Nutraceuticals as potential therapeutic agents for colon cancer: a review

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Abstract Colon cancer is a world-wide health problem and the second-most dangerous type of cancer, affecting both men and women. The modern diet and lifestyles, with high meat consumption and excessive alcohol use, along with limited physical activity has led to an increasing mortality rate for colon cancer worldwide. As a result, there is a need to develop novel and environmentally benign drug therapies for colon cancer. Currently, nutraceuticals play an increasingly important role in the treatment of various chronic diseases such as colon cancer, diabetes and Alzheimer's disease. Nutraceuticals are derived from various natural sources such as medicinal plants, marine organisms, vegetables and fruits. Nutraceuticals have shown the potential to reduce the risk of colon cancer and slow its progression. These dietary substances target different molecular aspects of colon cancer development. Accordingly, this review

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Abbreviations: ACC, acetyl CoA carboxylase; ACF, aberrant crypt foci; ACL, ATP-citrate lyase; ASTX, astaxanthin; COX-2, cyclooxygenase 2; DHA, decahexaenoic acid; DMH, 1,2-dimethylhydrazine; DR, death receptor; EGCG, epigallocatechingallate; EPA, eicosapentaenoic acid; FAS, fatty acid synthase; 5-FU, 5-fluorouracil; GADD, growth arrest and DNA damage; HMG-CoA, 3-hydroxy-3-methyl-glutaryl CoA; HUVEC, human umbilical vein endothelial cell; IGF, insulin-like growth factor; IL, interleukin; LDH, lactate dehydrogenase; MMP, matrix metallo-proteins; NF-κB, nuclear factor-kappa B; PRAP, prolactin receptor associated protein; TCA, tricarboxylic acid cycle; TNF, tumor necrosis factor; TRAIL, tumor necrosis factor-related apoptosis-induced ligand; VEGF, vascular endothelial growth factor

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briefly discusses the medicinal importance of nutraceuticals and their ability to reduce the risk of colorectal carcinogenesis.

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1. Introduction

Colon cancer is one of the most dangerous forms of cancer, with potential to spread to distinct parts of the body including liver, lung, ovaries and other gastrointestinal organs. So far, 5-fluorouracil (5-FU) is the first choice for colon cancer treatment, acting as an inhibitor of DNA synthesis. However, while synthetic chemical anticancer drugs prolong survival, they often have adverse effects and off-target actions. Based on this, nutraceuticals and phytochemicals have been investigated for colon cancer therapeutics. Nutraceutical is a term derived from nutrition and pharmaceutical, and are sometimes termed “functional foods.” Nutritional phytochemicals have a strong historical background and significant applications in modern medicine. These compounds are used in medicinal and commercial industries for cosmetics, food aids and additives.

Nutraceuticals have the ability to control the DNA damaging factors in cancer cells and regulate DNA transcription in tumors. They possess numerous therapeutic benefits such as antiobesity effects, cardiovascular effects, antidiabetic effects, immune enhancement, natural antioxidant activity, and anti-inflammatory effects. Fig. 1 shows different classes of nutraceuticals and their uses. The different stages of colon cancer warrant various treatment options such as chemotherapy, surgery, radiation and phytotherapy. All other forms of cancer therapeutics have significant adverse effects. Plant-derived nutraceuticals are advantageous for the treatment of colon cancer with additional benefit of improving overall health. These nutritional compounds have provided better treatment and showed fewer adverse effects. The incidence and mortality rates for colon cancer have been increasing in most of the countries, particularly US, European and part of Asian countries. This increasing incidence of colon cancer appears due to changing dietary constituents, physical activity patterns, as well as genetic influences. Fig. 2 shows the mortality and incidence rate of colon cancer in 2005–2012.

