

# Immune-Boosting Functional Foods: A Potential Remedy for Chinese Consumers Living Under Polluted Air

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## Abstract

The deterioration of air quality in China has resulted in many people looking for technological approaches or medical remedies to counteract the impact that air pollution is perceived to be having on their health and wellbeing. As the importance of diet on immune health is becoming increasingly well recognised, there is increasing interest in the development of food products designed to help the immune system recover from the impact of air pollution. A narrative literature review was undertaken to elucidate Chinese consumers' acceptance and market potential of functional food products designed to help the immune system recover from the impact of air pollution. Topics reviewed included, the functional food market in China, scientific findings on how functional foods / ingredients can enhance immune health, the actions that Chinese consumers take to limit exposure to and combat the effects of pollution and their perceptions of immune-boosting functional foods. Consumers' attitude towards functional foods including those designed to enhance the immune system were mainly positive, with scientific validation being important in determining the credibility of a product. This was despite the fact that the effectiveness of the functional food products currently in the market which purported to be remedies for pollution-driven impacts on the lung did not appear to be supported by scientific evidence. Numerous studies have reported functional foods could provide a wide range of benefits to immune health, including helping pollution-driven immune issues. This review shows that there would appear to be market demand for effective and scientifically-proven functional food products that help Chinese consumers' immune system recover from the impact of air pollution.

**Keywords:** functional foods, air pollution, Chinese consumers, immune-boosting foods, immune health

## 1. Background

The severity and persistence of air pollution in parts of China (Huang et al., 2014) means it is at the forefront of public attention (Huang, 2015) with Chinese residents becoming accustomed to waging an "anti-smog (haze) war" on an almost daily basis (Johnson, Mol, Zhang, & Yang, 2017). As the problem of air pollution develops due to changes in the underlying economy, it can take many years to reduce its impact owing to the time required to build the requisite scientific understanding and to develop and enforce effective control policies (Nielsen & Ho, 2017).

With every breath about 500 mLs of air and more than one million particles are inhaled, resulting in a volume of more than 10,000 litres of air and about 300 million particles being inhaled per person per day (Gehr & Heyder, 2000). The predominant air pollutant in China is particulate matter (PM) that has an aerodynamic diameter  $\leq 2.5\mu\text{m}$  (PM<sub>2.5</sub>). Also of concern is particulate matter with an aerodynamic diameter  $\leq 10\mu\text{m}$  (PM<sub>10</sub>) mainly comprised of ozone (O<sub>3</sub>), nitrogen dioxide (NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>) (Huang et al., 2014). Humans are not "allergic" to pollutants; that is, people do not generate adaptive immune responses to pollutants *per se*, rather most airborne pollutants function as mucosal adjuvants which by interacting with both the innate and adaptive immune cells moderate the adaptive immune responses leading to adverse health outcomes (Saxon & Diaz-Sanchez, 2005). For example, particulate and gaseous pollutants can initiate and exacerbate cellular inflammation of respiratory mucosa cells in the upper or lower airways (Müller & Jaspers, 2012). In particular, PM exposure increases the morbidity of respiratory illnesses such as lower respiratory infections (LRIs), asthma and chronic obstructive pulmonary disease (COPD). In addition, the long-term exposure to air pollutants increases the rates of cardiovascular, metabolic, and respiratory mortality (Chen, Zhao, & Kan,

2013; Wright, Ji, Geng, & Ding, 2016).

A survey of people living in the three megacities of Shanghai, Wuhan and Nanchang found that approximately 57% of 3868 participants were not satisfied with the current air quality and around 46% of them felt anxious when exposed to polluted air (Liu et al., 2016). A recent survey of 1050 Beijing residents, reported that 54% of respondents agreed or strongly agreed with the statement “the air pollution here is intolerable” and 68% agreed or strongly agreed that “smoggy and hazy weather has become a “new normal” (Johnson et al., 2017). These two studies thereby provide evidence that air pollution is a serious problem in China that is affecting its citizens quality of life (Johnson et al., 2017; Liu & Mu, 2016; Liu et al., 2016). It was therefore not surprising that the greatest perceived concern about air pollution is the risk that it poses to health, with 62% of 1050 Beijing residents agreeing or strongly agreeing with the statement “my health has been very much affected by air pollution” (Johnson et al., 2017). The survey data reported by Liu et al., (2016) stated that participants believed that the three greatest health risks linked to the exposure to air pollution were coughs/colds (approx. 69%), eye problems (approx. 63%) and skin allergies (approx. 49%) (Liu et al., 2016). Chinese people in online discussions have also expressed concern about the impact of air pollution on immune health and it is known that they believe that immune health is a significant determinant on health in general (Cong, Bremer, & Miroso, 2018). These findings are in line with a review of epidemiology studies, which confirm that PM exposure can increase the morbidity of respiratory illnesses (Wright et al., 2016).

