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PHYTOCHEMISTRY AND FUNCTIONAL APPLICATIONS OF *VITEX AGNUS-CASTUS*, *ACTAEARACE MOSA* AND *LEPIDIUM MEYENII*: A COMPREHENSIVE REVIEW

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Abstract

Aim: To summarise evidence on the bioactive compounds, health benefits, and functional food applications of chaste berry, black cohosh, and maca.

Objective: To identify active phyto-constituents and their mechanisms with their roles in reproductive and menopausal health. Also highlight functional food and nutraceutical applications with processing methods enhancing bioactive stability.

Discussion: Chaste berry, rich in flavonoids and iridoid glycosides, regulates prolactin secretion, aiding PMS, menstrual irregularities, and fertility. Black cohosh, containing triterpene glycosides and phenolics, relieves menopausal symptoms like hot flashes and mood changes. Maca, abundant in macamides and glucosinolates, provides adaptogenic, antioxidant, and fertility-enhancing effects. These botanicals are incorporated into chocolates, dietary supplements, powders, and beverages, improving compliance and product diversity. Advanced technologies such as freeze-drying and microencapsulation enhance phytochemical preservation and bioavailability.

Conclusion: Chaste berry, black cohosh, and maca serve as safe, natural ingredients promoting women's hormonal and reproductive wellness. Their integration into functional foods and nutraceuticals represents a promising approach to support women's health through nutrition-based therapy.

Keywords: Functional foods, Nutraceuticals, health, Hormonal modulation, Food applications

1. Introduction

Medicinal plants have been a key component of health care in civilised societies and continue to be the main source of treatment for thousands of years before the development of synthetic drugs. To this day, it is estimated by the World Health Organisation that almost 80 per cent of the worldwide population uses plant-based remedies as primary healthcare. Along with the increased incidence of lifestyle disorders, hormonal disturbances, and reproductive health issues, scientists and industries are once again showing interest in botanicals, which are not only therapeutically effective but also have many nutritional advantages (Verma et al., 2024). Chaste berry (*Vitex agnus-castus*), black cohosh (*Actaea racemosa*), and maca (*Lepidium meyenii*) are particularly conspicuous among such botanicals and are used in the context of women's health,

endocrine regulation, and in developing functional foods (Rodríguez et al., 2022; Zhang et al., 2025).

2. Conventional and Past Relevance

The role of medicinal plants in human health systems has always been at the centre stage, and the ethnopharmacological value of *Vitex agnus-castus* (chaste berry), *Actaea racemosa* (black cohosh), and *Lepidium meyenii* (maca) indicates their strong attachments in the cultural context. These plants were long known to have a role in reproductive and endocrine health long before their active constituents were identified by modern pharmacology. The folk medicine has a significant foundation in its traditional applications, which can be utilised today to validate their scientific and nutraceutical (Ekor & Oduwole, 2022).

2.1. Chaste Berry (Vitex agnus-castus)

The chaste berry made its way to ancient Greece and Rome, where it was known to have an effect on reproductive health. Both Hippocrates (460-377 BCE) and Dioscorides (40-90 CE) mentioned that the plant could be used in the treatment of gynaecological disorders, such as menstrual disorders and uterine disorders (Certo et al., 2017). The plant was commonly known as agnus castus, based on a Greek name agnos, meaning chaste; it was a symbol of purity. In the Middle Ages, chaste berry was planted in monastery gardens was referred to as monk pepper. Historically, it is said that monks used the dried fruits to lower sexual desire, which indicates the opinion that the plant will help in achieving celibacy (Huerta et al., 2024). Simultaneously, Mediterranean women were employing the plant to control their menstrual cycle, relieve premenstrual tension and improve the fertility rates.

According to the latest ethnopharmacological surveys, these applications were common in Europe and the Middle East and underline the topicality of Vitex extracts in the treatment of premenstrual syndrome (Ekor & Oduwole, 2022). These traditional ways of usage are consistent with the current pharmacological data that chaste berry affects the level of prolactin release and the performance of dopamine receptors (Ibrahim et al., 2008). Chaste berry fruits are not typically eaten as staple foods and have interesting nutritional and phytochemical constituents for their health effects. The proximate analysis reveals that the dried fruits have 12-16 per cent protein, 8-10 per cent lipids and 40-45 per cent carbohydrates, with the dietary fiber constituting a major portion (Huerta et al., 2024; Ibrahim et al., 2008). Mineral profiling has revealed the presence of calcium, magnesium, potassium and iron in it, which has led to the traditional use of it in reproductive health. The lipid fraction includes essential fatty acids (linoleic acid and oleic acid) in abundance, and phytochemical screening confirms that it contains flavonoids (casticin, orientin, isovitexin), iridoid glycosides (agnuside), and diterpenes, which are important in dopaminergic and hormonal regulation (Ekor & Oduwole, 2022).

