

Metabiotics and their Health Benefits

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Abstract

Probiotics are said to confer a number of health benefits on the host through their varied mechanisms of action in the human GIT. But a number of limitations exist with use of live probiotics. We are yet to be sure about the optimal dosage of probiotics, their specific mode of action, duration of the beneficial effects and the nature of the final results. The metabolic substances elaborated by probiotics and or their structural components, popularly called as metabiotics are said to provide more precise results in the above said aspects. These substances are said to possess better absorption, metabolism, distribution, and excretion abilities compared with classic probiotics based on live microorganisms. Hence use of metabiotic products may provide a more precise approach for treatment of pathological conditions associated with the imbalance of host microbiota.

Keywords: Probiotics, GIT, metabiotics, health benefits, metabolites

Scientific studies are increasingly proving the importance of gut microbiota and their interactions in human health. Recent decades saw emergence of probiotics as one of the most relevant tools to manipulate gut microbiota for human health benefits. Although, use of probiotics has shown them to be safe and beneficial, we are yet to define the optimal amount of bacteria for probiotic effects. Also, there is no single mechanism of action for all probiotics (Pflughoeft *et al.*, 2012, Yazdankhah *et al.*, 2009).

Moreover, the beneficial effects of probiotics may be short-lived, inconsequential, or ambiguous (Kinross *et al.*, 2011 Van Reenen *et al.*, 2011, Kiseleva *et al.*, 2011). Although the history of live probiotic use does not high-light any area of serious concern, recent well-documented events of adverse effects and uncertainty about the level of their risk require new alternative approaches in prophylaxis and treatment of pathological conditions associated with the imbalance of host microbiota. Metabiotics,

the metabolic substances elaborated by probiotic organisms, may be a step towards that.

WHAT ARE METABIOTICS?

Metabiotics are the structural components of probiotic microorganisms and/or their metabolites and/or signaling molecules with a known chemical structure that can affect the microbiome and/or human metabolic and signaling pathways, optimizing the composition and function of indigenous microbiota and host-specific physiology, immunity and neuro-hormonbiology, and regulating metabolic and/or behavior reactions connected with the activity of host indigenous microbiota. Different probiotic strains can become the source for metabiotic substances. Metabiotics (Shenderov, 2012, Shenderov, 2011) are also known by different names such as 'metabolic probiotics' (Vahitov *et al.*, 2006 and Vahitov *et al.*, 2005), 'postbiotics' (Tsilingiri and Rescigno, 2013), 'ghostprobiotic' (Taverniti *et al.*, 2011), 'Heat-killed probiotic' (Indriyani *et al.*, 2012), 'biological drugs'

(Sonnenburg *et al.*, 2011), or ‘pharmacobiotics’ (Caselli *et al.*, 2011).

Metabiotics have certain advantages over classic probiotics such as defined chemical structure, dosage, safety and long shelf-life. Besides, metabiotics possess better absorption, metabolism, distribution, and excretion abilities compared with classic probiotics based on live microorganisms. A detailed molecular understanding of metabiotics can turn them into significant, specific, and active contributors to the benefits derived from probiotics (Shenderov, 2011 and Sonnenburg *et al.*, 2011). Metabiotics display wide inhibitory activity against various species of pathogens. Metabiotic substances contain various metabolites and signaling molecules which display broad antibacterial spectrum and immunomodulatory actions (Savadogo *et al.*, 2006, Liasi *et al.*, 2009, Gaggia *et al.*, 2010 and Cicienia *et al.*, 2014).

Types of metabiotics and their health benefits

Probiotic strains can produce different sets of Low Molecular Weight (LMW) bioactive molecules which can be attractive candidates for metabiotic construction. Some groups of LMW compounds of probiotic microbe origin that may become the basis for manufacture of potential metabiotics are mentioned here under.

Bacteriocins

Bacteriocins are an abundant and diverse group of ribosomally synthesized antimicrobial peptides produced by bacteria and archaea (Alleson *et al.*, 2012). They make up a heterogeneous family in terms of heat stability, molecular mass, mode of release and action, microbial target, and mechanism conferring protection to the producing strain (Gordon *et al.*, 2007 and Heng *et al.*, 2007). A number of research studies have shown that bacteriocins have the potential to fight skin infections as well as oral, respiratory, gastrointestinal, pneumonia (Piper *et al.*, 2011, Kwaadsteniet *et al.*, 2010), candidiasis infections, mastitis infection (Akerey *et al.*, 2009), halitosis (Iwamoto *et al.*, 2010), *Clostridium* infection

(Rea *et al.*, 2010), infection with *L.monocytogenes* (Corr *et al.*, 2007, Svetoch *et al.*, 2011) and urogenital tract infections (Turovskiy *et al.*, 2009, Sutyak *et al.*, 2012). Many bacteriocins have been assessed for potential application as therapeutic agents some of which are mentioned in Table 1.

