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Chapter 7

LENTILS (*LENS CULINARIS* L.): LINKING WHOLE FOODS FOR BETTER HUMAN HEALTH

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ABSTRACT

The failure to link current agricultural production with human nutritional needs has led to the development of unhealthy food systems, which cause both malnutrition and chronic diseases. Malnutrition is responsible for the deaths of 30% of children under 5 years of age and accounts for 11% of the global disease burden. Poor diets and nutrition resulting from unhealthy food systems also create huge economic burdens for healthcare systems with negative consequences on child development and long-term direct impacts on sustainable development. Therefore, sustainable agricultural systems are essential for providing food energy and sufficient daily nutrients for humans, and in so doing support health and general well-being. Cool season food legumes, especially lentils (*Lens culinaris* L.), have the potential to provide adequate amounts of protein, prebiotic carbohydrates, and essential micronutrients; a 50 g serving can provide 3.7-4.5 mg iron (Fe), 2.2-2.7 mg zinc (Zn), 22-34 µg of selenium (Se), 50-250 µg of beta-carotene, and 50-300 µg of folates. Unlike other grains, lentils are very low in phytic acid (2.5-4.4 mg g^{-1}), which binds Fe and Zn and thus renders these nutrients poorly bioavailable. The present chapter provides an overview of current global lentil production, global malnutrition issues, and the promise of pulse crops, particularly lentil, as a whole food solution to combat global malnutrition issues. In addition, the superior mineral bioavailability profiles and genetic potential of lentil for further enrichment of bioavailable mineral micronutrients will be briefly discussed with respect to developing sustainable food systems.

Keywords: Lentils, biofortification, food systems, micronutrient malnutrition, minerals.

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GLOBAL HIDDEN HUNGER

The failure to successfully link agricultural production with human nutrition and health has led to the development of unhealthy food systems. These food systems can result in basic malnutrition and high-calorie diets, both of which are linked to common non-communicable diseases. Malnutrition and diet-related diseases together are the leading cause of deaths worldwide, accounting for approximately 20 million deaths per year (Kennedy et al. 2003). In particular, micronutrient malnutrition causes five million childhood deaths per year (Kennedy et al. 2003).

"Malnutrition" refers to a lack of essential nutrients necessary for human health and general wellbeing. The two types of malnutrition caused by unhealthy food systems are protein-energy and micronutrient malnutrition. Micronutrient malnutrition, also known as "hidden hunger", affects more than 2 billion people worldwide. "Hidden hunger" can impact physical and mental growth, organ function, immune system development, and can cause neurological and cognitive impairments. Women and preschool children have been found to be the most vulnerable (WHO, 2013). The present chapter primarily focuses on micronutrient malnutrition.

Stunting, underweight, and wasting are the major global health concerns linked to micronutrient malnutrition. Approximately 165 million children (26%) around the world are stunted (i.e. height-for-age below-2SD), 101 million (16%) are underweight (i.e. weight for age below-2SD), and 52 million (8%) are wasted (i.e. weight for height below-2SD) (de Onis et al. 2012). Some nutrient deficiencies are more common than others and the effects may vary. It is estimated that over 60% of the world's 7 billion people are Fe deficient, over 30% Zn deficient, 30% I deficient, and more than 15% are selenium (Se) deficient. Approximately 3 million children around the world develop xerophthalmia (damage to the cornea of the eye) and every year more than half a million children lose eyesight; both diseases are caused by vitamin A (beta-carotene) deficiency (WHO, 2013).

What really caused the present-day micronutrient malnutrition? In the mid-20th century a set of initiatives were undertaken resulting in a global phenomenon called the "green revolution." One of the green revolution's purposes was to produce calorie-rich foods to prevent mass starvation in populations around the globe. The green revolution mostly achieved its goals by developing and expanding cereal crop production to meet much of the world's calorie-based energy demands. However, while these initiatives did prevent mass starvation, they had other unintended consequences. The expansion of cereal crop production pushed the production of food legume crops to less-endowed marginal areas, thus negatively impacting global legume production levels (Bouis and Welch 2010; Graham and Welch 2000). Since 1970 South Asian cereal production has increased four times (Welch and Graham 1999). As a consequence, pulse production has decreased significantly in developing countries during the last 50 years.

