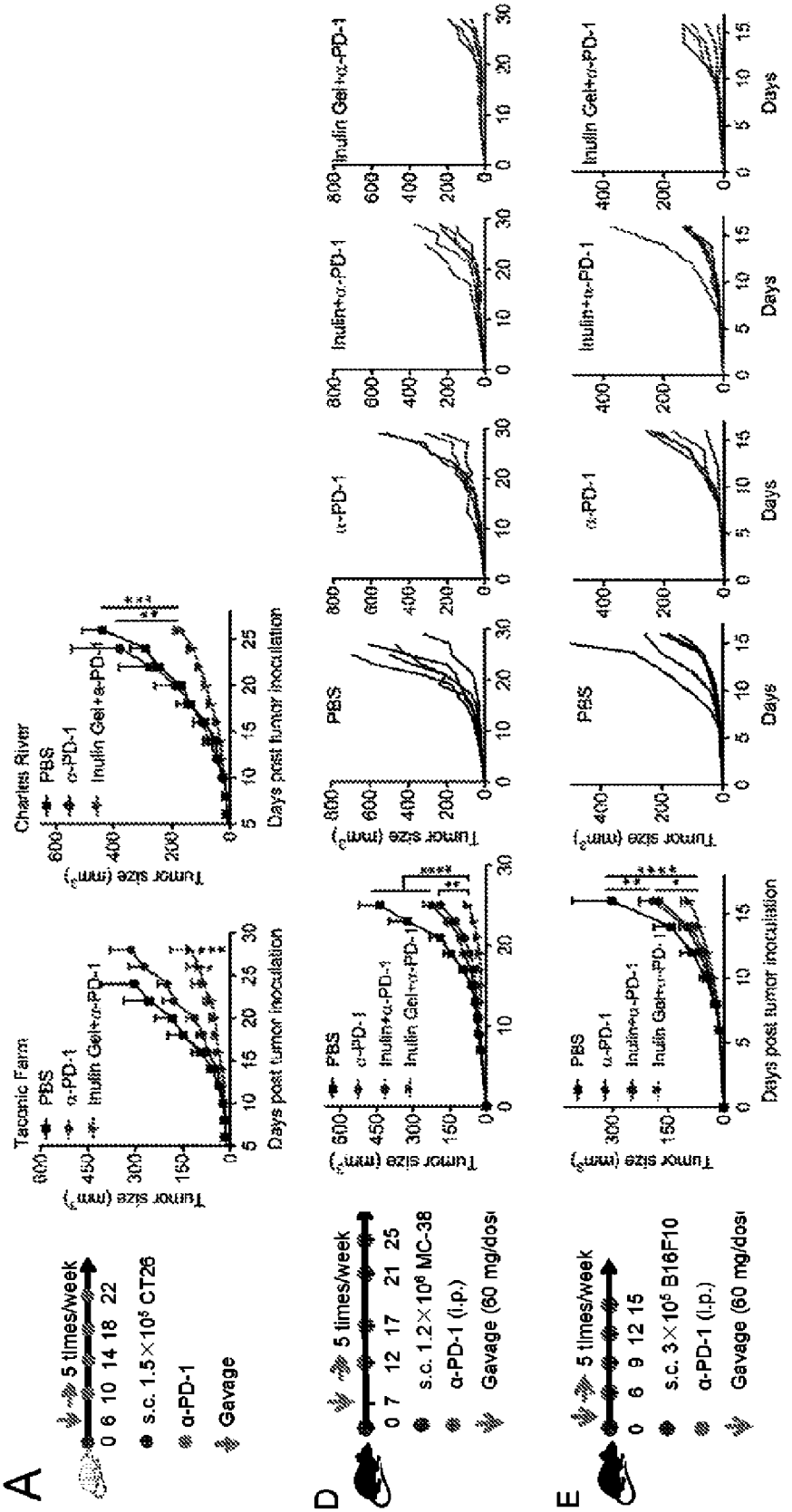

A
5 times/week
0 6 10 14 18 22
s.c. 1.5×10⁵ CT26
α-PD-1
Gavage
Tacanic Farm
Charles River
PBS
α-PD-1
Inulin Gel+α-PD-1
Tumor size (mm³)
Days post tumor inoculation
D
5 times/week
0 7 12 17 21 25
s.c. 1.2×10⁶ MC-38
α-PD-1 (i.p.)
Gavage (60 mg/dos
Inulin+α-PD-1
E
5 times/week
0 6 9 12 15
s.c. 3×10⁵ B16F10
α-PD-1 (i.p.)
Gavage (60 mg/dos
Days