Given the concerns around the impact of air pollution on health it should not be surprising that there is significant public, commercial and governmental interest in developing ways to protect individuals from the impact of air pollution and in the development of products to help the immune system recover from its effects. In this regard, functional foods can be considered to be a suitable option as Chinese consumers have a strong tradition based believe that food cannot only satisfy hunger and provide required nutrients but it can also improve physical and mental well-being, owing to their life long exposure to Traditional Chinese Medicine (TCM) based principles (Menrad, 2003; Roberfroid, 2000). The modern term functional food varies from country to county in terms of its definition and scope, as do the regulatory frameworks that control its use (Kaur & Singh, 2017). Most countries describe functional foods as containing bioactive components and ingredients that provide additional health benefits beyond basic nutrient requirements and are capable of reducing certain diseases (Lau, Chan, Tan, & Kwek, 2012). Some definitions are more specific and state that the food must provide “a clinically proven and documented health benefit for the prevention, management, or treatment of a chronic disease” (Martirosyan & Singh, 2015) while for other countries documented proof of the efficacy of a functional food is not required. Due to confusion around the meaning and regulation of functional foods some commentators believe that the term “Functional food” is essentially a marketing term (Henry, 2010; Siró Kápolna, Kápolna, & Lugasi, 2008). Therefore, while scientists are investing considerable resources into developing functional foods for which validated scientific claims can be made (e.g. New Zealand National Science Challenge (Anon, 2019)), many commonly available products that claim to be functional foods appear to have a limited scientific backing.

A good understanding of target consumers and market potential is required when developing any new functional foods or related products (Hamid, Said, & Meiria, 2019; Henryks, Pearson, Anisimova, & Sultan, 2015). While there are numerous studies reviewing either consumer-based literatures, such as perceptions of functional foods or air pollution, or laboratory-based literatures, such as immune-boosting ingredients, research that reviews and integrates findings from these disparate fields is limited. It is well-known that narrative reviews may be used to explore studies that investigate the needs and/or preferences of particular population groups (Best, Manktelow, & Taylor, 2014; Popay et al., 2006) by summarizing different primary studies from which conclusions may be drawn into an integrated interpretation (Kirkevold, 1997; Kitson, Marshall, Bassett, & Zeitz, 2013; Mays, Pope, & Popay, 2005). Therefore, to understand Chinese consumers’ acceptance and the market potential of functional food products designed to help the immune system recover from the impact of air pollution, an interdisciplinary narrative review of the literature of both English and Chinese literatures, was conducted by the first author who is an English-speaking Chinese national. This article starts off by assessing pollution-driven responses of Chinese consumers and the functional food market (Section 2). It then reviews consumers’ perceptions of immune-boosting functional foods (Section 3) and summarizes the scientific findings on the role of functional foods in helping immune health (Section 4). Such information can be used to support the commercial success of functional food products designed to help the immune system recover from the impact of air pollution.

## **2. Pollution-Driven Responses From Chinese Consumers and the Functional Food Market**

### *2.1 Chinese Consumers’ Interest in Air Pollution and Existing Remedies to Reduce the Impact of Air Pollution*

The frequency of words entered into search engines such as Baidu provide a useful indication of the level of interest or concern that people have in an issue (Zhang, Shen, Zhang, & Xiong, 2013). Using Baidu Index, a search for the popular keyword regarding air pollution, “雾霾” (Fog & smog) was compared to the keyword “奶粉” (Milk powder). Milk

powder was chosen as a comparison topic, as owing to historical scandals (Pei et al., 2011) Chinese consumers have significant food safety concerns around milk powder. The relative search frequency of the pollution-related term Fog & Smog was dramatically higher than for milk powder (Figure 1), with the frequency of searching mirroring episodes of severe smoggy weather in China, including December 2013 (Wikipedia, 2018), December 2015 (Liansai, 2016) and December 2016 (Greenpeace, 2016).

Further evidence of consumers' interest in searching for remedies against air pollution is the evolution of the "Smog Economy" which is based on the sale of equipment such as air purifiers, air monitoring equipment and anti-pollution masks (Johnson et al., 2017). For example, during a bout of smog in 2014 in Beijing, approximately 217,000 facemasks were sold within one week (Duggan, 2014; XinhuaNet, 2014), and state media reported panic buying of facemasks during the December 2015 red alert (Independent, 2015). Another example of the concern that Chinese people have around air pollution includes the popularity of mobile phone apps that provide air quality data (Johnson et al., 2017) and the promotion of holidays to smog-free destinations, such as in 2014 when a major Chinese travel agency Ctrip, spent 360 million Yuan on subsidizing travel for tourists from seven cities including Beijing, Tianjin, and Taiyuan, in order to promote its "smog (haze)-escape-trips" (Johnson et al., 2017).

