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Processing of Herbal-Based Natural Products and Functional Foods: A Review

(Pemprosesan Produk Semula Jadi dan Makanan Berfungsi Berasaskan Herba: Suatu Ulasan)

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ABSTRACT

The growing worldwide emphasis on health and wellness, leading to increased demand for natural plant-based ingredients in foods. This shift is driven by concerns over synthetic additives in processed foods, giving rise to the popularity of plant-based functional foods. The global functional food market is projected to reach $275.77 billion by 2025, with a surge in demand for plant-based immune-boosting products due to the COVID-19 pandemic. Malaysian herbs, with their rich history of culinary and traditional use, are gaining attention as functional ingredients. However, their incorporation into food products requires more advanced processing methods and research. Malaysia's biodiversity offers untapped economic potential, and the country's herbal industry is experiencing growth in exports and research investments. Herbal ingredients, containing active phytochemicals, are sometimes referred to as botanical substances and can be incorporated into formulations for functional foods. The review classifies herbal-based food products as herbal medicine, botanical food, or food-drug interphase (FDI). Herbal processing methods are crucial for ensuring the functionality of herbal-based products. Primary processing steps include sorting, cutting, drying, and grinding. Specific processing functions involve retaining active compound contents, enhancing effectiveness, reducing toxicity or side effects, and changing active compound properties or functions. The review also discusses the application of herb combinations in functional foods, highlighting the need for careful consideration of interactions between herbs and other components. Approaches to functional food development in Malaysia include refining existing products, creating new formulations, and integrating novel processing technologies. Future research directions include enhancing bioavailability and functionality of active compounds, exploring nanosystem technology, and incorporating nutrigenomics for disease prevention through dietary interventions.

Keywords: Active compounds; functional food development; herbal processing; natural product

ABSTRAK

Penekanan global yang semakin meningkat terhadap kesihatan dan kesejahteraan menyebabkan permintaan yang meningkat untuk ramuan berasaskan tumbuhan semula jadi dalam makanan. Perubahan ini dipacu oleh kebimbangan terhadap bahan tambahan sintetik dalam makanan proses, menjadikan makanan berfungsi berasaskan tumbuhan semakin popular. Pasaran makanan berfungsi global dijangka akan mencapai $275.77 bilion menjelang 2025, dengan peningkatan permintaan untuk produk penggalak imuniti berdasarkan tumbuhan disebabkan oleh pandemik COVID-19. Herba di Malaysia yang kaya dengan sejarah dalam penggunaan kulinari dan tradisi, semakin diberi perhatian sebagai bahan berfungsi. Namun, penggunaan herba dalam produk makanan memerlukan kaedah pemprosesan dan penyelidikan yang lebih canggih. Kepelbagaian biologi Malaysia menawarkan potensi ekonomi yang belum dimanfaatkan sepenuhnya dan industri herba negara ini mengalami pertumbuhan dalam eksport dan pelaburan penyelidikan. Ramuan herba, yang mengandungi fitokimia aktif, kadang-kadang dirujuk sebagai bahan botani dan boleh disertakan dalam formulasi makanan berfungsi. Ulasan ini menerangkan produk makanan berdasarkan herba sebagai ubat herba, makanan botani atau perantaraan makanan-ubat (FDI). Kaedah pemprosesan herba adalah penting untuk memastikan fungsi produk berdasarkan herba. Langkah pemprosesan utama termasuklah penyusunan, pemotongan, pengeringan dan pengisaran. Fungsi pemprosesan tertentu melibatkan pengekalan kandungan sebatian aktif, peningkatan keberkesanan, pengurangan toksisiti atau kesan sampingan dan mengubah sifat atau fungsi sebatian aktif. Ulasan ini turut membincangkan penggunaan gabungan herba dalam makanan berfungsi, menyoroti keperluan pemerhatian terhadap interaksi antara herba dan komponen lain. Pendekatan pembangunan makanan berfungsi di Malaysia termasuk penambahbaikan produk sedia ada, penciptaan formulasi baru, dan integrasi teknologi pemprosesan baharu. Hala tuju penyelidikan masa hadapan termasuklah meningkatkan ketersediaan biologi dan fungsi sebatian aktif, penerokaan teknologi nanosistem dan menggabungkan nutrigenom bagi pencegahan penyakit melalui diet.