FIG. 14

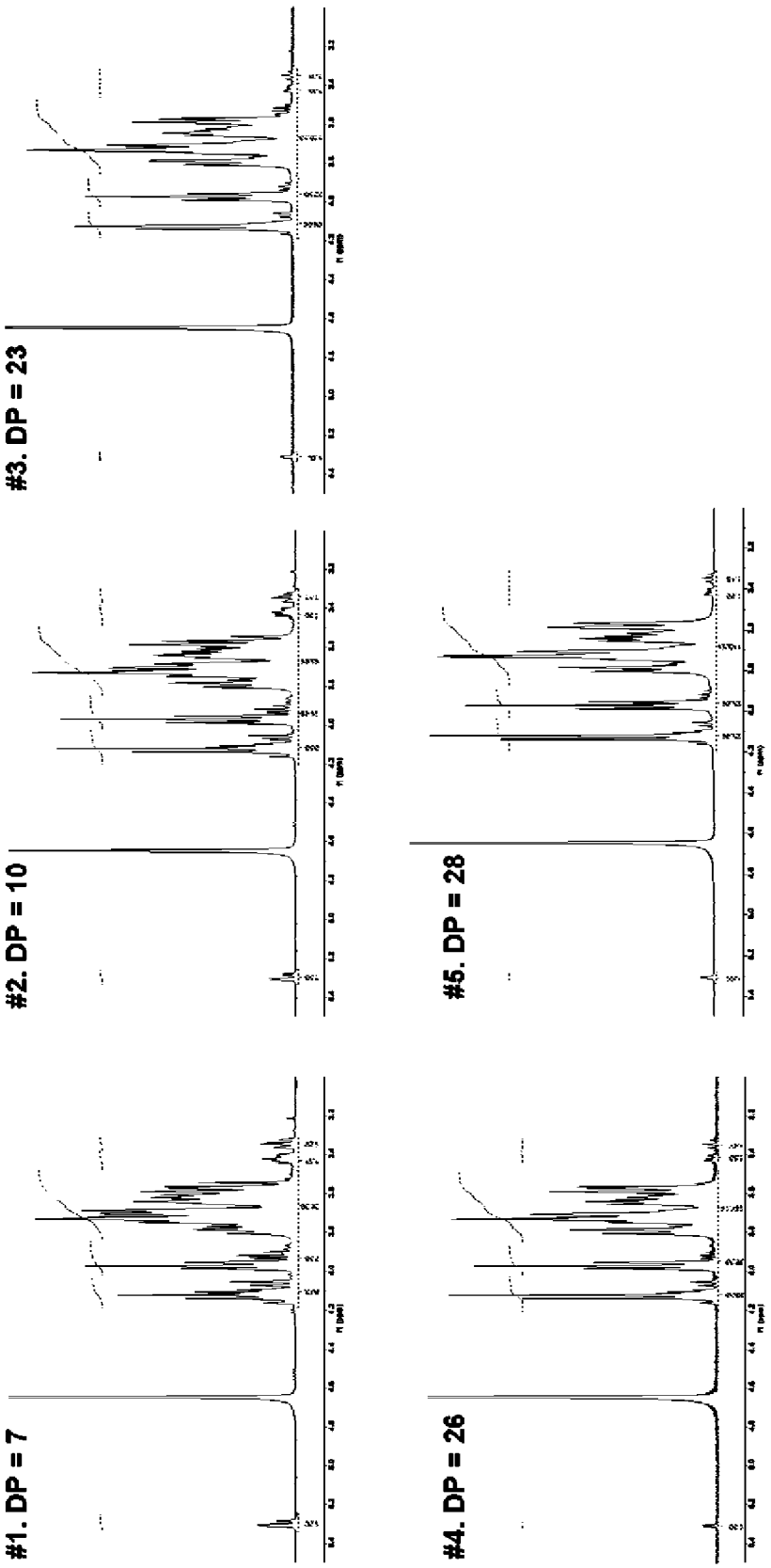