2.2. Black cohosh (Actaearace mosa)

One of the best-recorded ethnomedical histories of indigenous plants is that of Black cohosh, a perennial herb that grows native to eastern North America. Some of the Native American tribes, such as the Cherokee, Iroquois, and the Algonquin, also used the rhizome to treat menstrual cramps as well as menopause to rheumatism and respiratory diseases (Mahady et al., 2002). Its other uses, like snakebite remedy and insect repellent, make its common names include black snakeroot and bugbane. The reputation of the plant as a women's herb was developed at an early stage, where aboriginal healers prescribed the decoction of the root to abnormal menstrual cycles, a sore delivery, and making the transition during menopause easier. According to the

records of modern understanding that its action could be mediated by serotonergic and dopaminergic syntheses (Nikolic et al., 2015). It has been used mainly due to secondary metabolites instead of providing macronutrients because the rhizome is not consumed as food. The dried rhizome has been reported to contain carbohydrate levels of up to 50-55%, crude fiber 15-18 and protein of approximately 8-9% in proximate studies (Mahady et al., 2002). Mineral profile is characterised by the presence of potassium, calcium, and manganese that can have an indirect effect on bone-supportive processes in menopause. It has a phytochemical composition made up of triterpene glycosides (actein, cimicifugoside), phenolic acids, and isoferulic acid derivatives that have been associated with the ability to modulate serotonergic and dopaminergic pathways (Nikolic et al., 2015). Recent studies note that there are polyphenols that have antioxidant activity that are also present and add to its therapeutic repertoire, although the variation in commercial extracts is a quality issue (Zhang et al., 2025).

2.3. Maca (Lepidium meyenii)

The annual or biannual plant Maca, which is cultivated in high-altitude areas of the Peruvian Andes (3,800-4,500 m), is a part of Andean diet and traditional medicine dating back more than two thousand years. Archaeology indicates that maca was already domesticated in pre-Incan times and its farming history is recorded in Chinchaycocha plateau (Dini et al., 1994). It was called locally maca-maca or Peruvian ginseng, and it was valued both as a food source and a medicinal plant with fertility-promoting and energy-giving effects. Inca civilisation considered maca a sacred crop and it was used to be given to warriors and nobles. Spanish conquest chroniclers documented that maca was given to soldiers to restore energy in lengthy campaigns and to animals to achieve greater reproductive success (Valerio & Gonzales, 2005. Different color varieties of maca (yellow, red, and black) were considered to have various medicinal effects, and this classification is now proved by biochemical research that indicated that phytoconstituents were different in different phenotypes (Gonzales, 2012; Rodríguez et al., 2023; Wuttke et al., 2003). Clinically, it has strengthened the use of maca in fertility and metabolic regulation, further uniting the traditional knowledge and contemporary practice (Rodríguez et al., 2022). Among the three botanicals, maca is the only plant that doubles up as a food crop, and its nutritional value is rich like other root crops. Maca roots are composed of 55-60 percent carbohydrates, 10- 14 percent protein, 2-3 percent lipid and 8-9 percent fiber on a dry weight basis (Dini et al.,1994; Gonzales, 2012). The characteristics of the protein fraction are a well-balanced essential amino acid mineral composition, containing lysine and leucine, which justify the status of the protein as a functional food. Lipids are also sources of polyunsaturated fatty acids, although in low quantities. Maca contains minerals (calcium, iron, zinc and copper), vitamins C, B1 and B2 (Valerio & Gonzales, 2005). The different varieties (yellow, red, black) vary in the nutrient density and bioactive compounds: red maca contains more polyphenols; black maca exhibits improved protein and macamides (Rodríguez et al., 2023; Chavez & Muñoz, 2022).