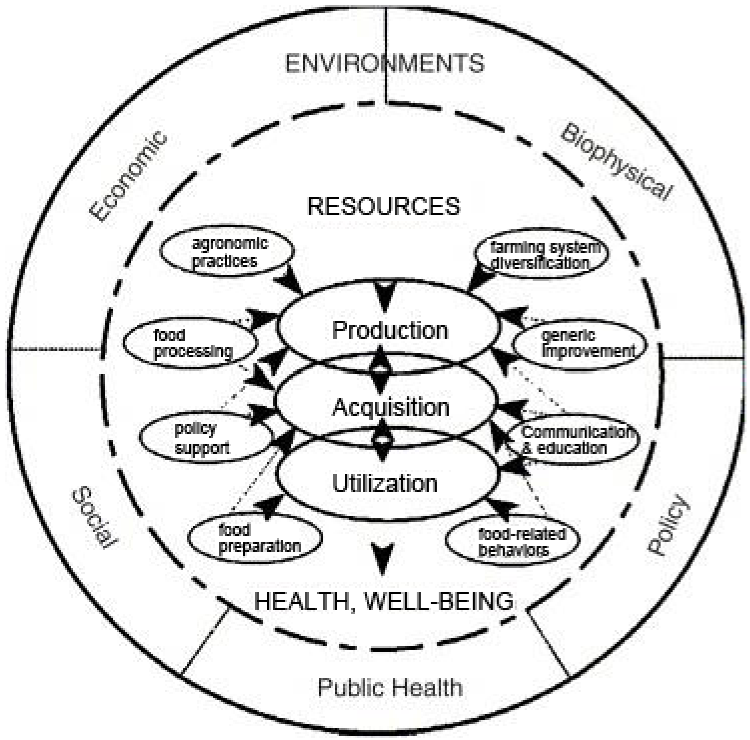
In the present day, these calorie-rich, micronutrient-deficient diets are not only affecting people's health but are also placing a burden onto the economy. Food and nutrition insecurity leads to energy and nutritional deficiencies, infectious diseases, and chronic diseases, all of which negatively affect the agricultural productivity of smallholder farmers in Asia and Africa. These diseases also affect the health care industry, where malnutrition is straining health care resources. These issues can be resolved by developing sustainable food production with healthy and diverse crops such as traditional pulse crops. Various measures can enable these traditional pulse crops to serve as a foundation for economic development and healthful food systems. These measures include biofortification (breeding for micronutrient-enhanced crops), crop selection, critical agricultural inputs, and the demonstration of these crops' economic and nutritional benefits. Among all the possible target crops, the incorporation of nitrogen-fixing pulses provides the greatest promise, as they can potentially accomplish all of these goals.

LINKING FOOD SYSTEMS TO HUMAN HEALTH

Every human requires at least 50 nutrients including water, carbohydrates, essential fatty acids, amino acids, vitamins, trace elements, and minerals to maintain a healthy life style (Table 1; Welch and Graham 2005). However, most food systems are not well-constructed around these nutrients, leading to micronutrient malnutrition, obesity-linked diseases, and the economic burdens discussed earlier. These issues could be reduced by the integration of traditional pulse crops with cereals, oils seeds, fruits, and vegetables. An ideal conceptual food system is shown in Figure 1. A healthy food system approach links the processes of production, acquisition, and utilization in regards to nutritious foods, leading to multiple benefits including healthier human activities and improved sustainable crop production (Welch and Graham 2005). Agriculture is the primary source of all micronutrients for human consumption; for that reason, the integration of crops and farming systems for greater micronutrient delivery through agriculture might be a sustainable solution to reduce micronutrient deficiencies.

By linking agriculture to nutrition research, food systems can be established which boost food security globally. This can be achieved by: (1) determining current ecological and health-related opportunities and challenges faced in different food systems around the world; (2) determining the impact of improving healthful food systems on diet and health; (3) developing sustainable agricultural and food security approaches to produce healthy foods by introducing traditional legume crop systems with animal husbandry; (4) developing appropriate health food marketing approaches for value-added functional foods; and (5) increasing public awareness of the relationship between sustainable ecology, food systems, diet, and health (Welch and Graham 2005).