Kata kunci: Pembangunan makanan berfungsi; pemprosesan herba; produk semula jadi; sebatian aktif

INTRODUCTION

The focus on health and wellness among consumers is a worldwide trend. There is increasing demand for foods with natural plant-based ingredients due to recent public awareness of the possible side effects of synthetic additives and their prevalent use in processed foods (Siti Nurul Huda et al. 2016). As such, the growing popularity of plant-based functional foods is envisaged to have a strong influence on the future of the food industry, while there has been a pattern of decline in animal-based products. Based on market research, the revenue generated by the global functional food market is projected to grow from USD 174.75 billion in 2019 and USD 280.7 billion in 2021 to reach USD 275.77 billion in 2025. Furthermore, it is anticipated to experience a compound annual growth rate (CAGR) of 8.5% from 2022 to 2030 (Grand View Research 2023). The demand for plant-based functional foods is expected to observe a further upward trend in 2020 since many consumers are now opting for immunity-boosting food products amidst the recent COVID-19 pandemic.

Herbs or botanicals have long been utilized as flavoring and aromatic substances in culinary uses, for maintaining health, and for treating various ailments in traditional medicine. The potential of Malaysian herbs as functional ingredients is currently being revived. However, much of the current use of herbs in food development is rudimentary in terms of processing methods. The solution to the development of local herbal-based functional food may lie in further research and development (R&D). Research can be conducted to impart specific health benefits within herbs to a food product in a more refined manner, as well as to improve the processing of herbs to maintain the effectiveness and bioavailability of the herb's active compounds. The diverse interactions between the active compounds of various herbs can also be explored.

Developing countries are encouraged to diversify their food exports by harnessing the potential of indigenous natural resources that have not been fully explored (Jaenicke & Hoschle-Zeledon 2006). Hence, Malaysia's abundant resources of medicinal herbs hold vast untapped economic potential for wider use, domestic cultivation, and commercialization. Despite being rich in biodiversity resources, Malaysia annually imports around RM1.2 billion worth of herbal products, positioning itself as a net importer in this category, with over 80% of these products being brought into the country (Rajendran & Kamarulzaman 2023). However, according to Comtrade (2018), Malaysia's herbal industry has experienced significant growth, with an 8% rise in value sales as the export of herbal products increased tremendously from RM 0.46 million in 2011 to RM 0.80 million in 2018. Herbal-based products are projected to record a 3% constant growth rate annually to hit revenue of RM 1.50 billion in 2022.

Herbs have now been classified as one of the potential agricultural commodities under Malaysia's National Key Economic Area (NKEA). The value of Malaysia's herbal market is projected to grow annually at a rate of 8-15% (Mohd. Hafizudin et al. 2019). This is due to significant attention from the government and international corporations, which have made more investments in R&D works for local herbs (Bloomberg 2019). The future focus of the Malaysian herbal market is not just on primary products such as crude herbs, but also on functional foods with added value.