Maca is a nutritional and therapeutic plant because of the presence of macamides and macaenes as the only lipidic secondary metabolites. Although these three plants belong to geographically and culturally diverse environments, their historical applications demonstrate an impressive thematic overlap among all of them: each was linked to reproductive health, hormonal balance and vitality. Chasteberry was associated with the control of menstruation in the Mediterranean, black cohosh with menopause soothers in the Native American medicine and maca with fertility and stamina in the Andean community.

Chasteberry was associated with the control of menstruation in the Mediterranean, black cohosh with menopause soothers in the Native American medicine and maca with fertility and stamina in the Andean community. This overlapping of ethnomedical functions in remote cultures reinforces their biological possibility and contributes to the reasons why they remain in the spotlight even in current nutraceutical and functional food practices (Chavez & Muñoz, 2022; Zhang et al., 2025). In these botanicals, the most nutritionally complete and versatile functional food is maca, which contains both macronutrients and micronutrients in large quantities. Conversely, chaste berry and black cohosh are pharmacologically active but do not contribute much to the total macronutrient content; but contain bioactive compounds (iridoids, flavonoids, triterpenes) that alter hormonal, neurological, and antioxidant activity. The nutrient-richness of maca and phytochemical specialisation of chaste berry and black cohosh give rise to their joint applicability in the development of nutraceutical and functional food products (Verma et al., 2024).

Figure 1. (a) Chaste Berry (b) Black Cohosh (c) Maca

3. Global Relevance to Women's Health

The health of women deals with a very wide spectrum of physiological and psychological functions between menarche and menopause and further. Premenstrual syndrome (PMS), dysmenorrhea, PCOS, infertility and menopausal transitions impact millions of women around the world, commonly diminishing quality of life and causing social, economic and health burden. The World Health Organisation in 2021 states that almost three-quarters of women during the reproductive age report that there is some kind of menstrual or premenstrual pain, and as many as three-quarters of women post-menopause report vasomotor symptoms, including hot flushes and night sweats. These statistics demonstrate the adventurous necessity of safe and effective interventions in the healthcare of women.

3.1. Conventional Therapy Limitations

Women have been given the traditional methods of hormone replacement therapy (HRT), oral contraceptives, and synthetic drugs, which have definitely enhanced their health. Nevertheless, their extended use is often related to negative consequences. Major trial programs, including the Women's Health Initiative, have shown that the long-term use of HRT is a risk factor in breast cancer, outbreaks of cardiovascular system disorders, thromboembolism, and stroke (Sharma & Verma, 2022). In the same light, selective serotonin reuptake inhibitors (SSRI), which are frequently used to treat mood disruptions caused by PMS, are dependable, can lead to weight gain, and cause gastrointestinal upset. That has propelled women around the world to find plant-based, natural, and culturally familiar options, many of which have their origins in systems of traditional medicine. Chaste Berry, black cohosh and maca are among them and have been internationally recognised with clinical evidence and a broad availability and consumer demand of natural therapies.

3.2. Application of Chaste Berry, Black Cohosh and Maca

3.2.1. Global Women's Health

Chaste berry is a botanical that has been most openly researched in the case of premenstrual and menstrual regulation. Randomised controlled trials indicate that *Vitex agnus-castus* extracts have noteworthy efficacy in diminishing the PMS symptoms including tenderness in the breasts, irritation, anxiety and fluid retention. It has been reported that relief rates of up to 90 percent post-menstrual cycles occurred (Cie et al., 2012). It has been found to work by modulating dopamine, inhibiting excessive secretion of prolactin, a hormone that is found to cause PMS-related mastalgia and menstrual problems (Ibrahim et al., 2008). This causes chaste berry to be particularly applicable in infertility caused by hyperprolactinemia. Chaste berry is used as a part of herbal pharmacopoeias around the world: It is Commission E approved in Germany against PMS and menstrual cycle disorders. It is sold as a dietary supplement in the United States where it is common in health stores. In India and Southeast Asia it is used in polyherbal formulations to address gynecological health. Therefore, chaste berry is added to an international herbal arsenal of non-hormonal control of menstrual and reproductive health.