Reactive oxygen species can cause problems in normal cells. Free radicals such as O2 and OH may increase normal human colonocyte activity and result in the formation colon polyps. Natural antioxidants such as quercetin are derived from fruits and plant resources and can limit the oxidative damage in colon cells. Quercetin belongs to a family of plant-derived flavonoid phytochemicals and is effective for inducing apoptosis in colon cancer cells. Likewise, dietary uses of onion might be able to suppress the proliferation of normal cells. Onion contains high levels of quercetin, which inhibits the effects of colon cancer proliferation in both in vitro and in vivo studies. Lentinan naturally occurs in the edible mushroom Lentinus edodes. The lentinan compound is known as β-1,3-glucan. It is one of the important drugs used as anticancer agents and is used clinically for colon cancer treatment. Lentinan significantly reduces the formation of colon tumors in an animal model.

Selenium is an important dietary mineral found in broccoli extract, red wine, dietary fiber, pepper, soya, cloves, fenugreek, ginger, apple and other vegetables. Selenium is associated with up to a 50% decrease in the risk for colon cancer. Yellow mustard oil is synthesized by the brassica family of plants and has been examined for its potential anticancer properties. Mustard contains a complex mixture of long-chain polysaccharides that may play a protective role in colon cancer formation. Essential oils such as eicosapentanoic acid (EPA), docosahexaenoic acid (DHA) and omega-3 fatty acids are also used to treat and prevent cancer and cardiac diseases. Particularly, the consumption of fish and fish products reduces the risk of colon cancer progression. Recently developed live micro-organisms such as...
as probiotics are also important dietary supplement for humans. Probiotics balance the mix of intestinal microbes and have beneficial effects on the human digestive system. Environmental factors and dietary habits can alter the colonic bacteria and lactobacilli concentration, and may lead to the formation of polyps and malignant tumors. Hence intake of probiotics may inhibit preliminary cancer cell growth. The clinically used probiotics may be preventing colon cancer progression in an N-nitroso-N-methylurethene-induced murine colon adenocarcinoma model in mice. Cancer cells from the spleen of treated mice were isolated and purified by flow cytometry for mRNA analysis. The diseased mice were continuously fed probiotics to monitor recovery from epithelial or crypt damage.

However, the therapeutic benefits of nutraceuticals have not yet been clearly demonstrated. Nonetheless, preliminary characterization and epidemiological studies show that different nutritional packages can control and prevent colon dysfunction. Dietary supplements enhance colon activity and reduce the incidence of colon cancer. These nutraceuticals could be naturally occurring in various plants, bacteria, fungi, algae and marine resources. Hence, this review focuses on important nutraceutical compounds derived from the plant and marine sources as used for treating and controlling colon cancer behavior.

2. Colon cancer and bioenergetics pathways

So far, many studies have shown that nutraceutical metabolites can regulate tumor metabolism and growth. The biochemical observations on colon cancer are expressed in abnormal levels of common enzymes and radical changes in the glycolysis pathway. Lactate dehydrogenase (LDH) is a cluster of enzymes involved in energy metabolism. LDH is one of the marker enzymes for the detection of colorectal cancer; it has been shown that increases in the level are associated with the initial stages of colon cancer. The higher activity of HMG-CoA reductase and high levels of mevalonate-derived metabolites such as isoprenoid compounds are associated with the initial stages of colon cancer. Koukourakis et al.20 showed that HMG-CoA reductase expression is very high in human colon cancer. The higher activity of HMG-CoA reductase and high levels of mevalonate-derived metabolites such as isoprenoid compounds are clear evidence of cancer formation. The study showed that important biomolecules are differentially regulated between cancer and normal cells, with significant differences in metabolites of colon cancer tissues. The intermediates of the tricarboxylic acid cycle and lipids were decreased in cancer cells; however, metabolites in the urea cycle, purine, pyrimidine and amino acid synthesis were generally at decreased fat synthesis and increases lipolysis from liver and adipose tissue storage lipids. In cancer cells, the enzymes ATP-citrate lyase (ACL), acetyl CoA carboxylase (ACC), and fatty acid synthase (FAS) are habitually over expressed relative to normal cells. Particularly, the FAS is used as a cancer biomarker for diagnostic purposes. Fas inhibitors are able to activate apoptosis in colon and breast cancer cell lines without affecting normal lipogenic tissues.