Table 1: Bacteriocins which have been studied for potential application as therapeutic agents

| Bacteriocins | Producer strain | Potential Pharmaceutical applications |
|------------------------|-----------------------------------|--|
| Ancovenin | <i>Streptomyces spp.</i> | Treating high blood pressure |
| Epidermin | <i>Staphylococcus epidermidis</i> | Treating skin infections |
| Lacticin 3147 | <i>Lactococcus lactis</i> | Treating mastitis infections |
| Mutacin | <i>Streptococcus mutans</i> | Treating dental carries |
| Nisin | <i>Lactococcus lactis</i> | Treating peptic ulcer |
| E1, E4, E7, E8, K & S4 | <i>Escherichia coli</i> | Treating hemorrhagic colitis and hemolytic uremic syndrome |

Source: Gillor *et al.*, 2005, 2009; van Heel *et al.*, 2011, Brand, 2013.

Short chain fatty acids and organic acids

Short-chain fatty acids (SCFA) are the major anions within the intestinal lumen and are mainly produced by anaerobic fermentation of undigested carbohydrates and, to a lesser extent, proteins (Topping and Clifton, 2001). Clinical studies have showed that the administration of SCFAs such as butyrate, acetate and propionate has a positive effect on the treatment of ulcerative colitis, crohn’s disease, antibiotic-associated diarrhoea and obesity (Binder, 2010; Chambers *et al.*, 2014). Several studies have showed that the administration of short-chain fatty acids or dietary fibre to both rats and humans causes a decline in the plasma concentrations of cholesterol (Fushimi *et al.*, 2006, Aritsuka *et al.*, 2016). Proposed health benefits of some of the short chain fatty acids and organic acids are shown in Table 2. Propionate

is a gluconeogenic substrate which inhibits the utilisation of acetate for lipid and cholesterol synthesis (den Besten *et al.*, 2013). Moreover it has been shown to inhibit inflammation and modulate adipokine production in adipose tissue (Al-Lahham *et al.*, 2010b, 2012). It has also improved insulin resistant in the inulin control group when taken with inulin (Chambers *et al.*, 2014). The oral administration of acetate improved glucose tolerance and suppressed obesity (Yamashita *et al.*, 2007). Acetate reduces the appetite by changing the expression profiles of appetite regulatory neuropeptides in the hypothalamus through activation of citric acid pathway (Frost *et al.*, 2014). Microbially produced lactate is generally converted into propionate or butyrate by a subset of lactate-utilizing bacteria

(Flint *et al.*, 2012). Lactate can have diverse metabolic and regulatory properties such as immune function, being an energy source for cell turnover, Histone deacetylase (HDAC) inhibitor, and signalling molecules. Microbially produced lactate may affect physiological functions in the vagina either through HDAC modulation or G protein coupled receptor 81(GPR81) signaling (Boskey *et al.*, 2001). A study by Haraguchi *et al.* (2014) showed that polyphenols in conjunction with high-fat diet raised cecal succinate levels and inhibited growth and proliferation of colon cancer cells.

Proteins, peptides, amino acids

Amino acids are the constructive components of proteins and peptides. Amino acids can serve as