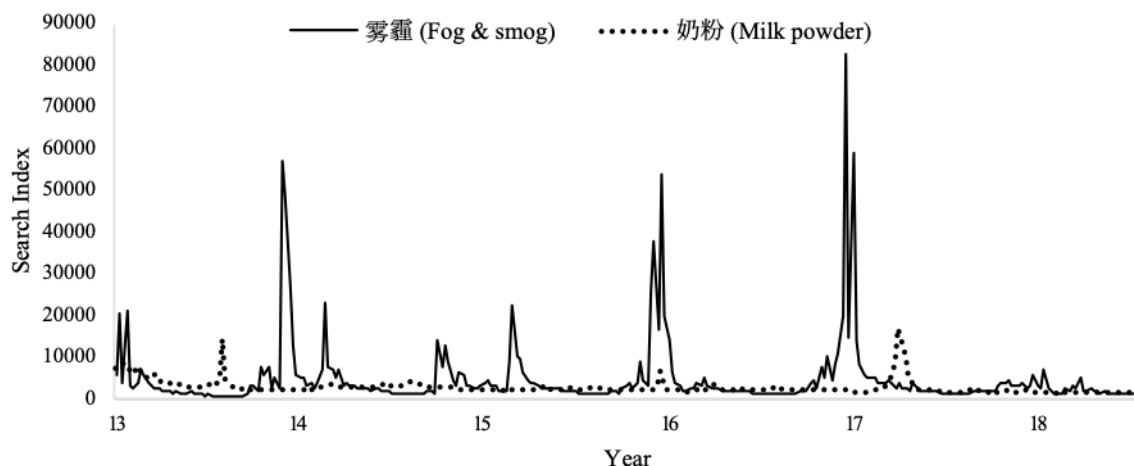


Figure 1. Comparison of Baidu Index of “雾霾” (Fog & smog) and “奶粉” (Milk powder), from 1<sup>st</sup> January 2013 till 24<sup>th</sup> July 2018 (Baidu Index, 2018)

## 2.2 Functional Foods Available in the Chinese Market to Help Fight Against the Adverse Effects of Air Pollution

Based on TCM principles, Chinese consumers have a holistic approach to food and medicine believing that they are of equal importance in preventing and treating disease (Weng & Chen, 1996). Therefore, dietary therapy is well accepted by Chinese people who wish to have a healthy lifestyle in which illnesses are prevented (Stockert et al., 2007). This acceptance of the role of food in health accounts for the quick market production and uptake of TCM “anti-smog” therapies and lung-related supplements, touted to deal with the adverse impact of air pollution on the lung. Many “anti-smog” foods are widely available in Chinese medicine shops, pharmacies and online sites (Wong, 2017). Approximately 31% participants of 1050 residents in Beijing chose to eat more “anti-haze (smog)” food to protect themselves and their families against air pollution (Johnson et al., 2017). While the idea of using TCM to counteract the harmful effects of air pollution has been promoted by Chinese media (Liu, 2017a) and on social media platforms, such as WeChat (Liu, 2017b), scientific evidence supporting the health claims of many of the products on the market is hard to find. This is in part due to the fact that while TCM has been practiced for at least 2000 years in China (Stockert et al., 2007), pollution-related concerns are a relatively new area for TCM. To help meet the market demand for products to address pollution related concerns, products have been produced based on existing TCM anti-inflammation therapies. Therapies in the form of anti-smog teas, soups or porridge (Wong, 2017) which contain TCM herbs such as dried flowers and roots are being touted as being able to help people deal with smog and “cleanse lungs (清肺)”, a Chinese term which means cleaning pollutants or dust from the lung (Liu, 2017a). This is despite the fact that according to TCM principles and theories, the real meaning of “cleanse lungs” is restricting overactive functions or relieving inflammation, namely “cleanse the hyperfunction of lungs (清肺热)” (Wang, 2016). Therefore, in reality the function of many TCM based herb therapies being sold as ways to help remove pollutants from the lungs, is instead helping to relieve inflammation symptoms caused by exposure to polluted air and helping in the maintenance of a healthy immune system (Jiang, 2005; Lao, Xu, & Xu, 2012; Stockert et al., 2007). A number of TCM experts have publicly denied the efficacy

of so-called “anti-smog” foods (Ecns.cn, 2017; Liu, 2017; Wang, 2016; Wong, 2017) and many TCM experts believe that such products should only be recommended by professional TCM practitioners, based on individual specific health conditions.