Past attempts to address micronutrient malnutrition include food fortification, dietary supplementation, dietary diversification, and agronomic-fortification of staple crops, with each having only limited success (Broadley et al. 2006; Combs, Jr. 2001; Welch 2002). Sustainable solutions to micronutrient malnutrition call for approaches linking food systems with human dietary needs. Biofortification, the process of enriching micronutrients into staple food crops through conventional plant breeding and modern biotechnology, provides a sustainable, long-term solution to global micronutrient malnutrition. For example, the biofortification of food crops with highly bioavailable iron (Fe), zinc (Zn), selenium (Se), iodine (I), beta-carotene, and folic acid is urgently needed to combat micronutrient malnutrition in both the US and the developing world. HarvestPlus has made progress on the biofortification of rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.), pearl millet (*Pennisetum americanum* Leeke), and common bean (*Phaseolus vulgaris* L.) (Saltzman et al., 2013). Limited work has been done on the biofortification and bioavailability of micronutrients in pulse crops.



Welch and Graham 2005.

Figure 1. Conceptual model of food system. Adapted with permission.

Several agricultural tools are now available to increase the level of micronutrients in staple food crops so as to meet human nutrition requirements. These include: (1) agronomic biofortification including fertilization, crop diversification, rotation, and location sourcing, and (2) genetic biofortification through conventional plant breeding and GMO techniques. Agronomic biofortification through micronutrient fertilization is a widely used method for Zn, I, Se, copper (Cu), and nickel (Ni). For example, an effective Se fertilization has been reported from Finland, Australia, and New Zealand (Lyons et al. 2009; Lyons et al. 2003; Lyons et al. 2005). In Australia, soil application of Se increased wheat grain Se levels by 20- to 133-fold, and foliar application increased levels by 6- to 20-fold in wheat (Lyons et al. 2004).

However, agronomic biofortification may not always be feasible, especially for Fe, because of the tight homoeostatic mechanisms that regulate Fe absorption, translocation, and redistribution within the plants (Grusak et al. 1999; Welch 1995). The regulation of the homoeostatic control mechanism in plants is not fully understood (Grusak et al. 1999). Furthermore, soil or foliar application of soluble ferrous form is not an effective method for increasing Fe levels in plants due to the rapid oxidation in soils and low mobility in phloem (Graham and Welch 2000). Chromium, boron, and vanadium are also ineffective on agronomic biofortification because of their low phloem mobility.

Table 1. The essential major- and micro-nutrients for humans

Category	Component
1. Energy	Carbohydrate
2. Water	Water
3. Proteins (amino acids)	Histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine
4. Lipids (fatty acids)	Linoleic acid, linolenic acid
5. Macronutrients	Na, K, Ca, Mg, S, P, Cl
6. Microelements	Fe, Zn, Cu, Mn, I F, B, Se, Mo, Ni, Cr, Si, As, Li, Sn, V, Co (B_{12})
7. Vitamins	A, D, E, K, C, B_1 (thiamin), B_2 (riboflavin), B_3 (pantothenic acid), B_6, folic acid, biotin, niacin, B_{12} (cobalamin)

Welch and Graham, 2005.

GLOBAL LENTIL PRODUCTION

Lentil (*Lens culinaris* ssp. *culinaris*) is an important food legume crop with various uses as food and feed because of its protein and micronutrient-rich grains and straw. Globally, it is cultivated as a rainfed crop on 4.08 million ha area with 4.36 million tons of production during 2009-2011 (Table 2; FAOSTAT, 2013). The major geographical regions of lentil production are North and South America (45%), South Asia and China (31%), Central and West Asia and North Africa (14%), Sub-Saharan Africa (2%), and Australia (2%).

South Asia grows lentil on 1.85 million ha with 1.36 million tons of production exclusively as a post-rainy season crop on residual moisture. West Asia and North Africa's (WANA) main producers are Turkey, Syria, Iran, and Morocco; these countries grow winter and spring-planted lentils on 0.58 million ha with 0.63 million ton production. In Sub-Saharan Africa, Ethiopia and Eritrea are the major producers with 0.11 million ton lentil from a 0.10 million ha area. In recent years, area under lentil has expanded manifolds in the Northern Great Plains of North America (Canada and USA), which produces 1.97 million ton lentil and has emerged as the foremost production base. Australia grows lentil on 0.16 million ha area with 0.22 million tons production. The average productivity of lentil in South Asia and WANA region is less than the world average mainly due to the prevalence of different diseases with varying intensity.