HERBS AS INGREDIENTS FOR NATURAL PRODUCTS AND FUNCTIONAL FOODS

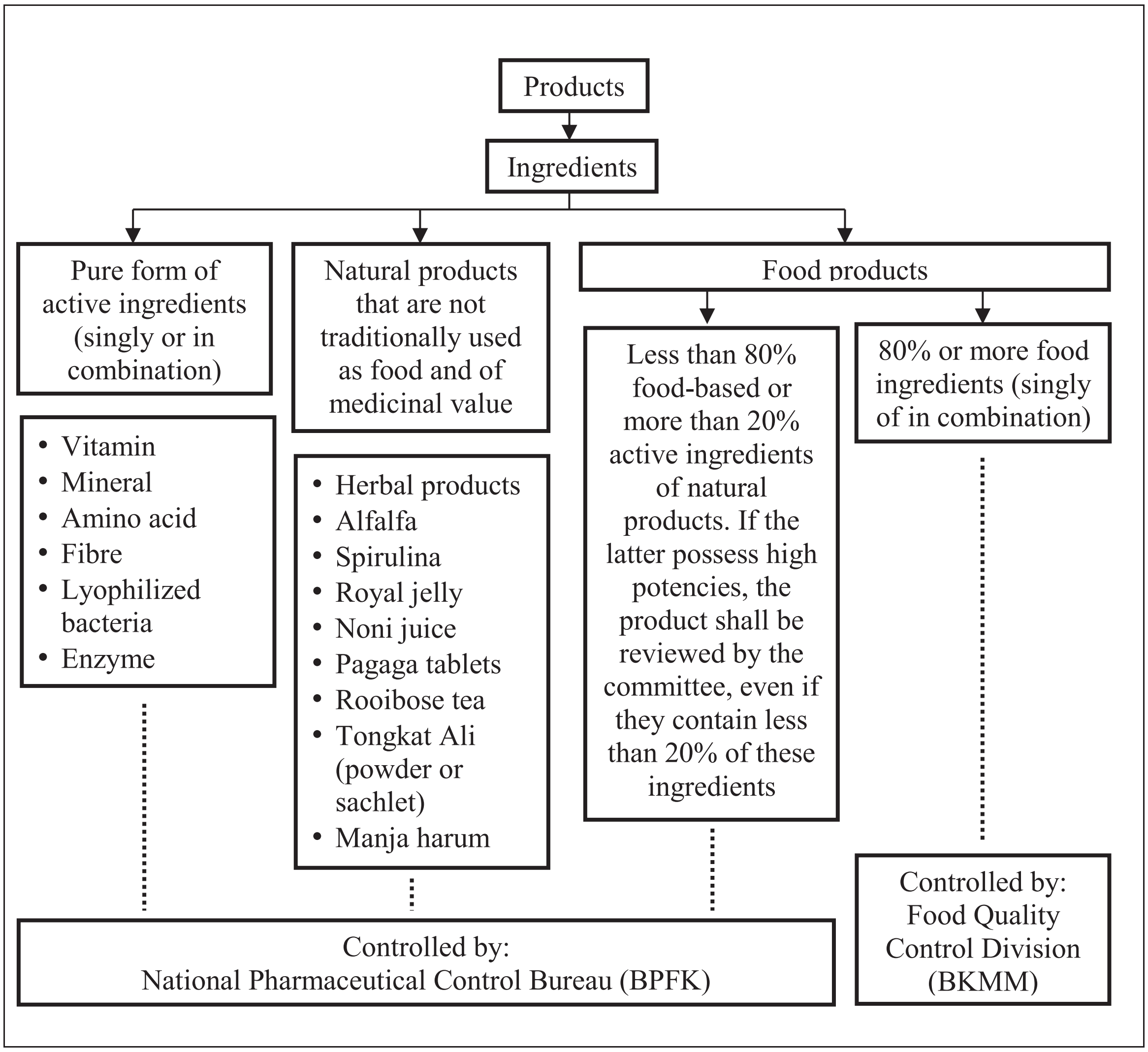
Herbal ingredients, also known as natural products, contain active phytochemicals that are usually used in traditional therapies for the treatment of various health problems. Processing techniques such as extraction and separation are required to obtain these active compounds, which are then incorporated into the formulation of herbal products (Wink 2010). In food processing, very often herbal ingredients (dry herbs or extracts) are added to enhance flavour or aroma. In this context, these herbal ingredients are not used for their therapeutic values. They are referred to as botanical substances, and the products derived are usually referred to as botanical foods. For instance, the U.S. Food and Drug Administration (FDA 2022) has listed about 370 botanical substances that are Generally Recognized as Safe (GRAS) for use in foods and beverages. Examples of current varieties of plant-based functional foods in the American market, according to the type of evidence supporting their functionality, the strength of that evidence, the recommended intake amount, and the regulatory status, are listed in Table 1.

Based on the registration guidance by the Ministry of Health, Malaysia (MOH 2023), herbal-based food products can be classified into: (i) herbal medicine, (ii) botanical food, or (iii) food-drug interphase (FDI). These products are regulated either by the Food Quality Control Division (BKMM) or the National Pharmaceutical Control Bureau (BPFK), depending on the content of active compounds in the products and their therapeutic values. Classification of food-drug interphase (FDI) products is outlined in Figure 1.

TABLE 1. Varieties of plant-based functional foods in the American market

Functional food	Active Compounds	Health Benefit	Type of Evidence	Strength of Evidence	Recommended Intake Amount	Regulatory Status
Fortified margarines	Plant sterol and stanol esters	Reduce total and LDL cholesterol	Clinical trials	Very Strong	1.3 g/day for sterols	Health claim
Psyllium seed husk powder	Soluble fiber	Reduce total and LDL cholesterol	Clinical trials	Very strong	1 g/day	Health claim
Soy powder	Protein	Reduce total and LDL cholesterol	Clinical trials	Very strong	25 g/day	Health claim
Whole oat products	β-Glucan	Reduce total and LDL cholesterol	Clinical trials	Very strong	3 g/day	Health claim
Cranberry juice beverage	Condensed tannins: pro-anthocyanidins	Reduce urinary tract infections	Small number of clinical trials	Moderate	300 mL/day	Conventional food
Garlic tablet	Organosulfur compounds: allicin, allylic sulfides	Reduce total and LDL cholesterol	Clinical trials	Moderate	600–900 mg/day	Conventional food or dietary supplement
Green tea drink	Catechins	Reduce risk of certain types of cancer	Epidemiological	Weak to moderate	Unknown	Conventional food
Spinach, kale powder	Lutein, zeaxanthin	Reduce risk of age-related macular degeneration	Epidemiological	Weak to moderate	6 mg/day	Conventional food or dietary supplement
Processed tomato products	Lycopene	Reduce risk prostate cancer	Epidemiological	Weak to moderate	Daily	Conventional food
Cruciferous vegetable products	Glucosinolates, indoles	Reduce risk of certain types of cancer	Epidemiological	Weak	3 or more servings/ week	Conventional food