A related concept to the use of TCM is the use of supplements which claim to reduce the impact of polluted air on the lung. Examples of such products available in China or online include commercial products from Australia and New Zealand (Table 1). Imported “health” related products from western countries have better credibility in China owing to scandals involving Chinese produced health food products (Xing, 2011). The rise of cross-border imported e-commerce has also increased the use of Western products by providing an efficient and convenient channel for consumers to purchase international products. A survey in 2011-2016 of consumers in tier 1 to 3 cities found that approximately 40% of them had purchased imported supplement products through cross-border imported e-commerce, and about 70% of them believed that international brands were of higher quality than local brands and they stated that they were willing to pay a premium for imported brands (Berger, 2017). Dietary supplements were commonly purchased and Australia and New Zealand were among the most popular countries of origin for such products (Tmall Global, 2017). For instance, during the Double Eleven Sale in 2017, the online shop Chemist Warehouse, an Australian pharmacy retailer, reached 100 million in gross merchandise volume within 7 hours on Tmall, the biggest cross-border e-commerce importer (Tmall Global, 2017). Similarly, New Zealand based companies have been enjoying considerable success in selling supplements in China in recent years (Scattergood, 2018).

In addition to claiming to reduce pollution-driven impacts on the lung, many of the products listed in Table 1 including Deep Lung Health (Harker Herbals), Lung Restore Capsules (Thompson’s) and Original Lung Detox Liquid (Healthy Care), claim that they also work on and support the immune system. However, reliable scientific validation to back up the claims of many of these products is hard to find, despite a number of the products indicating that they perform specific functions. For example, Lung Clear (Bioglan) on its official website states that “*its formulation is based on traditional and scientific evidence to help your lungs and supports healthy respiratory function*” (Bioglan, 2018).

### **3. Consumers’ Perceptions of Immune-Boosting Functional Foods World-Wide and in China**

Owing to the obvious challenge that air pollution is presenting to Chinese consumers and the positive attitude that Chinese consumers have towards dietary therapy, there is a strong market potential for functional food products that can address Chinese consumers’ concerns around air pollution, such as its impact on immune health. As a deep understanding of consumers can be the difference between the success of a new product and one that disappears without trace, it is vital to fully understand consumers’ perceptions towards immune-boosting functional foods.

#### *3.1 Evidence That Consumers Are Interested in Foods That Can Boost Immune Health*

In western societies it has been reported that a wide range of consumers have positive attitudes towards immune-boosting foods, including consumers in California, USA who had a positive attitude towards the use of probiotics (Bruhn et al., 2002); consumers in Des Moines and Harrisburg, USA, who were willing to pay more for intragenic products labelling enhanced antioxidant compared with products with conventional plain labels (Colson & Huffman, 2011); adults in USA and adolescents in Australia who take a wide range of nutritional supplements to achieve perceived benefits regarding immune health such as maintaining overall health and wellness and preventing common colds (Dickinson, Blatman, El-Dash, & Franco, 2014; O’Dea, 2003). Higher educated and older females were positively associated with those seeking health benefits (Lynam, McKeivitt, & Gibney, 2011) and in a study from Ireland it was reported that elderly consumers were more likely to make specific purchases to maintain their health status, such as the purchase of dairy products claiming to help boost the immune system (Lalor, Madden, McKenzie, & Wall, 2011).

Evidence is available in China as well. Based on four focus groups and twelve interviews in Shanghai, a recent qualitative study indicated that functional foods, including immune-related supplements and TCM therapies with perceived properties of boosting the immunity, were a popular option for Chinese consumers seeking options to help improve their immunity (Bremer, Miroso, Kaye-Blake, Cong, & Harker, 2018). A survey in 2011 on health food consumption in China reported that 77% of consumers ranked “immune enhancement” as an important function, with 49% of consumers ranking “nutritional supplementation” and “antifatigue,” as being second equal most important functions (Centre for High-Value Nutrition, 2014; Medina, 2011). Health food is a very important component of functional foods and such products must meet Chinese governmental approval and validation requirements. Under *National Standard for Food Safety – Health Food* (GB 16740-2014), a health food is defined as “any food stuff claiming to have specific health functions”, or “to supplement nutrition with vitamins and minerals for a specific functional purposes”. A health food should be designated as being useful for specific consumers, owing to its ability to regulate bodily functions, such foods are not designed to treat disease, and they should not cause any acute, sub-acute or chronic negative effects when consumed by humans” (Anon, 2014). Of the 27 health claims for health foods, approved by Chinese Ministry of Health, “enhancing immunity” is the health claim most frequently used (Anon, 2017b, 2017c).

Based on the evidence presented above immune health and foods making immune health claims appear to be an important focus for Chinese consumers.