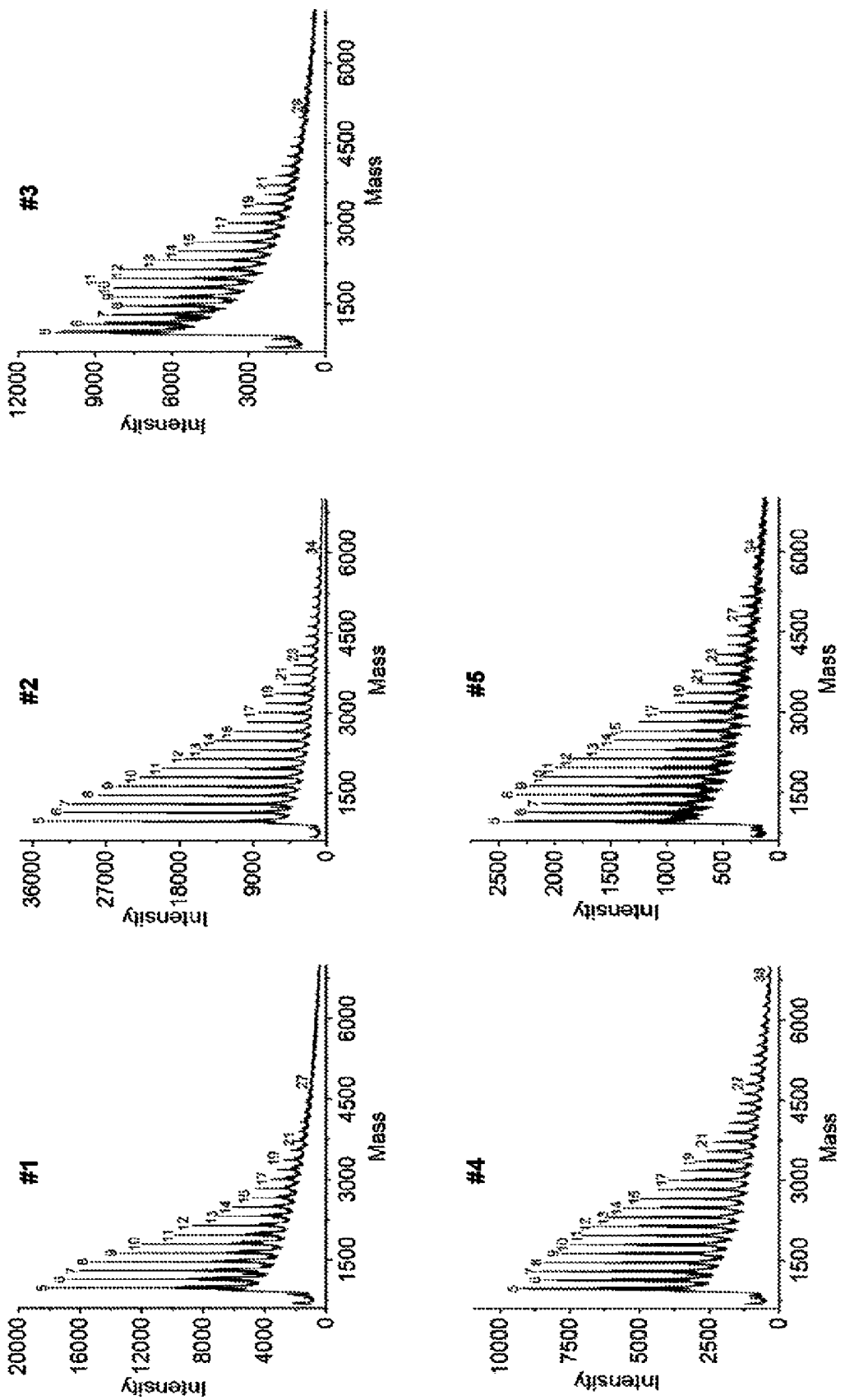