3. Nutraceuticals effective for colon cancer therapeutics

Nutraceuticals are thought to enhance human health and prevent chronic diseases. Fiber content in vegetables and fruits may reduce the risk of colon cancer formation. These food supplements have been proposed as chemo-preventive agents for colon cancer treatment. Also, plant-derived polysaccharides act as protective role in the development of colon lesions.
Pro-oxidants are associated with a high risk of cancer. Free radicals can induce posttranscriptional modification in cancer and over express their related proteins. Antioxidant food supplements are an important component for treating and controlling cancer development. Fig. 4 shows clinically important secondary metabolites and their analogous structures. Adequate consumption of dietary nutraceuticals is a reasonable way to maintain health and avert the formation of colon cancers. The most common reasons for the consumption of dietary supplements are to control the symptoms of cancer and to prevent future disease. Dietary supplements such as microalgae, plant derivatives and vegetables are a rich source of vitamins, minerals, amino acids and other micro-nutrients. These natural sources have a major role in health and disease. Moreover, colon cancer is widely reported as being reduced by the use of various nutraceuticals such as folate, calcium, tomato-soy diet, fiber and vitamins. Nevertheless, the recommended dosage of nutraceuticals is very important and clearly related to benefit the patients. However, it is necessary to avoid hypervitaminosis, formation of calculi and other obesity-related problems.

Recently, nutraceuticals encapsulated by nanoparticles have been developed in nanomedicine. The hybrid systems made of anticancer drugs such as cisplatin, apoferitin, methotrexate, and 5-fluorouracil have been developed with a drug delivery carrier like layered double hydroxide (LDH) and platinum nanoparticles. The nutraceutical-containing nanoparticles rapidly interact with cancer cells and provide promising anticancer chemotherapy agents with biocompatibility. Some biological agents/nutraceuticals such as antibodies, proteins, polysaccharides, aptamers, and peptides have been able to direct nanoparticle targeting to tumor cells. Similarly, targeting nutraceuticals to tumors can enhance their effectiveness: nanoparticles encapsulating curcumin are more effective than the free curcumin, eventually inhibiting NF-κB regulated transcription and angiogenesis.

3.1. Carotenoids for colon cancer

Carotenoids are a major class of secondary metabolites with many biological activities such as free radical scavenging properties, skin tone improvement and potential for cancer treatment. Generally carotenoids are classified into two main subclasses such as hydrocarbon carotenoids including β-carotene, α-carotene, lycopene and oxycarotenoids which include lutein and zeaxanthin, as well as other compounds. Carotenoids have many applications in the clinical and commercial fields. β-Carotene has been shown to be efficient in controlling cellular damage from free radicals. Secondary metabolites can influence and effectively react with free radicals in the inner part of the cell membrane. The natural compounds have been more effective in maintaining membrane integrity and antimutagenic properties. The unsaturated nature of lycopene has potential efficiency to provide free radical scavenging activity and inhibit cancer progression. Lycopene is present in various dietary sources such as tomatoes, grapes, and papaya. Carotenoids are used for the prevention of colon and gastrointestinal cancer. Tumor necrosis factor-related apoptosis-inducing ligand (TRAIL) is a protein that induces apoptosis in cancer cells. TRAIL has been targeted in microtubule formation in the cell cycle. Halocynthianthxin is a dietary carotenoid and combined with TRAIL can significantly induce apoptosis in DLD-1 colon cancer cells. The combined drug treatment involves important anticancer effects such as poly(ADP-ribose) polymerase cleavage, induction of caspase inhibitors and nuclear condensation. These mechanisms of halocynthianthxin have shown the potential to

Figure 4 Structures of clinically important secondary metabolite used in colon cancer treatment.
regulate programmed cell death in colon cancer cells. Other phytochemicals such as xanthophyll, astaxanthin, cryptoxanthin and zeaxanthin metabolites have been used for the treatment of colon cancer.33