The top 11 countries, namely Canada, India, Turkey, USA, Australia, Nepal, China, Ethiopia, Syria, Iran, and Bangladesh account for 96% of the global production. World lentil production has risen steadily by nearly five times (475 %) in the past 50 years, from an average of 0.92 million tons in 1961-63 to 4.36 million tons in 2009-11. This growth is primarily from an expanding harvested area from 1.64 million ha in 1961-63 to 4.08 million ha in 2009-11. Additionally, this increase also reflects an improvement in productivity from an average yield of 560 kg/ha in 1961-63 to 1070 kg/ha in 2009-11 (FAOSTAT, 2013).

Table 2. Global trends in lentil production

Period	World			Developing countries			Developed countries		
	Area (m ha)	Production (m tonnes)	Yield (kg/ha)	Area (m ha)	Production (m tonnes)	Yield (kg/ha)	Area (m ha)	Production (m tonnes)	Yield (kg/ha)
1961-63	1.64	0.92	559	1.38	0.71	517	0.26	0.20	787
1971-73	1.81	1.08	596	1.53	0.82	540	0.28	0.25	905
1981-83	2.51	1.68	667	1.79	0.99	554	0.72	0.69	950
1991-93	3.33	2.67	802	2.18	1.54	703	1.14	1.13	990
2001-03	3.73	3.04	814	2.49	1.73	696	1.25	1.31	1049
2006-08	3.62	3.16	873	2.37	1.65	696	1.25	1.51	1207
2009-11	4.08	4.36	1070	2.34	1.73	740	1.74	2.63	1514

FAOSTAT, 2013.

Lentil consumption is highest in Asia, where seven of the top 11 lentil-producing countries lie. Most production (56%) is consumed locally with only 44% of the global production exported (FAOSTAT, 2013). The global import and export of lentil are 1.71 and 1.79 million tons, worth 1.55 and 1.48 million USD, respectively. Lentil remains in short supply in South Asia and WANA regions due to a gap between present production (1.19 and 0.48 million tons) and consumption (1.83 and 0.88 million tons). The demands for lentil in these two regions are expected to rise further due to population growth and rising income. By 2030, the world lentil consumption is estimated at 5.5 million tons, an increase of almost 1 million tons from the present level (Clancey 2009).

BIOFORTIFICATION OF LENTILS

Lentil belongs to the genus *Lens*. All members of the genus *Lens* are self-pollinating diploids (2n=2x=14) and the haploid genome size of the cultivated species, *Lens culinaris* ssp. *culinaris* is 4,063 Mbp (Baum et al. 2008). There are two types of cultivated lentils, small-seeded microsperma and large-seeded macrosperma. Lentil is a slender, semi-erect annual plant with compound leaves, white to pale blue/violet flowers, and small pods with one or two seeds. Seeds are generally lens shaped with a range of cotyledon colors including red, yellow, and green. The International Center for Agricultural Research in the Dry Areas (ICARDA) has a global mandate for research on lentil improvement for dry areas around the world (Baum et al. 2008). The following sections will discuss recently published lentil biofortification research efforts.

Minerals

Iron and Zinc

Lentils are rich in proteins (20-30%), low-digestible carbohydrates, dietary fiber, and a range of micronutrients (Bhatty 1988). Lentil provides protein nutritional benefits by virtue of its amino acid profiles, which complement those of cereal proteins to produce a dietary protein mixture of high biologic value. It is considered a “clean crop” due to its high nutrition quality, low levels of antinutrients, and flatulence-causing carbohydrates, and it produces a substantially low glycemic index when compared to cereals and other pulses (Bhatty 1988).

Mineral biofortification research on lentil was initiated in ICARDA in early 2000. Approximately 1000 lentil accessions were evaluated for Fe and Zn concentrations. The results indicated wide genetic variation for Fe (41-109 mg/kg) and Zn (22-78 mg/kg) concentrations in lentil seeds (Baum et al. 2008). Furthermore, multi-location testing for biofortified lentils began in 2009 in Bangladesh, Ethiopia, India, Nepal, and Syria. Since then, significant progress has been made; the high Fe and Zn lentil cultivar ILL 7723 is proposed to release soon (Saltzman et al. 2013). Currently available biofortified Fe and Zn varieties from ICARDA are listed in Table 3.