FIG. 15



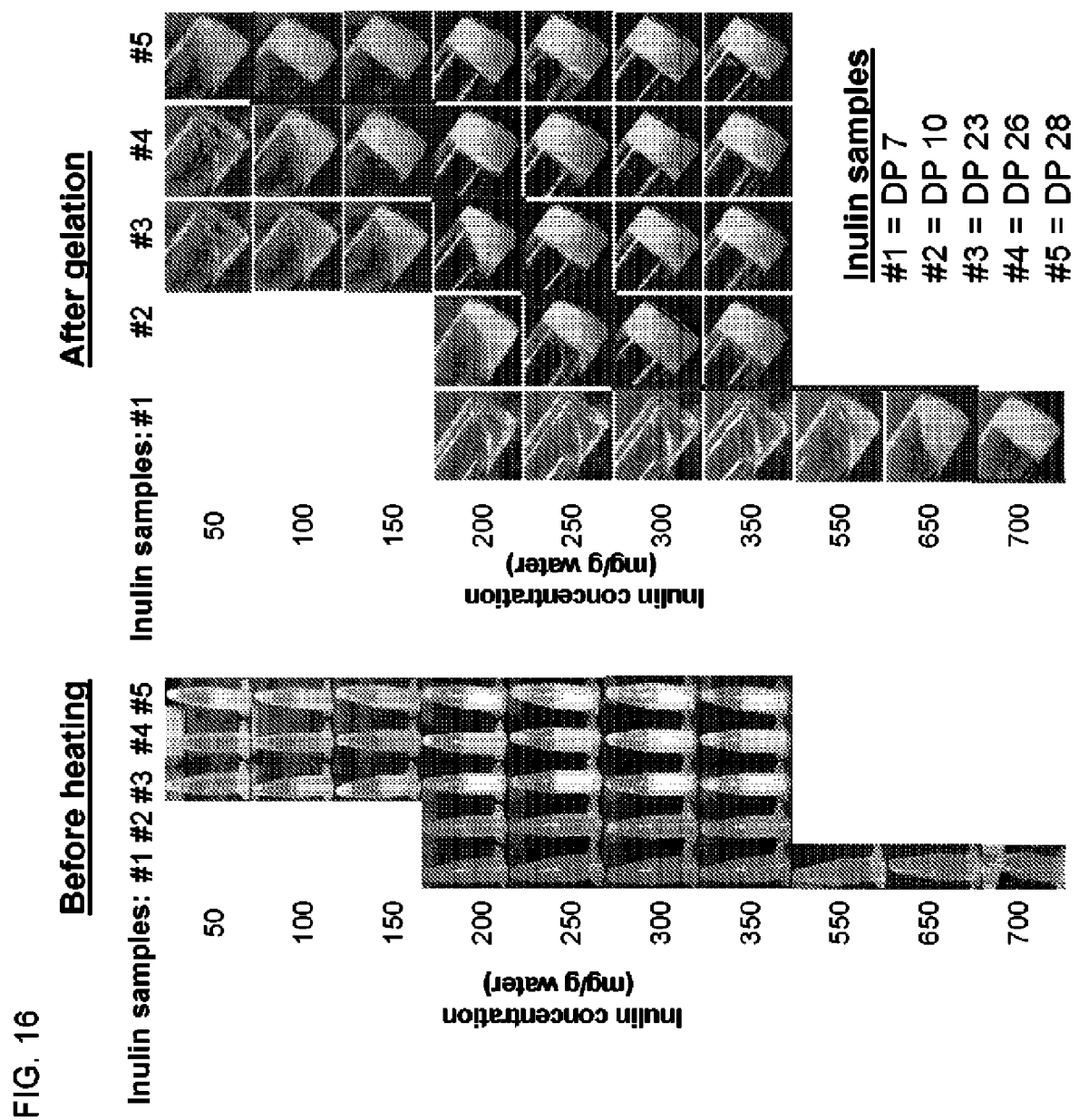

Before heating
Inulin samples: #1 #2 #3 #4 #5
50
100
150
200
250
300
350
550
650
700
Inulin concentration (mg/g water)
After gelation
Inulin samples: #1 #2 #3 #4 #5
50
100
150
200
250
300
350
550
650
700
Inulin concentration (mg/g water)
Inulin samples
#1 = DP 7
#2 = DP 10
#3 = DP 23
#4 = DP 26
#5 = DP 28