Source: adaptation from Hasler (2002)



Source: MOH (2020)

FIGURE 1. Classification of food-drug interphase (FDI) products

THE POTENTIAL OF NATURAL PRODUCTS

Active phytochemicals present in herbal ingredients are primarily the plant's secondary metabolites, which consist mainly of organic compounds. These compounds can be classified into three major classes: (i) terpenes (including volatiles, carotenoids, and sterols), (ii) phenolics (such as phenolic acids, flavonoids, and tannins), and (iii) nitrogen-containing compounds (like alkaloids and glucosinolates). Secondary metabolites serve as a source of natural products, which are typically found as small molecules within plants and hold significant importance for their biological activities (Mazid, Khan & Mohammad 2011; Yeshi et al. 2022). Research focused on natural products typically centers around the identification and evaluation of these secondary metabolites, owing to their potential to be employed as natural chemical substances across various fields.

Natural products derived from herbal plants are commonly utilized in traditional therapies to address a range of health concerns, including body pain, swelling and rheumatism, through the utilization of herbal formulations. Particularly within Asia, and notably within Chinese medicine, diverse herbal formulations cater to specific purposes such as exterior relief, digestive issues, blood regulation, and physiological disorders. Additionally, a variety of Chinese herbal teas serve distinct healthcare purposes. Certain traditional medicinal practices have now transitioned into commercial products, available for external application or consumption as food and beverages. In Western nations, there is a growing trend toward the adoption of natural products, with reports indicating that 80% of adults in the United States have sought out natural products for their potential health benefits (Umaru 2023).

The history of utilizing plants and herbs as medicinal remedies dates back thousands of years. Among the earliest documented records is the Chinese text known as the *Shen Nong Ben Cao Jing* or *The Divine Farmer's Materia Medica* as translated by Yang Shou-zhong, believed to have originated before 2697 B.C. This ancient work catalogued 361 medicinal substances, with 252 of them derived from herbal plants for the treatment of various ailments (Yang 1998). Similarly, the *Ebers Papyrus* (1550 B.C.) contains extensive documentation of herbal knowledge employed in Egyptian medicine (Aboelsoud 2010). Despite having endured for millennia, these traditional medicines persist in present times due to their enduring value as healthcare and medicinal products.

In the present day, researchers are actively engaged in the study of medicinal plants to scientifically uncover their active natural components. While natural products are typically defined as chemical compounds synthesized by living organisms, they are commonly recognized as natural chemical substances possessing medicinal properties. These compounds can be extracted from various sources, including terrestrial plants, marine organisms, or microorganisms. Within plants, commonly utilized parts for natural product extraction encompass leaves, flowers, branches, bark, rhizomes, roots, seeds, and fruits (Hans-Jorg & Stephan 2011). The content of active pharmaceutical ingredients (API) within plants typically falls within the range of 0.3 to 3% (Hans-Jorg & Stephan 2011).

Certain diseases, such as cancer and HIV, remain incurable through modern synthetic medicine. In response, scientists worldwide are persistently striving to develop suitable treatments, with a particular emphasis on the active compounds found in plants, herbs, and fruits as potential anti-disease agents, rather than standalone medications. Numerous studies have been conducted on natural products, some of which indicate that specific natural compounds derived from plants, herbs, and fruits exhibit encouraging anti-HIV and anti-cancer properties (Gwendoline et al. 2010). To date, a multitude of compounds have been isolated from natural sources, demonstrating inherent anti-HIV properties (Inder, Sandip & Bhutani 2005; Serna-Arbeláez et al. 2021).

Natural products also possess significant potential for crop protection. Contemporary agricultural practices commonly rely on chemical pesticides, especially in large-scale plantations, to meet the world's escalating food demands due to population growth. However, consistent and prolonged use of chemical pesticides can induce plant resistance, leading to instances of pesticide overuse. This, in turn, may result in potential health risks when consumed. In response, many nations have introduced enhanced pesticide registration procedures, such as the Food Quality Protection Act in the United States. These regulations have effectively curtailed the availability of synthetic pesticides for agricultural use. Modern agronomic approaches emphasize green technology and organic farming, favoring biological-based pesticides and fertilizers if applied. As part of this movement, researchers are actively developing natural product-based pesticides to generate new alternatives to synthetic pesticides (Souto et al. 2021). Studies involving natural products can uncover specific compounds that play crucial roles in controlling bacteria, microbes, and termites, which can subsequently serve as references for producing bio-based crop protection products.