3.2.3. Menopause Treatment

Menopause is a universal change marked by a decrease in estrogens that cause vasomotor symptoms, psychological symptoms and musculoskeletal symptoms. Black cohosh is becoming one of the most popular herbal substitutes of HRT. Its effect in minimizing hot flushes, night sweats, anxiety, and the mood swings has been consistently proven by clinical trials and meta-analysis (Mahady et al., 2002; Nikolic et al., 2015). The non-estrogenic mode of action is what makes black cohosh relevant to the global setting. In comparison with phytoestrogens like soy isoflavones, black cohosh does not directly interact with estrogen receptors; however, it has its effects via serotonergic and dopaminergic mechanisms (Sharma & Verma, 2022). This is symptom-relieving with no adverse effects of estrogen-based therapies. Black cohosh extracts are medically prescribed and are reimbursable in healthcare systems in Germany. It is one of the best-selling lubricated herbal supplements in the United States, for managing menopause. In the meantime, in China and India it is also studied within the framework of integrative medicine, which indicates acceptance of the practice worldwide.

3.2.4. Fertility Enhancement

Infertility has almost 15 percent cent among couples in the entire world, with serious

psychological and social implications. Maca, a Peruvian plant, has attracted worldwide attention on the basis of its adaptogenic and fertility-promoting effects. Both men and women show that the application of maca enhances the number of sperm, its motility, libido, and ovulatory activity (Ibrahim et al., 2008; Patil et al., 2021). In addition to fertility, maca has also been shown to possess adaptogenic properties, enhancing energy metabolism, decreasing stress and increasing fatigue resistance. These properties are more specifically applicable to the contemporary lifestyles, which were high-stress, sedentary lifestyles and deteriorating reproductive health. The universal popularity of Maca can be traced to the fact that it has given life to a common superfood that is mass-produced. Maca powders, capsules and beverages are consumed by sportsmen, busy workers and couples that desire fertility help in North America, Europe and Asia. It is also known as Peruvian ginseng, which emphasizes its two functions as a nutritional food and a reproductive tonic.

3.2.5. Holistic Beyond Reproduction Impacts

Though the main applicability of chaste berry, black cohosh and maca is in the capacity to normalise the reproductive and endocrine health, their impact is even more absurd in various events of the holistic health of women. This broadened therapeutic focus is growing in current literature, indicating the inability to isolate reproductive health and its related psychological, musculoskeletal, and metabolic areas.

3.2.6. Mental health

The influence of the psychosocial aspect of female health has been generally undervalued, even though there are close connections between the hormonal changes and the psychological well-being. PMS and menopause are both marked by an unstable mood, anxiety, irritability and there are instances of clinical depression. Chaste berry, an agent that regulates dopaminergic pathways and levels of prolactin, plays a role in decreasing PMS-related irritability and anxiety (Cie et al., 2012). Due to its serotonergic effect, black cohosh is proven to resolve the issue of hot flashes and at the same time relieve anxiety, sleep disorders, and depressive tendencies (Nikolic et al., 2015). These results imply that the advantages of the plants are not limited to somatic symptoms, and the plants offer psycho-neuroendocrine support beneficial to the quality of life.

3.2.7. Bone and muscle health

Menopause increases bone resorption, and osteopenia, osteoporosis, and these disorders are associated with loss of estrogen and are known to afflict millions of post menopausal women globally. Although bone density is increased with direct estrogen replacement therapy, this approach has many limitations due to its risks. An emerging body of evidence proposes that via anti-inflammatory and neuromodulatory pathways, the black cohosh plays a supportive role in inhibiting bone loss, but the data are still early (Freudenstein,2007). Likewise, the nutrient-dense profile of maca rich in calcium and potassium and the adaptogenic mechanism it has, can indirectly contribute to musculoskeletal strength and resilience in post menopausal women. Combined, these plants provide supplementary methods to physical vitality in the aging process.

3.2.8. Metabolic health

Insulin resistance, weight gain, and lipid abnormalities are often exacerbated by hormonal imbalances in the course of PCOS and menopause. These metabolic abnormalities present a risk of type 2 diabetes and cardiovascular disease. The high concentration of nutrients and bioactive macamides in Maca aids in the metabolism of energy and glucose regulation (Gonzales, 2012). Besides the vasomotor effect, black cohosh has demonstrated possible advantages for lipid

profile and vascular health, and this indicates that it is useful in the prevention of cardio-metabolic risk among post menopausal women (Sharma & Verma, 2022). Therefore, these botanicals can be used as integrative agents, connecting reproductive health to metabolic wellness in general. Combined, the holistic efficacies of chaste berry, black cohosh, and maca make them important not just as gynecological agents, but as botanicals that meet the multi-dimensional needs of women in mental, musculoskeletal and metabolic domains.