3.2. Flavonoids for colon cancer

Luteolin is found in numerous edible plants and vegetables such as green pepper, celery and perilla. Naturally isolated luteolin secondary metabolites are clinically proven to be effective colon cancer agents. In vivo studies showed that luteolin can decrease tumor incidence and multiplicity in dimethyl benzanthracene-induced papillomas. Also, many in vitro studies have reported that luteolin stimulates apoptosis in several cell lines33,35. Demidenko et al.33 demonstrated that luteolin induced HT-29 cell cycle block, preventing cancer cell growth at the G1/S and G2/M phases. Furthermore, luteolin suppresses the over expression of some antiapoptotic proteins in affected cells and regulates the expression and activity of CDC2 (CDK1) kinase and cyclin B1 proteins, which initiate the G2/M transition phases observed in luteolin-treated colon cancer cell lines. Use of moderate concentrations of luteolin significantly increased cancer cell apoptosis.

Fisetin is a flavonoid natural substance, occurring in many fruits and vegetables including cucumbers. We observed fasting-induced apoptosis of poly(ADP-ribose) cleavage, which is considered a biomarker of apoptosis. Similarly, caspase-3 was activated in fisetin-treated colon cancer cells. Fisetin can modulate the expression of Bcl-2 metabolites to induce the mitochondrial apoptotic pathway in cancer cells and increases the proapoptotic Bak protein in colon cancer cells.36

3.3. Polyphenolic clusters for colon cancer therapeutics

Polyphenols are natural phytochemicals used to treat various viral and fungal diseases. They are derived from various sources such as plants, seaweeds, marine algae and microorganisms. Polyphenols include different organic constituents such as flavones, flavonols, isoflavones, catechins, epigallocatechin-3 gallate (EGCG) and epicatechins. Numerous plants are reported to have polyphenols in their extracts. Polyphenols isolated from tea plants are well studied for their biological properties. Consumption of green tea protects against several types of chemically induced cancer in animal models.35 Green/black tea is one of the most popular and easily affordable drinks in the world. It has important active metabolites and antioxidant compounds to enhance the health benefits. Green tea contains a high amount of antioxidant polyphenols which effectively controlled cancerous growth in both in vitro and in vivo models. Green tea contains many phytochemicals such as heterocyclic amines, flavones and saponins, and can alter the xenobiotic metabolizing enzymes. These metabolites induce the signal transduction pathway which leads to induction of apoptosis and cell cycle arrest. Some studies have asserted that the high consumption of black tea is also associated with reducing the risk of digestive tract cancers.10

Curcumin is one of the most important secondary metabolites for anticarcinogenic properties and is already used clinically. Curcumin affects the molecular level of protein expression in colon cancers such as COX-2, VEGF, IL-1, IL-6, IGF and Chemokines. The drug targets the active site of COX-2 in malignant cells and it modulates the action of TNF-α and NF-κB factors. Likewise, curcumin is well known clinically as a chemopreventive agent used during the initiation and progression stages of digestive tract cancer.37 Wang et al.38 have explained that curcumin inhibits the secretion of gastrointestinal hormones such as neurotensin. Human colorectal cancer cell line HCT 116 treated with curcumin altered the hormone neurotensin action and induced the IL-8 expression in a time- and dose-dependent manner.