ACTIVE INGREDIENTS FOR FUNCTIONAL FOODS

According to the Food & Drug Administration (FDA), food is defined as any substance intended for consumption through eating, drinking, or chewing, aimed at acquiring taste, distinct aroma, and nutrients. In the contemporary landscape, the concept of 'food as medicine' has emerged as the cornerstone driving the innovation of novel food products geared towards promoting good health. This category of products, characterized as possessing qualities that straddle the line between food and medicine, often referred to as the 'half food half medicine' or 'food-drug interphase (FDI)', is commonly denoted as 'health foods'. Technically, the term 'health foods' specifically encompasses functional foods and nutraceuticals (Aronson 2017; Chua 2013; Hegarty 2000).

Functional foods and nutraceuticals fall into a distinctive product category, often accompanied by a variety of interchangeable synonyms. However, as of now, there lacks an internationally acknowledged regulatory definition for these products. In a general sense, functional foods encompass substances or ingredients, whether naturally occurring or introduced during processing, that offer specific health-enhancing effects beyond conventional nutritional value. For instance, this could involve beverages fortified or enriched with vitamins (Percival & Turner 2001). In contrast, nutraceuticals comprise well-defined and standardized active compounds extracted from other food sources, which are then incorporated into a simplified matrix. Typically, these compounds are present in dosages surpassing what could be naturally obtained from regular food items. Examples include dietary supplements formulated as powders, capsules, and softgels (Aronson 2017; Bagchi & Nair 2016).

Aligned with the global mega-trend of health and wellness, the forthcoming evolution of food products must incorporate functional attributes to remain competitive within the global market. Given the growing interest in plant-based products, it is understandable that numerous food manufacturers are presently exploring herbs as fresh avenues for sourcing functional ingredients. Examples of active ingredients and compounds that have been derived from plants and microorganisms are listed in Table 2.

HERBAL PROCESSING

The processes involved in herbal processing distinguish herbal-based functional food products from conventional food product counterparts. In-depth knowledge on how particular herbal processing methods influence herb traits becomes highly essential. While certain processing techniques may seem simple, they play a crucial role in determining the functionality of herbal products. These procedures necessitate meticulous organization, validation, and implementation guided by scientific insights. This approach ensures that the end products not only meet fundamental quality standards but also guarantee safety and notably, effectiveness or efficacy, thereby conferring the status of 'functional' upon the food products (Chua 2007).

BASIC FUNCTIONS

After harvesting, raw herbs typically undergo several primary processing steps, including sorting, cutting, slicing, drying, and grinding. The primary purposes of these processing steps are as follows: (i) enhancing product cleanliness and purity, (ii) mitigating contamination by microorganisms, (iii) addressing unpleasant flavors and tastes, and (iv) facilitating usage (Zhu 1998).

The fundamental objective of primary herbal processing is to ensure that the resulting products attain the necessary levels of physical quality and desired taste. The processing of herbal products must consistently meet requirements for authenticity, quality, efficacy, and safety assurances (WHO 2017). In Malaysia, the Good Manufacturing Practices (GMP) were introduced to the food industry in 1996 with the aim of ensuring the fulfillment of the aforementioned aspects before herbal products are brought to market (Ramli 2000).

TABLE 2. Examples of active ingredients and compounds derived from plants and microorganisms

Natural sources	Active ingredients and compounds of proven efficacy (indication)
Leaves	Artemisinin (malaria), digoxin (atrial fibrillation)
Barks	Quinine (malaria), salicylates (fevers), taxol (cancers)
Seeds	Ispaghula (laxative), senna (laxative)
Fruits	Capsaicin (postherpetic neuralgia)
Cereals	Prebiotics (gut health), dietary fibre (digestion)
Roots	Emetine (amoebiasis)
Mushrooms	Penicillin (infections), psilocybin (depression, anxiety)
Algae	Alginic acid (blood sugar regulation, cholesterol reduction), dietary fibre (digestion)
Bacteria	Antibiotics from actinomycetes, streptomycin, tetracyclines, macrolides (infections)

Source: Adaptation from Aronson (2017)

SPECIFIC FUNCTIONS

The active phytochemical contents of herbs are significantly affected by the methods and conditions of processing. The breakdown or decomposition of these active compounds can also occur during the storage of the end products. Hence, in addition to the primary processing steps mentioned earlier, several pharmacopoeias emphasize the vital role of specific processing procedures for herbal materials. The subsequent section outlines the specific functions and objectives of these herbal processing procedures.