Table 2: Proposed health benefits of short chain fatty acids and organic acids

| SCFA | Proposed health benefits | References |
|------------|---|--|
| SCFAs | Treatment of ulcerative colitis, Crohn's disease, AAD and obesity Decline in the plasma concentrations of cholesterol | Chambers <i>et al.</i> , 2014 Binder, (2010) Aritsuka <i>et al.</i> , 2016 |
| Butyrate | Anti-colon cancer Anti-inflammatory Anti-colorectal cancer Anti-inflammatory Efficient HDAC inhibitor Decreases intestinal epithelial permeability | Fushimi <i>et al.</i> , 2006 Hamer <i>et al.</i> , 2008; 2012 Flint <i>et al.</i> , 2012 Donohoe <i>et al.</i> , 2012 Van Immerseel <i>et al.</i> , 2010 |
| Acetate | Improved insulin sensitivity Improved glucose tolerance Suppresses obesity Reduces the appetite | Gao <i>et al.</i> , 2009 Yamashita <i>et al.</i> , 2007 Frost <i>et al.</i> , 2014 |
| Propionate | Act as gluconeogenic substrate Inhibits the utilisation of acetate for lipid and cholesterol synthesis Anti-inflammatory | den Besten <i>et al.</i> , 2013 Al-Lahham <i>et al.</i> , 2010a Al-Lahham <i>et al.</i> , 2010b, 2012 |
| Lactate | Immune function Energy source HDAC inhibitors Signalling molecules | Flint <i>et al.</i> , 2012 Boskey <i>et al.</i> , 2001 |
| Succinate | Anti-colon cancer | Haraguchi <i>et al.</i> , 2014 |

precursors for the synthesis of SCFA by bacteria (Tome *et al.*, 2013), suggesting an interplay between microbial activity and host amino acid and SCFA homeostasis. Glutamate/ glutamine is a key compound in the cellular metabolism, it therefore serves as a unique brain fuel and performs some other important functions such as detoxification of ammonia, as a hepatoprotective agent, to aid in peptic ulcer healing, and others (Zareian *et al.*, 2012). One of the leading roles of glutamic acid in pharmaceuticals is that of a neurotransmitter. Lysine is required by the body to synthesize L-carnitine, which is a substance required for the conversion of fatty acids into energy. Lysine also helps in calcium absorption and collagen formation which are important for muscle and bone health. It also supports or acts as a precursor in the synthesis of enzymes, antibodies, and some hormones as well. Methionine is an excellent natural

lipotropic agent that processes and eliminates fats from the liver and acts as a natural detoxifying agent removing heavy metals from the body and excess histamine from the brain.

In addition, it has antioxidant properties as well and thus protects the body against free radicals (Chaitow, 1985). Tryptophan is an essential amino acid with a unique indole side chain which indicates its use as a precursor for a number of neurotransmitters in the brain, for example, serotonin, melatonin, and niacin associated with appetite, sleep, mood, and pain perception. Its application lies in the chemical synthesis of some antidepressant drugs and in the treatment of schizophrenia (Porter *et al.*, 2005; Heijden *et al.*, 2005). γ -Aminobutyric acid (GABA) acts as the major inhibitory neurotransmitter in the mammalian central nervous system. GABA improves the plasma

Table 3: Bioactive peptides identified in fermented milk products

| Dairy Products | Identified bioactive peptide | Activity |
|------------------------|---|-------------------------------|
| Cheese type | β -CN (8–16), β -CN (58–77), | Phosphopeptides, precursor of |
| Parmigiano- Reggiano | α s2-CN(83–33) | β -casomorphin |
| Cheddar | α s1-CN fragments | Several |
| | β -CN fragments | Phosphopeptides |
| Italian varieties: | β -CN (58–72) | ACE-inhibitory |
| Mozzarella, Crescenza, | | |
| Gogonzola, Italico | | |
| Gouda | α s1-CN (1–9), β -CN (60–68) | ACE-inhibitory |
| Festivo | α s1-CN (1–9), α s1-CN (1–7), α s1-CN (1–6) | ACE-inhibitory |
| Emmental | α s1-CN fragments | Immuno-stimulatory, |
| | β -CN fragments | several |
| | | phosphopeptides, |
| Manchengo | Ovine α s1-CN, α s2-CN, | antimicrobial |
| | β -CN fragments | ACE-inhibitory |
| Fermented milks | β -CN (74–76), β -CN (84–86), | Antihypertensive |
| Sour milk | κ -CN (108–111) | |
| Yogurt | Active peptides not Identified | Weak ACEinhibitory |
| Dahi | Ser-Lys-Val-Tyr-Pro | ACE-inhibitory |

Source: Korhonen, 2009; Haque *et al.*, 2009.

concentration, growth hormones and the protein synthesis in the brain (Cho *et al.*, 2007). GABA intake can regulate sensations of pain and anxiety, and lipid levels in serum (Kono *et al.*, 2000, Miura *et al.*, 2006).