Table 1. Examples of supplements available in the Chinese market which claim to combat the adverse impacts of air pollution

Product Name	Advertised Benefits	Key Ingredients	Brand
Clear Lungs	<ul style="list-style-type: none"> <li>Protect the lungs from the effects of air pollution &amp; other inhaled toxins</li> <li>Support those with dry or productive coughs &amp; a wheezy chest</li> <li>Ease &amp; soothe a red raw throat</li> <li>Support the liver against environmental toxins</li> <li>Provide antioxidant support</li> </ul>	<ul style="list-style-type: none"> <li>Thyme</li> <li>Elecampane</li> <li>White horehound</li> <li>Manuka Honey</li> <li>Licorice</li> <li>Rosemary</li> <li>Ginger</li> </ul>	Radiance (Radiance, 2018)
Deep Lung Health	<ul style="list-style-type: none"> <li>Aid removal of mucus built up in the lungs</li> <li>Support healthy breathing</li> <li>Support clogged or “heavy” lungs and airways</li> <li>Support healthy breathing</li> <li>Support lung health</li> <li>Help smoker's congestion</li> <li>Help those living in areas of high air pollution</li> <li>Recover from ills and chills</li> <li>Boost the immune system</li> </ul>	<ul style="list-style-type: none"> <li>Cayenne pepper</li> <li>Coltsfoot</li> <li>Elecampane</li> <li>Ginger</li> <li>Horehound</li> <li>Kumarahou</li> <li>Licorice</li> <li>Lungwort</li> <li>Pleurisy root</li> </ul>	Harker Herbals (Harker Herbals, 2018)
Healthy Lungs	<ul style="list-style-type: none"> <li>Help fight the effects of air pollution</li> <li>Help clear the airways</li> <li>Support healthy breathing</li> </ul>	<ul style="list-style-type: none"> <li>Thyme</li> <li>White Horehound</li> <li>Ginger</li> <li>Aniseed</li> </ul>	Goodhealth (Goodhealth, 2018)
Lung Clear	<ul style="list-style-type: none"> <li>Support lung health</li> <li>Maintain healthy mucous membranes of the respiratory tract to support healthy respiratory function</li> <li>Help healthy respiratory function</li> <li>Contain natural anti-inflammatories</li> </ul>	<ul style="list-style-type: none"> <li>Vitamin C</li> <li>Thyme</li> <li>Mullein</li> <li>Turmeric</li> <li>Rosemary</li> <li>Marshmallow</li> <li>Fenugreek</li> <li>Blackcurrant anthocyanidins</li> <li>Broccoli</li> </ul>	Bioglan (Bioglan, 2018)
Lung Restore Capsules	<ul style="list-style-type: none"> <li>Help relieve wheezing, shortness of breath and a sore throat</li> <li>Help clear excess mucus from the lungs</li> <li>Provide antioxidant activity, assisting the lungs with oxidative stress caused by environmental pollution and second hand smoke, whilst also supporting the immune system</li> <li>Relieve coughs and colds</li> </ul>	<ul style="list-style-type: none"> <li>Licorice root</li> <li>Horse-heal root</li> <li>Reishi mushroom fruit</li> <li>Ginger rhizome</li> </ul>	Thompson's (Thompson's, 2018)
Original Lung Detox Liquid	<ul style="list-style-type: none"> <li>Reduce oxidative stress and inflammation</li> <li>Boost immune function and regulate allergic reactions</li> <li>Relieve bronchial and respiratory irritation</li> <li>Relieve cough and mucous congestion</li> <li>Assist in the management of upper respiratory tract infection</li> <li>Help make breathe easier by drying the secretion of nose</li> <li>relieve oxidative stress as potent antioxidant</li> <li>Counter the harmful effects of pollutants as chelating agents</li> </ul>	<ul style="list-style-type: none"> <li>Broccoli seed extract</li> <li>Olive leaf extract</li> <li>Horseradish root extract</li> <li>Taurine</li> <li>Methionine</li> <li>Pyridoxine hydrochloride</li> <li>Peppermint oil</li> <li>Rosemary oil</li> </ul>	Healthy Care (Healthy Care, 2018)

### *3.2 Chinese Consumers' Perceptions of the Importance of Scientifically Validated Health Claims*

Product information available to consumers can have a significant effect on purchase decision making, with scientific information playing an important role in the marketing of scientifically validated products (Bruhn et al., 2002; Karim et al., 2011; Xing, 2011). In USA for example, FDA (Food and Drug Administration) approval as well as endorsement by recognized health groups increased the believability of a health claim associated with probiotic products (Bruhn et al., 2002).