4. International Acceptance and Control

The universal adoption of these botanicals is indicative of their historical shift to evidence-based products in contemporary health and nutritionary systems. But as they are becoming more commercialized, it is also questionable in terms of quality assurance, safety, and regulation.

4.1. Europe

Europe has led in the adoption of herbal medicines in formal health care. Chaste berry and black cohosh are both indicated in the European Pharmacopoeia, and standardized extracts of the two have been authorized by the German Commission E to treat PMS, menstrual irregularities and menopausal symptoms (Mahady et al., 2002). These extracts are prescribed by physicians in Germany and by several other EU countries, and some may be reimbursed under healthcare insurance (indicating great institutional confidence in their effectiveness).

4.2. United States

The U.S. has made botanicals a category of dietary supplement subject to the Dietary Supplement Health and Education Act (DSHEA,1994). Chasteberry, black cohosh and maca are richly sold over-the-counter as capsules, tablets, tea, powdered products. Nevertheless, they are not pre-market clinical approved by the Food and Drug Administration (FDA), as they are in case of pharmaceuticals. This has led to the fast expansion of supply but also increased the fears of adulteration, contamination and incorrect labelling. It is important to note that the incidence of hepatotoxicity caused by black cohosh products of bad standard shows that special care is required (Teschke et al., 2013).

4.3. India and South East Asia

In India the addition of botanicals to healthcare is provided within the AYUSH system (Ayurveda, Yoga, Unani, Siddha, Homeopathy) and is regulated by the Food Safety and Standards Authority of India (FSSAI) in the use of nutraceuticals. Although chaste berry and black cohosh are comparatively new to the Indian markets, the functional ingredient of maca has become popular as a product in powders and capsules. An emerging trend is to include these botanicals in poly herbal nutraceutical preparations aimed at reproductive health as a result of the rising nutraceutical market in India (estimated USD 10 billion by 2025). In Southeast Asia, similar developments are evident. In Indonesia, *V. trifolia* is utilized in plant-based repellent formulations (Arpiwi et al., 2020). In Malaysia, *V. negundo* is incorporated into traditional and modern women's health products (Kamal et al., 2022), while *L. meyenii* (maca) has been investigated for its antidiabetic and metabolic-regulating activities (Othman et al., 2024). In Thailand, *V. glabrata* (khai-nao) exhibits antiestrogenic potential (Luecha et al., 2009), and *A. racemosa* (black cohosh) has been clinically tested in women for menopausal relief with good safety but limited efficacy (Tanmahasamut et al., 2014).

5. Market Trend and Applications in Functions Food

The growing demand of natural remedies, preventative nutrition, and safer alternatives to

traditional therapies in the world has greatly stimulated the increasing rate of nutraceutical and functional food industry as illustrated in Table 1. Health (especially that of women) has emerged as a target market segment with consumers turning to plant products to help them cope with reproduction, endocrine and age-related issues. The convergence of ethnomedicine and evidence-based innovation of products is evidenced by the duality of their application as traditional remedies and novel commercial components (Mahady et al., 2002; Gonzales, 2012). Incorporation of medicinal plants into the food systems has been receiving serious consideration in recent decades, with more and more consumers insisting on a natural remedial system that provides therapeutic effectiveness to their food systems in addition to nutritional value. Of these, *Vitex agnus-castus* (chaste berry), *Actaea racemosa* (black cohosh), and *Lepidium meyenii* (maca) occupy their own niche because of their traditional application in women's health and their newly found application in functional food developments. Although their pharmacological properties have been well-reported, their incorporation into food matrices differs based on their organoleptic properties, cultural acceptance as well as technological feasibility.