Furthermore, consumption of GABA-enriched foods can inhibit cancer cell proliferation (Park *et al.*, 2007) and improve memory and the learning abilities (Miura *et al.*, 2006). Some proteins secreted by the commensal microbiota might be responsible for the anomalous immune response observed in the framework of inflammatory bowel disease (Adams *et al.*, 2008; Ivison and Steiner, 2008, Schoepfer *et al.*, 2008). It secretes different effector molecules such as chemokines, cytokines or antibacterial peptides (defensins), mucus secretion, and modulation of the immune function and the response of the gut-associated lymphoid tissue (GALT) cells.

Probiotics when used as starter cultures are known to liberate certain specific protein fragments that have a positive impact on body functions and conditions and may ultimately influence health. These peptides are called bioactive peptides. Peptides with various

bioactivities (Table 3) have been identified in several dairy-products such as milk protein hydrolysates, fermented milks and many cheese varieties (Gobbetti *et al.*, 2002; Korhonen and Pihlanto-Leppälä, 2004; Sieber *et al.*, 2010). Some commercially available dairy products with bioactive peptides are listed in Table 4.

Nucleic acids and nucleotides

DNA and RNA act as the genetic code and translators for the proteins. Nucleotides are the constitutive units of DNA and RNA. Nucleotides are true nutraceuticals or functional ingredients frequently used to improve the disease resistance, to decrease mortality and to promote the growth rate. They are widely utilized in clinical nutrition and in mother milk substitutes. Nucleotides have beneficial effects on early infant growth (Singhal *et al.*, 2010), small intestinal growth and development (Rodriguez-Serrano *et al.*, 2010), intestinal microflora and immune function (Hawkes *et al.*, 2006; Gutierrez-Castrellon *et al.*, 2007). DNA vaccines have been used to prevent allergic response (Horner *et al.*, 2001). DNA aptamers have demonstrated promise in intervention of pathogenic

Table 4: Some commercially available products containing bioactive peptides

| Brand name | Product type | Health claims | Bioactive peptide | Manufacturer |
|--------------|----------------------------------|---|--|--------------------------------|
| Calpis | Sour milk | Reduction of blood pressure | VPP, IPP from β -casein and κ -casein | Calpis Co., Japan |
| Evolus | Fermented milk, calcium enriched | Reduction of blood pressure | VPP, IPP from β -casein and κ -casein | Valio, Finland |
| BioZate | Hydrolysed whey protein isolate | Reduction of blood pressure | Whey peptides | Davisco, USA |
| BioPURE-GMP | Whey protein Hydrolysate | Anticariogenic, Antimicrobial, Antithrombotic | Glycomacropeptide κ -casein fb(106–169) | Davisco, USA |
| Recaldent | Chewing gum | Anticariogenic | Caseinphosphopeptides | Cadbury Enterprises |
| Festivo | Fermented low-fat hard cheese | Reduction of blood pressure | α s1-casein f(1–6) RPKHPI, f(1–7) | MTT Agrifood Research, Finland |
| CholestBlock | Drink powder | Hypocholesterolemic | Soy peptides bound to Phospholipids | Kyowa Hakko, Japan |

Source: Korhonen, 2009; Haque *et al.*, 2009; Tidona *et al.*, 2010; Sharma *et al.*, 2011.

protein biosynthesis against HIV-1 integrase enzyme (de Saultrait *et al.*, 2002). Small interfering RNAs are being investigated to inhibit HIV (Martinez *et al.*, 2002), hepatitis (Zamore and Aronin 2003), and influenza infection (Ge *et al.*, 2003). Supplements containing good levels of nucleic acids have been recommended to retard aging, improve memory, or improve the immune or other protein functions.

Polysaccharides, peptidoglycans and other surface molecules

Many strains of probiotics are capable of elaborating EPS which are said to play an important role in conferring health benefits (Table 5). Orally administrated fermented milk containing either exopolysaccharide (EPS) producing *Lb. delbrueckii* ssp. *bulgaricus* or EPS-producing *S. thermophilus* has resulted in the reduction of colon cancer in male Fisher rats and exhibited a chemo-preventive effect *in vivo* (Purohit *et al.*, 2009). Kefiran, an EPS produced by *Lactobacillus* spp. increased T-cell activity and thereby decreased tumor growth in mice (Zubillaga *et al.*, 2001). Bacterial polysaccharides have been reported to exhibit antitumor activity; however the potency of activity depends on the branching structure (Yoon *et al.*, 2004).