FIG. 16

FIG. 17

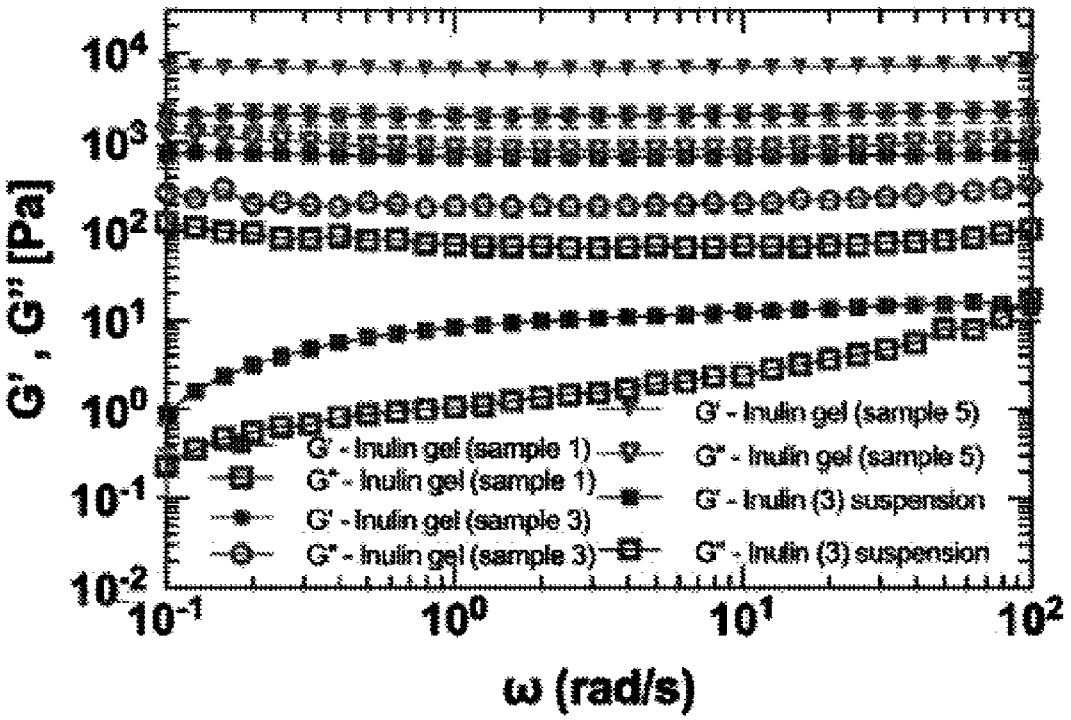

G', G" [Pa]
ω (rad/s)
G' - Inulin gel (sample 1)
G" - Inulin gel (sample 1)
G' - Inulin gel (sample 3)
G" - Inulin gel (sample 3)
G' - Inulin gel (sample 5)
G" - Inulin gel (sample 5)
G' - Inulin (3) suspension
G" - Inulin (3) suspension

FIG. 18

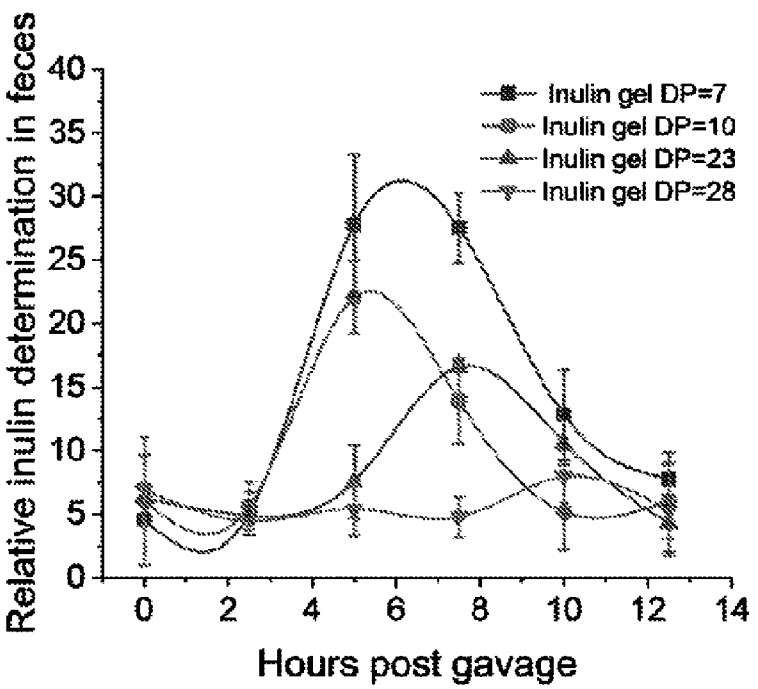

Relative inulin determination in feces
Hours post gavage
Inulin gel DP=7
Inulin gel DP=10
Inulin gel DP=23
Inulin gel DP=28