Retaining Active Compound Contents

Understanding the attributes of an active compound proves valuable in the selection of suitable processing technology and treatments that aid in preserving these active compounds within the herbal product. For instance, when considering compounds like flavonoids and vitamin C, they exhibit greater stability within a low pH environment compared to neutral or higher pH levels. Consequently, maintaining the product within an acidic condition contributes to the preservation of these compound contents (Bors et al. 1993).

Certain active phytochemicals are less stable and can easily decompose due to the activities caused by the enzymes that coexisted in the raw herbs. To safeguard these active compounds, it is necessary to deactivate or neutralize the involved enzymes. This can be achieved through heat treatments such as steaming or exposing the herbs to boiling water. According to Selman (1994), immersing various plant samples in hot water proves effective in retaining a higher vitamin C content compared to unprocessed samples. This effectiveness is attributed to the deactivation of the enzyme ascorbate oxidase. Such thermal treatments are commonly employed with numerous other herbs, particularly those containing glycosides. A notable instance is the decoction of dried flower buds of sophora *(Sophora japonica)*, which initially holds just 1.86% rutin; however, after heat processing, the rutin content in the decoction substantially increases to 5.07% (Guo et al. 2023; Zhu 1998).

The leaching process is another cause for the loss of phytochemicals in plant samples. Research has shown that an increase in chemical substances, such as calcium, can solidify plant tissues through the formation of ionic bonds with polysaccharides, especially galacturonan. For instance, during the pasteurization process and when chilies are stored, calcium chloride is added to retain phytochemical contents that have antioxidant characteristics (Lee & Howard 1999).

Enhancing Effectiveness

Research has shown that the efficacy of certain herbs can be enhanced by increasing the solubility of their active compounds. The corydalis tuber *(Corydalis yanhusuo)* is frequently employed as an analgesic agent due to its alkaloid content, specifically tetrahydropalmatine. Studies have shown that the alkaloid content in the decoction of dry-fried corydalis tuber with vinegar is nearly twice that of the unprocessed crude herb. This increase is attributed to the formation of a water-soluble alkaloid salt, resulting from the reaction between the initially less water-soluble alkaloid and the acetic acid in vinegar during processing. The heightened alkaloid solubility achieved, in turn enhances the effectiveness of the herbal decoction (Wu et al. 2021).

Furthermore, the effectiveness of herbal products can be enhanced through the formation of new compounds that pharmacologically more effective. Steamed ginseng *(Panax ginseng)* has been found to be more effective than sun-dried ginseng. Chemical analysis has demonstrated the formation of new compounds during processing, derived from the original compounds through the steaming process at higher temperatures. Panaxydol, which is less active, transforms into the more active and potent panaxatriol (Zhu 1998).

Reducing Toxicity or Side Effects

Apart from the necessary active phytochemicals, certain medicinal herbs also contain natural compounds that may produce side effects or be toxic. The undesirable negative effects of a herb can be reduced or neutralized through treatments such as thermal treatment or the addition of chemical substances. Pinellia root *(Pinellia ternata)* is naturally an expectorant and antitussive agent used to relieve cough. However, crude pinellia root may cause mouth numbing and tongue swelling. These side effects can be neutralized by treating the crude herb with an alum solution or by mixing it with ginger *(Zingiber officinale)* (Zhu 1998; Yu et al. 2015).

The toxic effects of a certain herb can be determined by conducting an animal toxicity test. This test can determine the safe dosage of the herbs involved (Schilter et al. 2003). However, in cases where toxicity tests did not exist in the past, processes were conducted to reduce or remove the negative effects of some medicinal herbs. These processes include heat treatment or the addition of chemical substances.

The root of aconite *(Aconitum carmichaeli)* exhibits analgesic and anti-inflammatory activities due to its content of diester-diterpenoid alkaloids, including aconitine and its analog elements. However, these active elements also have toxic effects on the human heart, especially when this herb is consumed in its raw form, leading to arrhythmia (Dickens et al. 1994). The toxic sites of aconitine are located at two ester groups, C_{14} and C_8. Detoxification of the alkaloid can be achieved by conducting a hydrolysis process on these two ester groups. Initially, the acetyl group is removed from C_8 during the first stage of the hydrolysis process, resulting in the formation of benzoylecgonine. Subsequent hydrolysis involves the removal of the benzoyl group at C_{14}, transforming benzoylecgonine into aconine, which is non-toxic. Hydrolyzing aconitine can be accomplished through immersion in boiling water, vaporization, or treatment with mild acid or alkaline solutions for a few hours. Importantly, the pharmacological activities required from the root of *Aconitum carmichaeli* are not affected by this hydrolysis process (Zhang et al. 2022).