In China scientific validation is also believed to play an important role in enhancing the credibility of food products. When 500 participants in Nanjing were shown scientific information (e.g. opinions of scientists and research report) the acceptance of foods providing medical functions and improved nutrition increased from approximately 41% to 48% (Zhong, Marchant, Ding, & Lu, 2002). Chinese consumers' purchase intention has been reported to be positively impacted by how much they trust the product information supplied (Zhang et al., 2018; Zhang, Xu, Oosterveer, & Mol, 2016). However, in general, scientific validation of food products, especially health foods, is lacking in the Chinese market. This lack of scientific validation can be of concern as shown by a survey of 500 participants' in Taiyuan which reported that 48.2% of participants were concerned about misleading advertisements and the lack of scientific validation of health foods (Xing, 2011).

## **4. Potential of Functional Foods to Help the Immune System**

A number of scientifically validated functional foods reported to have immune system enhancing properties are currently available (Lopez-Varela, Gonzalez-Gross, & Marcos, 2002) including functional yogurt containing probiotics and micronutrient supplement claiming immune-boosting properties (Table 2). Compounds reported to have immune enhancing properties include food ingredients or are found in natural immune-boosting whole foods. In addition, many studies are working on identifying plant compounds that target specific cellular events and complement the body's own immune actions upon exposure to known allergens such as air pollution (Coleman, Kruger, Sawyer, & Hurst, 2016; Sawyer, Stevenson, McGhie, & Hurst, 2017). In any event it is likely that the results from such research will support the development of functional foods with beneficial biological activities to help the immune system recover from the impact of air pollution (Nyanhanda et al., 2014).

### *4.1 Immune-Boosting Food Ingredients*

Probiotics, micronutrients, herbs, flavonoids and carotenoids have been reported to provide a wide range of benefits to immune health (Table 2). The immune-boosting property of probiotics is believed to be achieved by stimulating cytokine production and hence modulating gastrointestinal function (Table 2). For example, the ingestion of yoghurt containing probiotic bacteria can improve the phagocytic activity of granulocytes, which enhances natural immunity (Marteau, Vrese, Cellier, & Schrezenmeir, 2001; Sangwan, Tomar, Singh, Singh, & Ali, 2011; Schiffrin, Rochat, Link-Amster, Aeschlimann, & Donnet-Hughes, 1995).

Micronutrients, including vitamins and minerals, are nutrients that are required in relatively small quantities (Opara, 2002). A deficiency of Selenium (Se) is accompanied by a reduction in immune function (Lopez-Varela et al., 2002; Rayman, 2000), therefore supplementation with Se, even in "selenium-replete" individuals, can have a marked immunostimulant effect, including an enhancement of the proliferation of activated T cells (cytotoxic lymphocytes) and an improvement in NK-cell activity (Kiremidjian-Schumacher & Roy, 1998). Oxidant-mediated tissue injury is a particular hazard to the immune system, since phagocyte cells produce reactive oxygen species as part of the body's defense against infection. Adequate amounts of neutralizing antioxidants are therefore required to prevent damage to the immune cells (Lopez-Varela et al., 2002). Some antioxidant can be obtained directly from the diet including Vitamin A, C, E, flavonoids and carotenoids. The immune-boosting properties of Vitamins A, C, E have been indicated by numerous studies. A notable example is the research on reducing the duration of symptoms associated with the common cold by taking relatively high doses of Vitamin C (Hemilä & Chalker, 2013).

Table 2. Food ingredients reported to provide a benefit to immune health

Food ingredient	Immune-boosting property	Reference
Probiotics	Modulate the immune system <ul style="list-style-type: none"> <li>- Alleviate intestinal inflammation</li> <li>- Normalise gut mucosal dysfunction</li> <li>- Down-regulating hypersensitivity reactions</li> </ul>	(Hemsworth, Hekmat, & Reid, 2011; Isolauri, 2001; Marteau et al., 2001; Roberfroid, 2000)
Micronutrients		
Selenium	Effect immunostimulant <ul style="list-style-type: none"> <li>- Enhance proliferation of activated T cells (cytotoxic lymphocytes)</li> <li>- Improve NK-cell activity</li> </ul>	(Kiremidjian-Schumacher & Roy, 1998)
Vitamin A, C, E	Prevent damage to the immune cells (antioxidant) <ul style="list-style-type: none"> <li>- Neutralize reactive oxygen species</li> <li>- Improve immune functions and increase resistance to infection (Vitamin A)</li> <li>- Anti-inflammation and involve in immune responses on delayed-type-hypersensitivity skin tests, antibody production, lymphocyte proliferation and pulmonary function (Vitamin C)</li> <li>- Modulate host immune functions and differentiate immature T cells in the thymus (Vitamin E)</li> </ul>	(Grimble, 1996; Hughes, 1999; Lopez-Varela et al., 2002; Meydani, Fawzi, & Han, 2001)
Flavonoids	Modulate the immune system <ul style="list-style-type: none"> <li>- Antioxidant</li> <li>- Anti-inflammation</li> </ul>	(González-Gallego, García-Mediavilla, Sánchez-Campos, & Tuñón, 2010)
Carotenoids	Regulate immune function <ul style="list-style-type: none"> <li>- Antioxidant</li> <li>- Involve in gene regulation and apoptosis</li> </ul>	(Chew & Park, 2004; Gouveia & Empis, 2003)
Herbs	Stimulate immune response <ul style="list-style-type: none"> <li>- Active the body's nonspecific defence mechanisms against infectious organisms</li> </ul>	(Schulz & Blumenthal, 2004)