FIG. 19

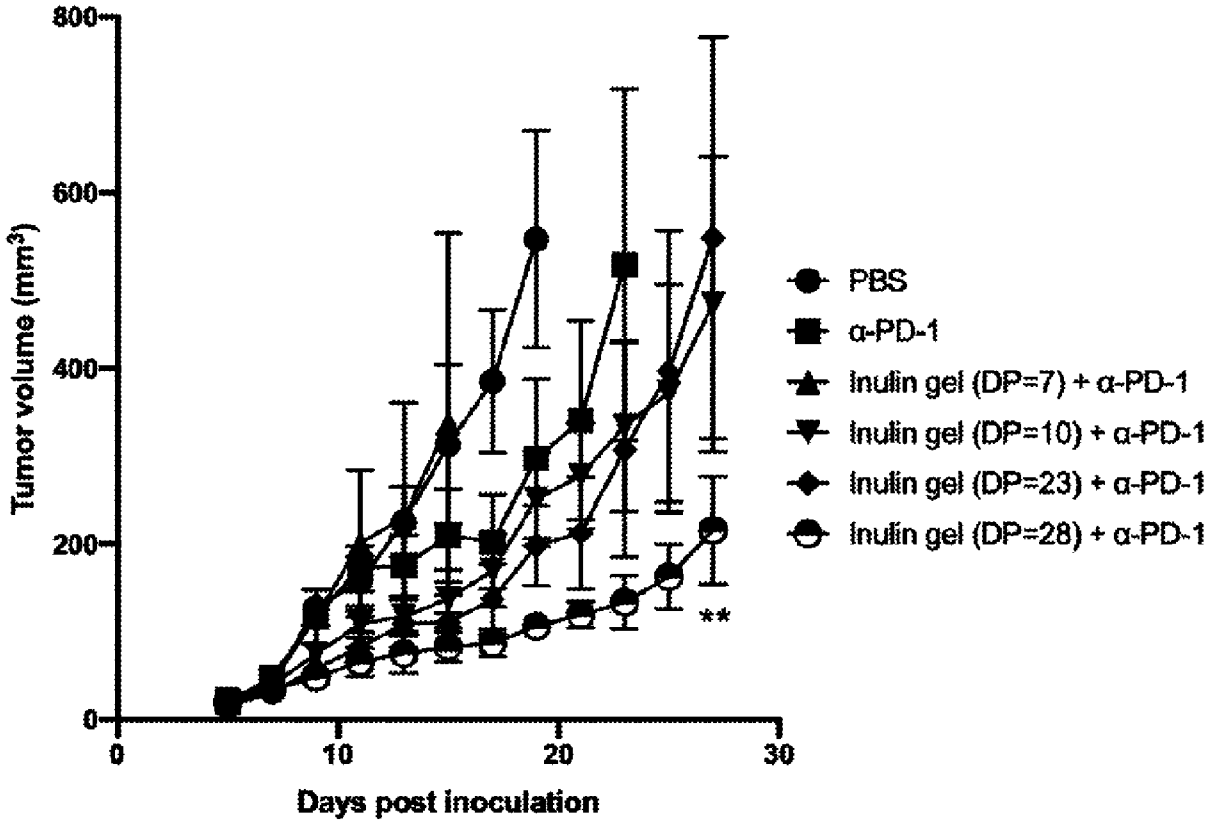

800
600
400
200
0
Tumor volume (mm3)
0
10
20
30
Days post inoculation
**
PBS
α-PD-1
Inulin gel (DP=7) + α-PD-1
Inulin gel (DP=10) + α-PD-1
Inulin gel (DP=23) + α-PD-1
Inulin gel (DP=28) + α-PD-1