5.1. Global Market Dynamics

It is estimated that the global market of herbal supplement and functional food will grow to more than USD 180 billion in 2025 (Grand View Research, 2023). Formulations in the health of women take up a significant share of this market as the awareness of hormonal health and reproductive disorders related to lifestyle is becoming clear. The increasing trend of not using synthetic hormone replacement therapies because of the side effects they cause also contributes to the increased demand of natural products (Sharma & Verma, 2022). Chaste berry has found a good niche in Europe with the inclusion in pharmacopoeias and prescriptions to premenstrual syndrome and menstrual irregularities (Ibrahim et al., 2008). It is extensively marketed as a dietary supplement in the United States and consumer awareness is on the rise in the Asian markets. Black cohosh is the leading menopause product in the market, especially in Germany and North America where it has a long history of being perceived as an alternative to hormone treatment and thus making steady sales (Nikolic et al., 2015). In comparison, Maca has broken the barriers of a clinical supplement, and it is now a globally marketed superfood, exported by Peru and included in powders, drinks, and snacks products as claimed to enhance vitality, fertility, and stamina (Gonzales et al., 2009).

5.2. Chaste Berry Functional Foods

In the past as an herbal infusion or tincture, chaste berry has found its way into food systems nowadays. Applications to experimentation involve the inclusion of standardized extracts into confectionery items like dark chocolate which is meant to provide palatability and therapeutic effects on a woman with PMS (Souto et al., 2020). Chaste berry is sold as herbal teas with sedative botanicals such as chamomile or peppermint to regulate the menstrual cycle and balance emotions. Even though the most common commercial form is the capsule and the tablet, continuous innovation implies an increase in the prospects of functional beverages and fortified foods (Ibrahim et al., 2008). Maca has moved beyond the flesh of ethnomedicine to become an international superfood that is consumed as a power-giving ingredient in powders, beverages,and snacks (Gonzales, 2012; Souto et al., 2020). Traditionally, chaste berry is taken as herbal teas and infusions, usually combined with calming botanicals like chamomile, peppermint or fennel in order to ease menstrual pain and enhance hormonal equilibrium. Its usage in modern food systems has also been extended in the functional confectionery products, fortified beverages, and functional chocolates to manage emotional wellness and premenstrual syndrome (PMS).As an

example, experimental additives of chaste berry extracts in standardized form have been introduced into the design of dark chocolate products not only to promote palatability but also to provide therapeutic value (Souto et al., 2020). Nevertheless, it has a powerful herbal flavor profile which restricts its immediate incorporation into standard foods and requires the application of more modern methods like microencapsulation and flavor-masking substances to increase consumer acceptance. In addition to the drink and candy, continued studies are being done to include it in snacks, baked foods, as well as nutraceutical powders, thus expanding its availability to the health-conscious consumers.

5.3. Black Cohosh and its Potential of Use

Traditionally black cohosh is ingested as a decoction of dried rhizomes, although contemporary commercialization is confined, in large part, to standardized extracts in capsules, tablets, and tinctures. It is commonly used together with other botanicals like red clover, or soy isoflavones in polyherbal preparations to support menopause (Mahady et al., 2002). The application of rhizome as food is still comparatively limited because of bitter flavor and complicated phytochemical structure. Nonetheless, the use of technological solutions including microencapsulation and flavor-masking agents has commenced to enhance its applicability to functional beverages and fortified formulations (Teschke et al., 2013). Similar encapsulation, stability and sensory investigations of cassava starch (Valerio & Gonzales, 2005) indicate technological approaches to engineering phytochemical-enriched botanicals to drink and nutraceutical powder formulations. As non-pill products grow in popularity, research and development prototypes with black cohosh as a base in beverage formats and nutraceutical powders as well as fortified dairy analogues are venturing into the market. Black cohosh, on the contrary, has fewer applications in food because of its bitter flavor and its multifaceted phytochemical composition. Historically used as the decoctions of dried rhizomes, its application to the modern situation has been limited to the capsules, the tablets and tinctures, especially in the formulae targeted at menopausal women. Nevertheless, with the emerging technological development, new frontiers of application have been made easier. As an example, encapsulated black cohosh extracts have been demonstrated in functional beverages and nutraceutical powders, with encapsulation also offering bitterness masking in addition to stability and controlled release. Polyherbal preparations containing black cohosh, soy isoflavones, red clover, or evening primrose oil are used in certain markets to treat menopausal symptoms in a combination of herbs that act synergistically. Its use as a mainstream food ingredient is not widely accepted and; nevertheless, the possibilities of functional dairy substitutes, herbal tea, and nutritional products fortified with it are possible because of active research on flavor modification, microencapsulation, and novel delivery methods (Teschke et al., 2013).