Flavonoids are biologically active polyphenolic compounds ubiquitously found in fruits, vegetables and nuts. A noticeable flavonoid group in fruits is proanthocyanidins and their monomer units, catechins (procyanidin) or gallic catechins (prodelphinidins), are the natural substrates of polyphenol oxidases and are involved in the browning phenomenon of fruits. A number of studies have suggested that flavonoids have immunomodulatory properties, including anti-inflammation and antioxidant properties (Cho et al., 2016; González-Gallego et al., 2010).

Carotenoids are a family of pigmented compounds that are synthesized by plants and microorganisms but not animals. They are present as micro-components in plants and are responsible for their yellow, orange and red colours (Rao & Rao, 2007). Fruits and vegetables constitute the major sources of carotenoid in the human diet (Agarwal & Rao, 2000; Britton & Khachik, 2009; Johnson, 2002). Close to 90% of carotenoids in the diet are represented by  $\alpha$ -carotene,  $\beta$ -carotene, lycopene, lutein and cryptoxanthin (Gerster, 1997). Studies on the role of carotenoids in antioxidant, gene regulation and apoptosis have advanced knowledge on the mechanisms by which carotenoids regulate immune function (Chew & Park, 2004).

Herbs are popular ingredients in many commercial products, such as dietary supplements. Some herbs are immune stimulants that can activate the body's nonspecific defence mechanisms against infectious organisms, particularly viral or bacterial pathogens. In practice, species of two botanical genera stand out among the immune-stimulant herbs: coneflower (*Echinacea* spp.) and mistletoe (*Viscum album*) (Schulz & Blumenthal, 2004).

#### 4.2 Naturally Immune-Boosting Foods

Flavonoids and carotenoids, as discussed above, are important dietary antioxidants beneficial to the immune system. Fruits and vegetables, in which the levels of these two antioxidants are high have been referred to as natural immune-boosting foods. The daily consumption of fruits and vegetables is a common dietary recommendation to support good health and to provide immune benefits (Kaur & Kapoor, 2001).

Naturally occurring food compounds, such as flavonoids and carotenoids, impart bright colours to fruits and vegetables and act as antioxidant and anti-inflammatory agents in the human body, which benefit the immune system (Kaur & Kapoor, 2001). Fruits, especially berry fruits such as blackberries, blackcurrants, blueberries, cranberries and raspberries, are good sources of flavonoids with immune-boosting functional properties including anti-inflammation, antioxidant and antiproliferation properties. Although carotenoids exist in many fruits and vegetables the carotenoid concentration in them varies widely. Generally speaking dark green vegetables and yellow, orange or red plant tissues have higher concentrations of carotenoids than other fruit or vegetables (Britton & Khachik, 2009), and such fruits and vegetables normally have similar immune-boosting properties as berry fruits (Table 3).

Antioxidant has been identified in blueberries, cherries, cocoa, cranberries, pomegranate, raspberries, broccoli, carrots, mango, spinach, sweet potatoes and tomatoes, and anti-inflammation properties have been associated with most if not all fruits (Table 3). The two most commonly reported immune-boosting functional properties associated with fruit and vegetables are antioxidant and anti-inflammation, which are considered to be useful biomarkers relevant to human health (Dangour et al., 2010).

Table 3. Some naturally immune-boosting foods that have been reported in the scientific literature