4. Marine nutraceuticals and their derivatives for colon cancer

The marine environment contains an extreme diversity of micro- and macro-organisms. Marine organisms contain structurally diverse bioactive compounds including many that are included in food and health care products. Marine organisms produce novel and pharmacological compounds with fewer adverse effects. Marine-derived bioactive compounds are of current interest to cure several ailments including colon cancers. However, researchers are focusing more on secondary metabolites isolated from marine and other natural sources. Recently natural product research has reported that from 1981 to 2012, 45% of new drugs and 80% drugs approved for anticancer agents were derived from natural products.39,40

4.1. Acetylapoaranotin

Acetylapoaranotin is a diketopiperazine disulfide that was isolated from marine Aspergillus sp. The acetylapoaranotin chemical structure contains disulfide bridges, which are responsible for the molecule’s cytotoxicity. The natural acetylapoaranotin compound can induce apoptosis in human colon cancer cells (HCT116) as confirmed by different apoptotic assays such as annexin-V/PI staining and PARP, caspase-3,-8,-9, and Bax cleavage. This compound also significantly inhibits tumor growth in vivo. Choi and researchers41 are evaluating the molecular role of diketopiperazine disulfides in apoptosis of the HCT 116 colon cancer cell line. Acetylapoaranotin has promising activity to regulate the Bcl-2 family of proteins and the proapoptotic protein Bax. Treatment of the cancer cell line HCT 116 with different concentrations of diketopiperazine disulfides was shown to initiate the caspase 8 activation in intrinsic and extrinsic pathways. Various types of marine-derived compounds have numerous biomedical applications such as the neuroprotective properties of seaweeds, chitosan for weight management and dentistry. Also marine plants and animals have a rich source of novel compounds with promising uses in the nutraceutical, medicinal and commercial food industries.42

The marine-based nutraceuticals such as glucon, sulphated polysaccharides, peptides and fatty acid immunomodulators have great application in the pharmacological and commercial industries. Seaweed-derived peptides and proteins can modulate the intestinal epithelium cell permeability and consequently enhance the intestinal absorption of macromolecules through the energetic pathways.43

4.2. Astaxanthin

Astaxanthin is one of the carotenoid classes of secondary metabolites, and is abundantly produced by Haematococcus pluvialis, crab and marine animals. The highest content of astaxanthin was found in H. pluvialis, a single-celled green algae. It’s chemical name is 3,3'-dihydroxy-β,β-carotene-4,4'-dione. Astaxanthin (ASTX) has diverse biological applications to control colon ulcers, inflammation, cancer, and neurological disorders. Astaxanthin is also used as a food supplement to enhance the optimal health for humans.44 Treatment of a colon cancer mouse model with astaxanthin was shown to
Siphonaxanthin is isolated from the marine green alga *Codium fragile* and remarkably suppresses cell viability, and induces apoptosis in human leukemia and colon cells. Siphonaxanthin has significant antiangiogenic activity by suppressing endothelial cell proliferation and HUVEC tube formation. Although siphonaxanthin had a strong angiogenic activity by suppressing endothelial cell proliferation and protease inhibitors, Table 1 shows the nutraceuticals targeting colon cancer at the molecular level.

### 5. Dietary supplements for colon cancer prevention

Nutraceutical products and their active metabolites effectively suppress a wide range of colon cancer cell lines, namely HCT-116, HT-29, SW 480, SW 620, CaCo2 and LoVo. In *in vitro* studies of various antioxidant fruits including black raspberry, strawberry, and grape seeds were proven to reduce intestinal tumors. Garlic has a diverse nutritional profile and is used to treat common and endemic diseases. Garlic contains various dietary ingredients such as organosulfur and S-allylcysteine compounds. It is a main precursor for inhibiting the growth of colon cancer in a clinical model. Rats used for experimental studies by oral administration of garlic extract exhibited decreased multiplication of cancer cells in the initiation stage, but during the late stage the extract was not effective. Also the extract has no clear scientific evidence for cancer preventive efficacy. Garlic extract also has some toxicity, increasing hemolysis and increasing the anemic condition of the patient. Fenugreek has high content of diosgenin, and it belongs to the steroidal group of saponins. Its cancer-preventative mechanisms have not been fully studied. So far some activity of the fenugreek crude extract supported the anti-proliferation activity against leukemia, colon and breast cancer cell lines.