5.4. Macaasa Global Superfood

Maca is the most adaptable of the three plants to food use; this is because over an extended period it was not only a staple crop in the Peruvian Andes, but it was also a medicinal plant. It is traditionally eaten as roasted roots, porridge, or beverages fermented, and have been adopted into the contemporary food systems in a smooth manner. In modern times the flour and powders of maca are added to cereals, baked goods, snack bars and smoothies. Also, there are maca-containing energy drinks, herbal tonics, and nutritional shakes that are marketed extensively to increase stamina, libido, and fertility (Gonzales, 2012). Its nutritional value and essential amino acids, minerals make it a super food. It has the added benefit of being a culture recognized food and medicine unlike chaste berry and black cohosh help in the mainstream global markets.

Table 1. Food and Pharmaceutical/Cosmeceutical/Therapeutic Applications.

Plant	Major Phytochemicals	Functional Activities	Food/Nutraceutical Applications	References
Vitex agnus-castus (Chaste tree)	Flavonoids (casticin, apigenin), Diterpenes, Iridoid glycosides	Hormonal balance (reduces prolactin), Antioxidant,Anti-inflammatory	Herbal teas, nutraceutical capsules for PMS &menopause, tinctures	(Lopresti, 2018; Daniele et al., 2005)
		Dopaminergic activity,Regulates menstrual irregularities, Relieves mastalgia	Pharmaceutical formulationsforPMS, infertility treatment; studied for acne therapy	(Mahady, 2005)
Actaea racemosa (Black cohosh)	Triterpene glycosides (actein, cimicifugoside), Isoflavones	Phytoestrogenic, Antioxidant,Anti-inflammatory	Dietary supplements for menopause relief, fortified drinks for bone health	(Avulaet al., 2011; Leach& Moore, 2012)
		Modulates estrogen receptors, Neuroprotective, Analgesic	Phytomedicine for menopausal symptoms; osteoporosis prevention; cosmeceuticals for skin health	(Ulloaet al., 2015)
Lepidium meyenii (Maca root)	Glucosinolates, Macamides, Alkaloids, Sterols, Polysaccharides	Adaptogen,Energy booster, Fertility enhancer	Maca powder in smoothies, energy bars, baked goods; nutraceutical capsules	(Gonzales, 2012; Rubio etal., 2011)
		Enhances libido, Improves sperm quality, Neuroprotective	Reproductive health supplements; mood enhancement,memory, neuroprotection; cosmetics for anti-aging	(Gonzales, 2012; Sethi etal., 2021)

Its nutritional value and essential amino acids, minerals, and secondary metabolites, which are very unique, makes it even more suitable to be positioned as a functional ingredient. It is therefore frequently compared to other superfoods in the world such as spirulina, chia seeds and matcha. It is traditional Andean food and modern superfood. It is long-roasted and used in porridges, soups, roasted roots, and as fermented drinks such as maca chicha (Dini et al., 1994; Valerio & Gonzales, 2005). The fact that it has a rich nutritional profile (carbohydrates, a variety of proteins, minerals, vitamins, and bioactive macamides) promotes its inclusion into modern diets (Gonzales, 2012; Wuttke et al., 2003). Maca, today is commercialized in powder, flour and extracts, commonly found in smoothies, energy bars, cereal, baked goods, and functional beverages. Having a bland nutty taste and known health effects like an energy boost, fertility requirements, and mood stabilization the product stands next to the likes of superfoods such as chia and spirulina. The unique bioactive properties of different types (yellow,red,black) of maca

are becoming marketed, and the maca continues to gain popularity in the context of global functional food innovation. Notably, specific color phenotypes of maca (yellow, red, and black) are actively being distinguished in the market according to their different nutritional and bioactive properties red maca being linked to high polyphenolic content and black maca better protein and macamides which broadens its application and consumer acceptance (Rodríguez et al., 2022; Zhang et al., 2025). This two-fold potential of maca as a nutritious food and a phyto-chemical active botanical highlights the outstanding potential to use maca as a model ingredient in future functional foods and personalized nutrition programs.