Foodstuff	Immune-boosting property (predominantly flavonoids)	Reference
Apple	Anti-inflammatory - Manage airway inflammation	(Sawyer et al., 2017)
Blackberry	Anti-inflammatory Antiproliferative	(Dai, Patel, & Mumper, 2007)
Blackcurrant	Anti-inflammatory - Alleviate lung inflammation - Manage airway inflammation	(Coleman et al., 2016; Hurst et al., 2010; Nyanhanda et al., 2014)
Blueberry	Antioxidant Immunomodulatory (T-cell function)	(Wang et al., 2010)
Boysenberry	Anti-inflammatory - Alleviate lung inflammation	(Shaw, Hurst, & Harper, 2016)
Cherry	Anti-inflammatory Antioxidant	(Ferretti, Bacchetti, Belleggia, & Neri, 2010)
Cocoa	Antioxidant Immunomodulatory (inhibitory mechanism)	(Sanbongi, Suzuki, & Sakane, 1997)
Cranberry	Antioxidant Antimicrobial Immunomodulatory (immunity-promoting)	(Dinh et al., 2014)
Grape	Anti-inflammatory Immunomodulatory (T-cell function)	(Percival, 2009)
Pomegranate	Anti-inflammatory Antioxidant	(Johanningsmeier & Harris, 2011; Zhao et al., 2016)
Raspberry	Antioxidant Antiproliferative	(Liu et al., 2002)
Foodstuff	Immune-boosting property (predominantly carotenes)	Reference
Broccoli	Antioxidant Immunomodulatory	(Mukherjee & Mishra, 2012)
Carrot	Antioxidant Antimutagenic	(Sharma, Karki, Thakur, & Attri, 2012)
Mango	Antioxidant	(O'Shea, Arendt, & Gallagher, 2012; Ribeiro, Queiroz, Queiroz, Campos, & Sant'Ana, 2007)
Spinach	Antioxidant	(Bergman, Varshavsky, Gottlieb, & Grossman, 2001)
Sweet potato	Antioxidant Anti-aging Antiproliferative Antimutagenic	(Shih, Kuo, & Chiang, 2009)
Tomato	Antioxidant Immunomodulatory	(Blum, Monir, Wirsansky, & Ben-Arzi, 2005; Watzl et al., 2000)



## Conclusions and Implications

This study is the first interdisciplinary review that comprehensively integrates literature ranging from the functional food market in China, scientific findings on how functional foods / ingredients can enhance immune health, the actions that Chinese consumers take to limit exposure to and combat the effects of pollution and their perceptions of immune-boosting functional foods. Chinese consumers pay a lot of attention to air pollution and its consequences, with the evolution of the “Smog Economy” being a case in point illustrating consumers’ demand for remedies against air pollution. The early, in market, functional food products designed to meet Chinese consumer’s desire for remedies against air pollution included foods such as “anti-smog” tea and supplements, mainly claiming to deal with pollution-driven impacts on the lung. However, many of these initial products do not appear to be supported by scientific evidence. For example, “cleanse lungs”, the claim of “anti-smog” tea, has been publicly stated as being as a misleading promotion (Anon, 2017b; Liu, 2017; Wang, 2016; Wong, 2017).

Both in China and in western societies, consumers’ attitudes towards functional foods, including those designed to enhance the immune system, are generally positive. Evidence demonstrating Chinese consumers’ acceptance of immune-boosting functional foods includes their preference for the generic health claim stating “enhances immunity”. Importantly, this research indicates that the acceptance of a functional food by Chinese consumers’ can be increased if scientifically validated information on its benefits is provided.

Numerous studies have reported that functional foods can provide a wide range of benefits to immune health, including helping to alleviate pollution-driven immune issues. Immune-boosting food ingredients include probiotics, micronutrients, herbs, flavonoids and carotenoids. In addition, owing to their high content of flavonoids and carotenoids many fruits and vegetables can be considered as naturally immune-boosting foods including berry fruits, dark green vegetables and plants with yellow, orange or red tissues.

### Agenda for future research

This study adds weight to the idea that immune-beneficial functional food products are potential solutions to help Chinese consumers’ immune systems recover from the impact of air pollution. The insights gained in this research indicate an exciting time ahead for manufacturers of functional foods designed for the Chinese market. Therefore, this literature review serves as a base for future studies in this area and indicates that consumer-oriented research is needed to support the commercial success of functional food products designed to improve the immune health for people facing persistent air pollution.

A road map for further research to support the commercial success of functional food products designed to help the immune health of people facing persistent air pollution is shown in Figure 2 in which future research questions are summarised under the following three points: air pollution, immune health and potential products. Market success will require an integrated understanding of consumers’ perceptions of air pollution, health and related products.



Figure 2. Road map for further research (with exemplary questions) to support the commercial success of functional food products designed to enhance the immune health of people facing persistent air pollution

### Practical implications

This literature review makes a strong practical contribution by providing important information to food manufacturers and marketers working on the development of functional foods for the Chinese market. The results of this study suggest that there are good opportunities for effective and scientifically-proven functional food products that help Chinese consumers' immune system recover from the impact of air pollution. However, innovators should develop products based on a good understanding of the unique perceptions of Chinese consumers, including their health concerns and what they state are desirable product attributes, including the need for scientific validation.

By demonstrating the gap between the market demand and the available products, this research suggests that in the Chinese market there is a strong demand for immune-boosting functional food products designed to combat the adverse impact of air pollution, especially for products backed by solid scientific evidence.

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