#### 5.1. Honey (eugenol)

Eugenol is a natural compound which is derived from honey and is present in some plant extracts including clove oil, cinnamon, Flos Magnolia, citrus and balm. Eugenol exhibited novel medical applications for curing various chronic diseases. It promotes apoptosis in colon cancer cells. Eugenol is a potential natural drug against colon cancer. Eugenol stimulates cell division in sub-G1 phase inducing apoptosis in regular time-dependent manner. It acts as a transducer of an apoptosis signal to control the production of non-protein thiols and matrix metallo-proteins (MMP). Eugenol-treated colon cancer cells demonstrated increased p53 activation and proline rich acidic protein (PRAP) cleavage.

#### 5.2. Omega-3 fatty acids

Fatty acids are long chain hydrocarbons which may vary from 10 to 30 carbons and are a component of lipids. Fatty acids such as saturated fatty acids and unsaturated fatty acids are found in marine fishes, microalgae, seaweeds, fish oil, algae oil and eggs. Omega-3 PUFAs have been broadly studied in clinical and pathological conditions. The consumption of omega-3-PUFAs and nutraceutical foods has been correlated with human health benefits. Omega-3 fatty acids have many clinical benefits, including reducing the risk of tumor growth and metastasis. The highest level of omega-3 fatty acids can alter

| Nutraceuticals | Molecular mechanism | Cancer cell line | Ref. |
|----------------|---------------------|-----------------|-----|
| α-Tocopheral   | Antiproliferation, oxidative phosphorylation | HCT-116 | 49  |
| Silibinin      | Reduced cell growth | HT-29 | 49  |
| Fenugreek      | Cytokines, redox reactions | HT-29 | 50  |
| Curcumin (turmeric) | Stimulation of MAPK, Psk/Akt | HT29 | 51  |
| Iron foods     | Transferrin receptor (TIR1) | Cao-2, HCT-116 | 52  |
| Graph seed     | Control the signaling related epigenetics, onco gene expression | HCT-116 | 53  |
| Zerumbone      | Upregulation of DR4 and DR5 MMP-9, Cdc family | HCT-116 | 54  |
| Allicin        | Inhibit the over expression TNF-α family gene | HCT-116 | 55  |
| Rhizochalin    | Caspase-3 and PRAP activation | HT-29 | 56  |
| Fucoxanthin    | Induce apoptosis | Cao-2, HT-29 | 57  |
| Protein and peptides (milk) | Hypoproliferation of epithelium | HCT-116 | 58  |
| Garcinol       | Inhibition of tyrosine phosphorylation | HT-29 | 59  |
| Xanthohumol    | Upregulation of caspase-3, -8, -9 | HT-29 | 60  |
| Boswellic acid | Decrease in cyclin D1 expression | HT-29 | 61  |
| β-Escin        | Induced cell cycle arrest at the G1/S phase | HT-29 | 62  |
| Quercetin      | Inhibition of cyclin D1 expression | SW 480 | 63  |
| Fisetin        | Activation of NF-κB and decrease in cyclin D1 expression | HT-29 | 34  |
The fingers print of phytochemical compounds, especially nutraceuticals, are well established for the treatment of colon cancer. Dietary phytochemicals are widely used as pharmaceuticals beneficial for human health and other commercial products. However, the mechanisms of action of nutritional databases need further development and better molecular identification in colon cancer treatment. Also the in vivo data for many potent dietary phytochemical activities is not yet analyzed. Nevertheless, the scientific community will be focused on naturally occurring nutraceuticals and their application in colon cancer therapeutics in detail. The natural diet contains diverse secondary metabolites such as flavonoids, steroids, sulphur-containing compounds, alkaloids, saponins, phenolic acids, vitamins, minerals and other antioxidant enzymes. These nutraceutical compounds may increase the protection from different factors such as red meat, high alcohol consumption and other drugs. Research has proven that the high intake of nutraceuticals is beneficial in the control of colon cancer generation. Finally, it should be recognized that single or clustered dietary nutraceuticals molecules are contributing to therapeutic action and will be important for future assessment.

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