Changing Active Compound Properties or Functions

Some medicinal herbs exhibit distinct characteristics, properties, or functions before and after undergoing treatment processes. For instance, thermal processes can result in the elimination, separation, or release of specific active compounds. These changes may subsequently alter the herb's biological nature or give rise to new properties and characteristic. Consider rhubarb root *(Rheum palmatum)*, which primarily functions as a laxative in its unprocessed state. However, after undergoing stir-frying, it demonstrates strong antibacterial activity. This transformation occurs due to the breakdown of the herb's phytochemical complex, known as anthraquinone glycoside during the frying process. The anthraquinone released during this process exhibits antimicrobial properties (Chen et al. 2018).

One more example, the fresh leaves of Ephedra *(Ephedra sinica)* are used to promote sweating (diaphoretic) and to treat high fever (antipyretic). After undergoing heat treatment along with honey, this herb will act as an antifatigue agent. This change in activity occurs because the essential oil responsible for diaphoretic and antipyretic activities is lost due to evaporation during the heating process. Meanwhile, the alkaloids ephedrine and pseudoephedrine, which are resistant to high temperatures, remain in the herb and will exhibit their anti-fatigue effects (Pi et al. 2011).

APPLICATION OF HERB COMBINATION

In herbal-based functional food products, the core functional and therapeutic impacts of herbs hinge upon the distinct properties of each individual herb and the strategic amalgamation of these herbs within the product's formulation. When it comes to the development of functional foods, a formulation comprising multiple herbs is generally believed to yield greater therapeutic benefits compared to a single herb, owing to its multifaceted effects on various targets. However, studies have demonstrated that not all herbs can be seamlessly mixed or employed in conjunction with one another or alongside other food ingredients. While certain combinations yield positive effects, others may have adverse consequences (Su et al. 2016; Zhu 1998).

From a modern pharmacological perspective, various theories elucidate the mechanisms underlying interactions between herbs and other food components. It is imperative to convey the potential adverse interactions before embarking on product development. Guidelines for the application of herb combinations have been outlined, referred to as the 'Seven Consequences', in the *Grand Materia Medica* rooted in their physiological effects as detailed in Table 3.

APPROACHES IN FUNCTIONAL FOOD DEVELOPMENT

Malaysia boasts a plethora of herb species holding significant potential for diverse forms of functional food development. In order to establish a niche in the herbal-based functional food markets, Malaysia can embark on product development grounded in indigenous knowledge encompassing aspects such as product formulation, form, and application (Aziz et al. 2005). The development of herbal-based functional food can be structured around three innovative approaches: (i) refining the processing parameters of existing conventional or traditional herbal-based products, (ii) devising new formulations by substituting local herbs for the less nutritious constituents in current existing food products, and (iii) integration with other novel processing technologies. Several illustrative examples are presented in Table 4.

Significant research efforts are presently aimed at enhancing the comprehension of functional foods due to their pivotal roles in future therapeutic advancements. Anticipations include the emergence of a broader array of specialized functional products tailored to meet the distinct requirements of various segments, including immunity boosters, wellness provisions for children and the elderly, sports nutrition for optimal athlete performance, digestive health support, weight management solutions, cardiovascular health aids, and more (Hartman 2015).

TABLE 3. Examples of herb application guidelines based on their physiologic effects

No.	Consequences	Interactions	Examples
1	Single Effect	Incorporate only a single herb within the product formulation	Ginseng *(Panax ginseng)* can be used as single herb in decoction for improving memory, physical stamina and athletic endurance
2	Mutual Accentuation / Reinforcement	Herbs with similar properties and functions are combined to amplify the intended effect.	Anemarrhena root *(Anemarrhena asphodeloides)* is used together with Chinese goldthread root *(Coptis chinensis)* to strengthen the effect of anti-inflammatory
3	Mutual Enhancement / Assistance	Herbs with similar or distinct functions are blended together, with one serving as the principal herb and the other as a subsidiary element. This arrangement aids in enhancing the effects of the principal herb	Poria mushroom *(Poria cocos)* is combined with astragalus root *(Astragalus propinquus)* as subsidiary herb for treating oedema
4	Mutual Counteraction / Fear	A combination wherein the toxicity or side effects of one herb are reduced or eliminated by another herb or substance	Aconite root *(Aconitum carmichaelii)* is a herb toxic to cardiac and nerve cells. However, when prepared with licorice root *(Glycyrrhiza uralensis)*, the toxicity of aconite root is mitigated
5	Mutual Suppression / Detoxication	While one herb mitigates the unfavorable side effects of another, the focus remains on the herb executing the beneficial suppressive action	Ginger *(Zingiber officinale)*, which is prescribed for cold prevention, suppresses the toxicity of pinellia root *(Pinellia ternata)*, commonly used to relieve cough. Pinellia root is toxic when used alone
6	Mutual Antagonism / Aversion	When two herbs are combined in a single formulation, they diminish or even neutralised each other's positive effects	Clove *(Syzygium aromaticum)* acts in opposition to turmeric *(Curcuma longa)*
7	Mutual Incompatibility / Opposition	The combination of two herbs leads to toxicity or harmful side effects that are not observed when either of the herbs is used individually	The mixture of licorice bark *(Glycyrrhiza uralensis)* and brown seaweed *(Sargassum pallidum)* may induce toxic effects on the cardiac muscle