Peptidoglycans determines the shape and preserves the integrity of the bacterial cell. Purified

polysaccharide-peptidoglycan complex (PSPG) from *Lb.casei Shirota* has anti-inflammatory actions in chronic intestinal inflammatory disorders (Matsumoto *et al.*, 2009).The peptidoglycan extracted from *Lb.paracasei* subsp. *paracasei*X12 (X12-PG) may have played an important role in its inhibitory effects on colon cancer (Wang *et al.*, 2014). Peptidoglycans of probiotic *L. rhamnosus* GG *viz.*, Msp1 (p75) and Msp2 (p40), were found to promote the survival and growth of epithelial cells under pro-inflammatory conditions (Yan *et al.*, 2007).

Many bacteria possess nanoscale fibrous extracellular appendages known as pili on their surfaces (Telford *et al.*, 2006).Pili-mediated bacteria-host interactions have been demonstrated in the probiotic Gram-positive bacterium *Lactobacillus rhamnosus* GG (Kankainen *et al.*, 2009). The pili identified in *L. rhamnosus* GG confer the ability to adhere to the intestinal epithelial cells (Caco-2) and human intestinal derived mucus; they also promote biofilm formation (Lebeer *et al.*, 2012). Furthermore, pili of *L. lactis* allowed the strain to adhere to intestinal epithelial cells (Caco-2) (Meyrand *et al.*, 2013). *L. rhamnosus* GG pili are involved in reducing IL8 mRNA expression provoked by other cell surface components, such as lipoteichoic acids (LTAs) in intestinal epithelial cells (Lebeer *et al.*, 2012). The roles of pili in bacterial adhesion, invasion, aggregation, formation of biofilms, and modulation

Table 5: Proposed health benefits of microbial polysaccharides

| Potential health benefits | Producer strain | References |
|--|--|---|
| Antioxidant potential by inhibiting hydroxyl and superoxide anion radicals | <i>Streptococcus spp.</i> and <i>B. animalis</i> | Kanmani <i>et al.</i> , 2011; Xu <i>et al.</i> , 2011 |
| Reduction of plasma cholesterol by ~33% | <i>Lb. mucosae</i> | London <i>et al.</i> , 2014 |
| Reduction of colon cancer | <i>Lb. delbrueckii</i> ssp. <i>bulgaricus</i> , <i>S. thermophilus</i> | Purohit <i>et al.</i> , 2009 |
| Antitumor | <i>Lb. acidophilus</i> , <i>S. thermophilus</i> <i>Lactobacillus delbrueckii</i> subsp. <i>Lactococcus lactis</i> ssp. | Kim <i>et al.</i> , 2010 Hassan, (2008) |
| Obesity induced Type 2 Diabetes | Levan (<i>Bacillus licheniformis</i>) | Dahech <i>et al.</i> , 2011 Xiu <i>et al.</i> , 2010 |
| Protection from intestinal inflammation induced by <i>Helicobacter hepaticus</i> | Polysaccharide A (PSA) of <i>Bacteroides fragilis</i> | Mazmanian <i>et al.</i> , 2008 |

of immunity are well established (Lebeer *et al.*, 2012; Danne *et al.*, 2012).

Plasmalogens and vitamins

Plasmalogens are a unique class of membrane glycerophospholipids containing a fatty alcohol with a vinyl ether bond at the sn-1 position, and enriched in polyunsaturated fatty acids at the sn-2 position of the glycerol backbone. Plasmalogens have been proposed to act as antioxidants in membrane physiology *via* protection of unsaturated fatty acids and membrane proteins from harmful oxidation (Wang and Wang 2010). Reduced brain plasmalogens can be demonstrated in various neurodegenerative disorders. These include Alzheimer disease (Han *et al.*, 2001), Parkinson's disease (Fabelo *et al.*, 2011), Down

syndrome (Murphy *et al.*, 2000) and experimental autoimmune encephalomyelitis (Singh *et al.*, 2004). Plasmalogens are a significant component of the cytoplasmic membrane of *B. animalis* subsp. *lactis* (Taylor *et al.*, 2012).