6. Technological Advances and Processing

It has been observed that the modern processing technologies have been central to the successful commercialization of these botanicals. Maca and chaste berry are typically freeze-dried (lyophilized), which helps to conserve heat-sensitive bioactive compounds, yet does not harm the nutritional preservation (Verma et al., 2018). Spray-drying is used to form stable powders that can be encapsulated or incorporated into a beverage formulation, whereas micro encapsulation enhances the protection of the sensitive phytochemicals, covers undesired flavor and better controlled release in food matrices (Patil et al., 2021). In the case of black cohosh, especially, encapsulation will provide stability and overcome sensory issues that otherwise restrict the use of black cohosh in food products. Standardization requirements have also played a critical role particularly with black cohosh as such variation in triterpene glycoside content may affect the efficacy as well as the safety (Mahady et al., 2002). The research on irradiation and structural modification of cassava and potato (Kumar et al., 2017; Kumar et al., 2017) shows that processing interventions can be used to optimize the starch matrices to be incorporated into nutraceuticals. Likewise, nanotechnology applications to food are acquiring interest in terms of protecting bio actives and improving delivery. To begin with, the need to find alternatives to synthetic therapies with natural ones is on the rise, which contributes to sales, especially in treating menopause and PMS (Sharma & Verma, 2022).

Second, the superfood status of Maca has made it a lifestyle product that is consumed by more than just people who have reproductive issues but also by sports people/professions and by health-conscious consumers (Valerio & Gonzales, 2005). Third, convenience and palatability are key factors, where functional foods or beverages like teas, chocolates, smoothies, and bars are more compliant than a capsule or a tincture. Lastly, the overall trend towards preventive healthcare has opened up opportunities to botanicals that can be used in everyday life and not limited to clinical practice (Nikolic et al., 2015).

7. Difficulties and Prospects

Although it has potential to grow, there are multiple issues that impede further incorporation of chaste berry, black cohosh and maca into functional foods. The unpleasurable flavor and sensory constraints of black cohosh continue to be challenges, but technology in processing partially addresses the challenges (Teschke et al., 2013). The authenticity and consumer confidence in the maca trade is destroyed through adulteration and mislabeling (Chavez & Muñoz, 2022) The other aspect posing a challenge to commercialization is regulatory differences between countries since different countries have different regulations in safety, labeling and standardization which hinder international trade. In addition, although current clinical literature is consistent with efficacy, there is a lack of substantial randomized controlled trials and assertions on functional food labels are stronger than the evidence itself (Nikolic et al., 2015). In prospect, there are avenues in the production of poly herbal and synergistic preparations with these botanicals

potentially being used together with other plant extracts or micronutrients to improve the effect. Digital health tools can also help personalized nutrition platforms be used to speed up the uptake of botanical-based functional foods that are customized to individual hormonal, metabolic, or reproductive requirements. It will also be necessary to continue investing in clinical validation, safety research, and new delivery mechanisms so as to guarantee credibility and long-term expansion of this market segment (Souto et al., 2020).

Conclusion

Three traditionally important botanicals that have made the move successfully into the international nutraceutical and functional food market include chaste berry (*Vitex agnus-castus*), black cohosh (*Actaearace mosa*) and maca (*Lepidium meyenii*). They are relevant, not only in the field of reproductive and endocrine health, where they are best known, but also overall, in their contribution to the overall well-being of the mind, musculoskeletal and metabolic health. Chaste berry has been largely related to premenstrual and menstrual disorders whereas black cohosh has become a popular belief among natural treatments in menopausal management. Instead, Maca is uniquely positioned between a traditional staple and a modern-day superfood and has both nutritional and pharmacological advantages. These botanicals are increasingly popular, and this popularity is seen as a reaction to the larger consumer trends in the direction of natural, food-derived healthcare. The innovations of functional foods in form of fortified drinks and herbal teas, to chocolate, powders and energy drinks show the potential of these plants in reaching the broader populations that are not necessarily found in traditional supplement users. The processing technologies, i.e. freeze-drying, spray-drying and micro encapsulation have improved the stability, palatability and bioavailability of their active compounds hence increasing market flexibility. However, there are still problems. Fluctuating phytochemical composition, adulteration risks, lack of large-scale clinical studies and variability in regulatory systems all remain obstacles to their uniform global adoption. These short comings will be dealt with through harmonized quality standards, strict clinical validation, and safety evaluation during the long- term.

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