Although biofortified lentil cultivars have been released in Southeast Asia, its production has been almost stagnant during the last 50 years. This stagnation is particularly visible in developing countries, and can be attributed to the relegation of its cultivation to marginal soils resulting in poor yields. For example, in Bangladesh farmers are shifting from lentils to high-yielding cultivars of rice and wheat. The main drivers causing the shift from lentils to other crops are poor soil conditions, frequent outbreak stemphylium blight disease, and non-availability of extra-short duration lentil cultivars which can fit into cereal-based systems. Therefore, biofortification efforts should focus on agronomic traits such as yield, phenology, disease resistance, and stress tolerance.

Table 3. List of high Fe and Zn lentil varieties

Variety	Target mineral	Concentration (mg/kg)	Released country
Idlid-2(ILL 5883)	Fe	73	Syria
Idlib-3(ILL 6994)	Fe	72	Syria
Beleza (ILL 7711)	Fe	74 for Fe; 56 for Zn	Portugal
Alemaya	Fe and Zn	82 for Fe; 66 for Zn	Ethiopia
Sisir	Fe and Zn	98 for Fe; 64 for Zn	Nepal
Khajurah-2	Fe and Zn	94 for Fe; 54 for Zn	Nepal
Barimasur-5	Fe and Zn	86 for Fe; 59 for Zn	Bangladesh
Barimasur-6	Fe and Zn	86 for Fe; 63 for Zn	Bangladesh

Baum et al. 2008; Saltzman et al. 2013.

Recent research in Canada has highlighted the micronutrient values of Saskatchewan-grown pulse crops (Thavarajah et al. 2011a). Canadian lentils are naturally high in total Fe, Zn, and Se, especially when compared with legumes grown in other world production areas (Baum et al. 2008; Thavarajah et al. 2008-; Thavarajah et al. 2009a). For example, 100 g of Canadian-grown lentils provides a minimum of 50-100% of the daily recommended allowances (RDA) for these nutrients. Moreover, data from Canadian-grown pulses show lentil has the genetic potential for increased amounts of total Fe, Zn, Ca, and Mg. Broad-sense heritability estimates for these elements are high, demonstrating the possibility to breed lentil cultivars that accumulate these elements in seed despite environmental influences (Thavarajah et al. 2008-; Thavarajah et al. 2009a). While the Canadian data show the promise of lentils, similar trends were observed in US-grown pulses including lentils, field pea (*Pisum sativum* L.), and chickpea (*Cicer arietinum* L.) (Amarakoon et al. 2012; Johnson et al. 2013b; Thavarajah and Thavarajah 2012). In addition, several studies were reported for Fe and Zn values for lentils grown in Spain, France, and the United Kingdom (Table 4). Overall, lentil is naturally rich in Fe and Zn; however, the micronutrient concentrations can be further enhanced by location sourcing and the selection of specific genetic materials which have been shown to enrich micronutrients.

Table 4. Iron and Zn composition (mg/kg) of lentils with different origins

Origin	Fe (mg/kg)	Zn (mg/kg)	Reference
ICARDA	41-109	22-78	Baum et al. 2008
Canada	73-90	44-54	Thavarajah et al. 2009
USA	56-70	28-38	Johnson et al. 2013b
Spain	82	37	Campos-Vega et al. 2010
France	80	-	Campos-Vega et al. 2010
UK	111-122	39-48	Campos-Vega et al. 2010

Selenium

Selenium (Se) is another essential micronutrient for biofortification research as 30 to 100 million people are Se-deficient. This deficiency is mostly due to low concentrations of Se in commonly eaten staple foods (Combs, Jr. 2001; Ellis and Salt 2003). Selenium is known to be an essential component of 25 selenoproteins. The consumption of selenium has been shown to help reduce the risk of cancer and viral infections, and has also proven useful in HIV treatment and protection from heavy metals including arsenic, cadmium, and mercury (Combs, Jr. et al. 2002; Combs, Jr. 2001; Thavarajah et al. 2007).

Selenium application might be necessary for developing countries to maximize lentil quality. In the past, Se-enriched fertilizers have been used in Finland to increase Se concentration in their major food crops (Wang et al., 1995). The addition of Se to Finnish fertilizer (16 µg/g as sodium selenate) resulted in an increase in Finnish people's daily Se intake from 39 to 110 µg of Se per day (Wang et al., 1995).