Probiotic bacteria that live in your intestinal tract also produce vitamins, including B-vitamins like folate, biotin and vitamin B12. The production of vitamin B1 and B2 by bacteria contributes to the total intake of vitamin B1 and B2 (Fabian *et al.*, 2008). It was reported that *Lactobacillus reuteri* CRL1098 was able to produce B12 (Taranto *et al.*, 2003). Vitamin K as well as vitamin D production by bacteria in the gut is also reported (Jones *et al.*, 2013). *In vitro* studies have demonstrated the production of high levels of folate (about 100 µg/L) by strains of *Lactobacillus*. Bifidobacteria strains

Table 6: Some of the commercially available metabiotic products

| Product | Description | Reference |
|---------------|--|----------------------------------|
| Hylak Forte | Manufactured by Ratiopharm/Merckle, Germany. It contains <i>Escherichia coli</i> DSM 4087, <i>Streptococcus faecalis</i> DSM 4086, <i>Lactobacillus acidophilus</i> DSM 4149 and <i>L. helveticus</i> DSM 4183. Presence of SCFA, lactic acid, and some other non-identified microbial metabolites in this drug. Health benefits for adults and children by producing positive shifts in intestinal microbiota, host acid-alkaline balance, water-salt metabolism, vitamins B and K balance and energy provision to intestinal epithelia and local immune cells. | (Belousova <i>et al.</i> , 2005) |
| Zakofalk | Prepared by Dr. Falk Germany. It contains supplements inulin and butyric acid. Recommended for the treatment of mild to moderately active inflammatory intestinal diseases. | (Roda <i>et al.</i> , 2007) |
| Bactistatin | It contains <i>B.subtilis</i> strain, Vitamin E. Recommended for increasing the immune defense function of the human body, selectively adsorbs and removes toxins and allergens, reduces bloating and cramps and improves the functional state of the gastrointestinal tract. | (www.bactistatin.com) |
| Aktoflor C | It is made up of lactic acid, lysine, succinic acid and mainly helpful for reducing intestinal disorder symptoms (diarrhea, constipation, bloating) and it prevents side effects of antibiotics. | (www.amt.allergist.ru) |
| Acilact | It is made up of <i>Lactobacillus</i> , Fructo-oligosaccharides, Lactoferrin. It is suitable for reducing the cholesterol level in the blood and for treatment of bacterial vaginosis. | (www.medicatione.com) |
| Nagipol | It consists of yeast autolysate beer containing proteins, amino acids (including the 8 essential) and vitamins of group B (B1-B6). Increased physical activity, reduced resistance to colds disease, anaemia and infectious diseases of the gastrointestinal tract and hepatitis are reported. | (www.noillen.bitballoon.com) |
| Lacteol Forte | It is heat killed product of <i>Lb.fermentum</i> and <i>Lb.delbruekii</i> . It can be prescribed for infants and patients with positive H.I.V. and immunodeficient patients. | (www.medicinep.com) |

also contribute to folate intake by the synthesis and secretion of folates in the human intestine (Strozzi & Mogna, 2008).

Various messenger or signal molecules

Symbiotic gut microorganisms release various soluble LMW molecules of different chemical nature. These LMW molecules are able to sense environment, interact with corresponding cell surface, membrane, cytoplasm and nucleic acid receptors, to reply quickly and coordinately by induction of special sets of genes and playing an important role in the control for many genetic and physiological functions, biochemical and behavior reactions, in supporting host health in general. Bacteria-host cells cross talk is mainly based on the exchange of signal molecules in both directions (Yuan *et al.*, 2008, Khmel & Metlitskaya, 2006 and Atkinson & William, 2009). Lectins are active regulators of metabolism and functional food ingredients (Shenderov & Lakhtin, 2004). They participate in adhesion processes and other functions (Lakhtin *et al.*, 2006). Probiotic lectins can function as cell surface building constituents, protecting and communicating components and growth and signal factors. The signal molecule autoinducer-2 (AI-2) and its cognate synthase LuxS are considered to be attractive candidates for multispecies communication at the gastrointestinal level (Lebeer *et al.*, 2008). AI-2 molecules produced by *E. coli* Nissle are found to influence the expression of cytokines in the mucosa of the colon in the mice.

Products containing metabiotics

A number of products containing metabiotics are commercially available. Some of which are shown in Table 6.

CONCLUSION

Metabiotics are a natural evolution of the probiotic concept and are considered to be one step ahead of live probiotics because of their well-defined chemical structure, dosage, safety, specificity, metabolic aspects and long shelf-life. Metabiotics are said to impart a plethora of health benefits through varied

mechanisms. But this warrants more and more in-depth studies to understand the mechanisms of action at molecular level to validate the health claims. This may promote further development of the probiotic concept and reduce health hazards of the current approaches in the prevention and treatment of diseases associated with imbalance of host microbiota. Further to market the metabiotic products, proper regulatory frame work is essential to prevent false claims.

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