FIG. 20

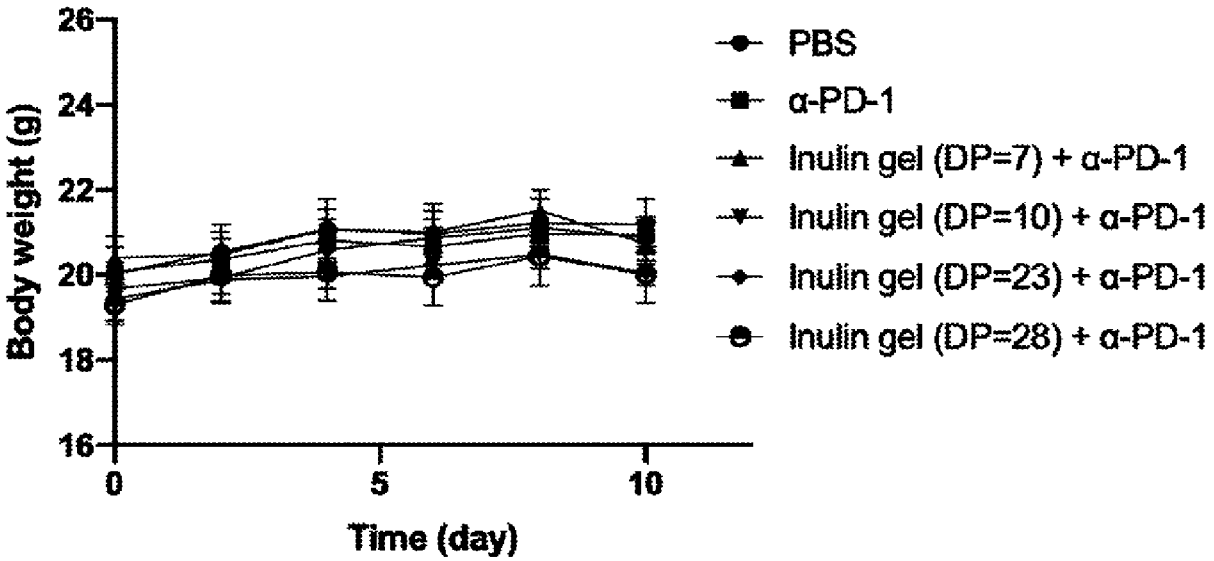


FIG. 21

Temp / ˚C	15% w/v	20% w/v	25% w/v	30% w/v
40				+
50			+	+
60	+	+	+	+
70	+	+	+	+

FIG. 22

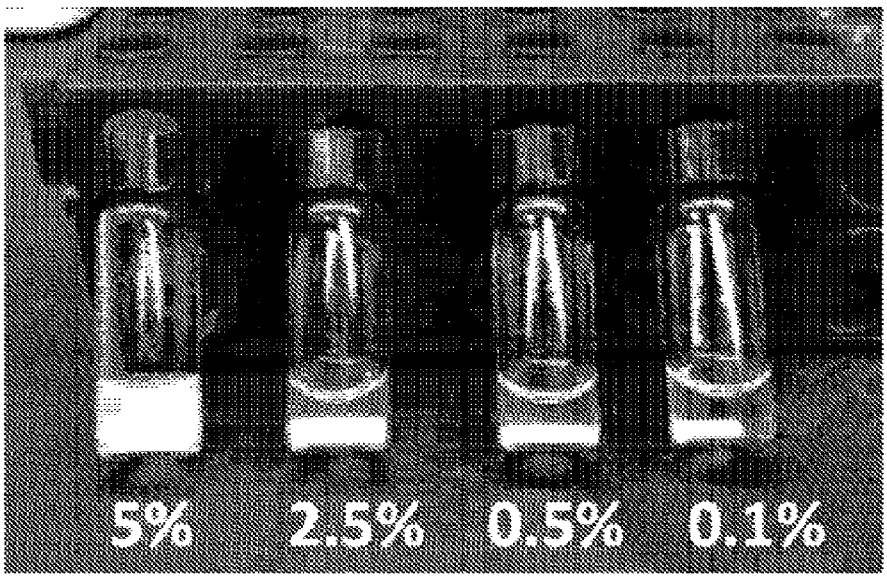


FIG. 23

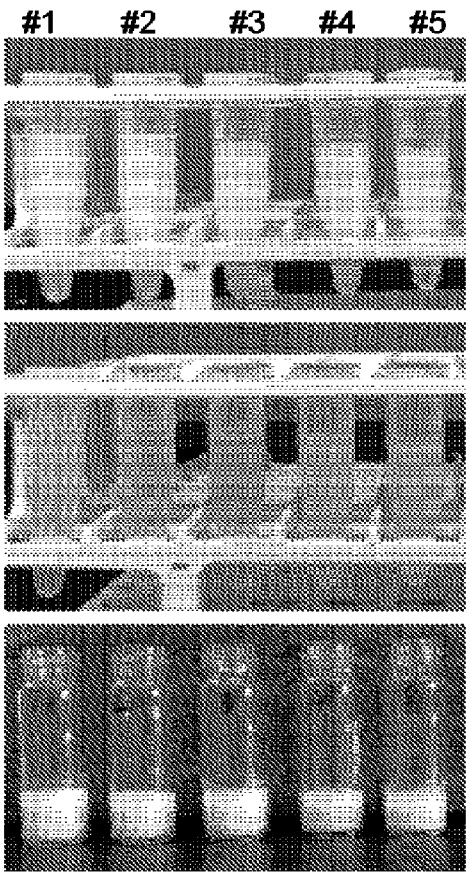
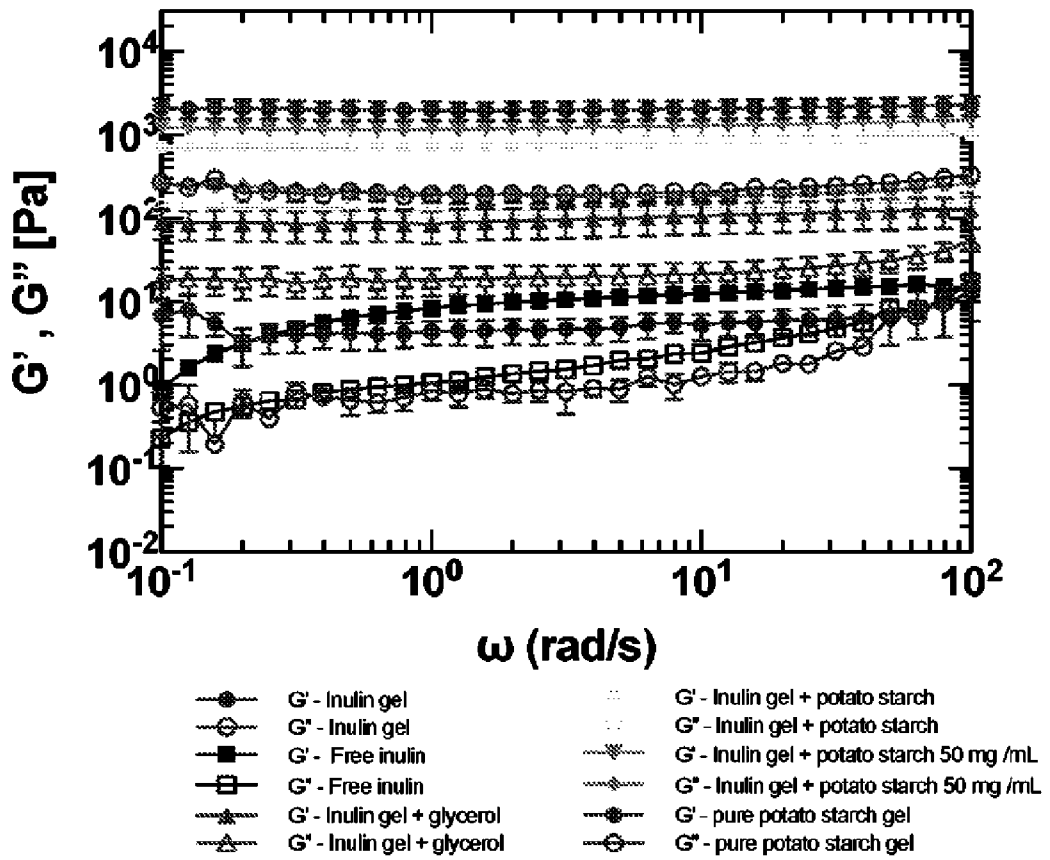
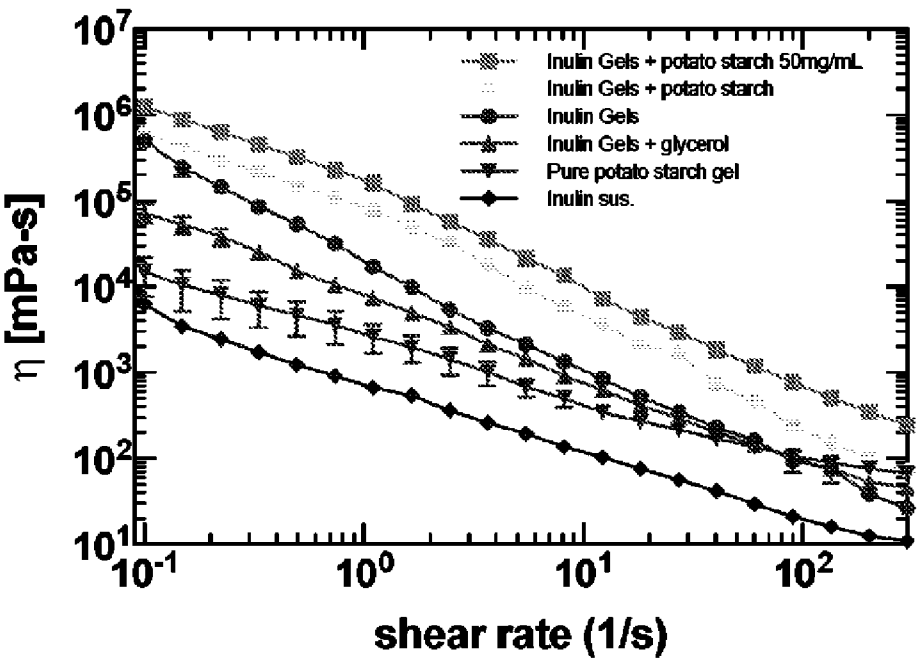


FIG. 24

	Excipient	Content % (w/w)
Inulin	-	23
	Potato starch	5.0
	Pectin	2.0
	Guar gum	0.5
	Bean gum	1.0
	Gelatin	5.0
	Glycerol	50.0

FIG. 25


G', G" [Pa]
ω (rad/s)
G' - Inulin gel
G" - Inulin gel
G' - Free inulin
G" - Free inulin
G' - Inulin gel + glycerol
G" - Inulin gel + glycerol
G' - Inulin gel + potato starch
G" - Inulin gel + potato starch
G' - Inulin gel + potato starch 50 mg /mL
G" - Inulin gel + potato starch 50 mg /mL
G' - pure potato starch gel
G" - pure potato starch gel


η [mPa-s]
shear rate (1/s)
Inulin Gels + potato starch 50mg/mL
Inulin Gels + potato starch
Inulin Gels
Inulin Gels + glycerol
Pure potato starch gel
Inulin sus.