Source: Adaptation from Su et al. (2016) and Zhu (1998)

In order to complement the research efforts and effectively facilitate the successful commercialization of resulting products, a globally applicable framework necessitates well-defined classification systems, standardized regulations, comprehensive labeling practices, and both domestic and international legislation. Another critical factor that contributes significantly to the success of local herbal-based functional food pertains to the protection of intellectual property rights, which encompasses trade secrets, patents, geographical indications, and traditional knowledge.

FUTURE DIRECTION

The primary areas of future R&D in herb-based functional food development will focus on enhancing the bioavailability and functionality of active compounds within herbs, to provide specific health benefits and their integration into functional food products. Special attention should also be paid to the application of herb combinations, as these may potentially alter the properties or functions of active compounds and consequently affect effectiveness, whether positively or negatively.

A high degree of interdisciplinary collaboration is imperative across fields such as food technology, nutrition science, biotechnology, and engineering for the advancement of future functional food research. An emerging discipline with profound implications for future R&D is nutrigenomics, which investigates the potential for disease prevention by analyzing the interplay between an individual's genetic profile and the development of diseases based on diet (Lau et al. 2013; Nath, Vatai & Banvolgyi 2023).

Another emerging technology is the nanosystem, encompassing phytosomes, nanoparticles, and nanoemulsions. Within this context, the active compounds of herbs find protection within nanodroplets (<100 nm), shielding them from the harsh conditions of the gastrointestinal tract. This preservation enhances their chemical stability and delivery performance. Furthermore, this technology has the potential to further enhance the characteristics of functional foods, including shelf-life stability, sensory attributes, and processing capabilities (Mostafa, Abd El-Alim & Kassem 2017; Pathak 2017). The nanosystem technology, initially developed for pharmaceutical applications, holds promise for potential utilization within the food industry to craft innovative functional food offerings in the future (Kumar, Baldi & Sharma 2019; Sivapriya et al. 2018).

TABLE 4. Approaches and examples

No.	Approaches	Examples
1	Refining the processing parameters of existing conventional or traditional herbal-based products	Enhancement of Malaysian satay paste through the infusion of herbs with thermogenic properties to boost metabolism and promote fat burning, or the inclusion of herbs with cancer prevention attributes
2	Devising new formulations by substituting local herbs for the less nutritious constituents in current existing food products	Development of granola bars featuring herbal additives like stevia to substitute for sugar, along with herbal antioxidants to replace butylated hydroxytoluene (BHT)
3	Integration with other novel processing technologies	Transformation of fruit juice with herbal extracts into popping boba utilizing molecular gastronomy techniques such as spherification

CONCLUSION

Amidst the global trend, the need to meet the demand for safe and beneficial food products is apparent. The ongoing COVID-19 pandemic further amplifies the interest in immunity-boosting solutions, leading to an increased demand for plant-based functional foods. This underscores the emergence of the herbal-based functional food sector, particularly pronounced in Malaysia due to its abundant biodiversity. To maintain competitiveness, strict adherence to regulations, quality assurance, safety, and the provision of evidence for efficacy in product development is imperative. Equally important is the exploration of innovative processing methods, given their influence on the potency of herbal compounds. Processing methods play a pivotal role in optimizing efficacy and safety. Thoughtful processing steps not only safeguard active compounds but also enhance their potency, reduce toxicity, and confer transformative properties. This dynamic interaction underscores the essential connection between processing techniques and the resulting functional outcomes. Looking forward, the future of herb-based functional food development encompasses interdisciplinary collaboration, nutrigenomics, and groundbreaking technologies like nanosystems. The fusion of these elements holds the potential to reshape the landscape of functional foods, ushering in a holistic era of well-being and nutritional empowerment.

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