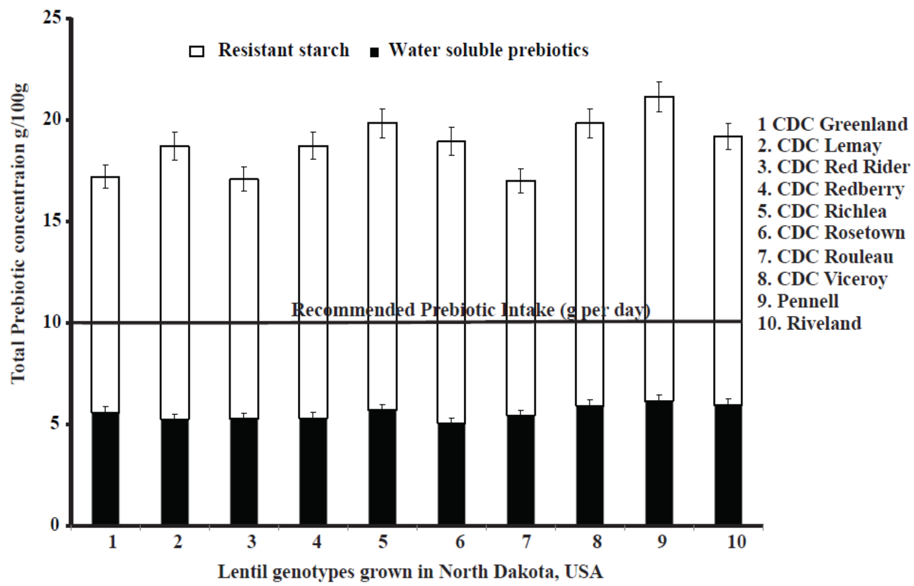
The Se levels of lentils produced in different countries vary with soil Se content. The highest Se concentrations were found in lentils from Nepal and Australia (180 and 148 µg kg^{-1}, respectively) and the lowest Se concentrations were found in lentils from Syria, Morocco, and Turkey (22, 28, and 47 µg kg^{-1}, respectively; (Thavarajah et al. 2011b). The Se concentrations found in lentils from North America were considerably higher. The total Se concentrations of 19 lentil genotypes grown at eight locations for two years in Saskatchewan, Canada ranged from 425 to 673 µg kg^{-1} (Thavarajah et al. 2008). In addition, the most recent data from North Dakota shows that mean Se concentrations from lentil ranged from 300-1445 µg kg^{-1}, respectively. Therefore, changes in soil Se concentration might play a greater role in determining the lentil seed Se concentration. Se uptake by lentil plant may be governed by several genes, and genetic selection for Se uptake might require minimum environmental influence. The broad sense heritability in Canadian-grown lentils was 40%, which could indicate significant environmental influence on Se uptake. However, there was 4-5-fold difference in Se uptake by lentil genotypes, indicating a significant genetic potential for enriching Se in lentils.

MINERAL BIOAVAILABILITY ISSUE

Biofortification efforts are meaningful only when the micronutrients are bioavailable. Generally, plant-based diets are rich in antinutrients that interfere with the absorption or utilization of minerals in human gut. Bouis and Welch (2010) reported that approximately 5% of the total Fe and 25% of the total Zn present in the seeds of staple food crops are bioavailable. Therefore, increasing the bioavailable form of Fe from 5 to 20% would be equivalent to increasing the total Fe by fourfold. In addition, mineral bioavailability is mainly dependent on the food matrix factors i.e. bioavailability promoters and inhibitors. Lentils have high concentrations of mineral bioavailability promoters (e.g., ascorbic acid, beta-carotene, and prebiotics) and low concentrations of inhibitors (e.g., phytic acid, and polyphenols).

Prebiotics

One benefit of the US-grown lentil in particular is its high quantity of prebiotics. In 1997, prebiotics were first defined as a "non-digestible food ingredient that beneficially affects the host by selectively simulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health" (Gibson and Roberfroid 1995). Almost all food oligosaccharide and polysaccharide including dietary fiber have been identified as prebiotics; however, it is important to highlight that not all dietary carbohydrates are considered prebiotics. Therefore, clear guidelines have been established for classifying a food ingredient as prebiotic based on the following: (1) the food component or ingredient resists host digestion, absorption, and adsorption processes, (2) the food ingredient is fermented by the microflora colonizing the gastrointestinal system, and (3) the food ingredient selectively stimulates the growth and/or the activity of one or a limited number of bacteria within the gastrointestinal system (Gibson 2004).



Original data from Jhonson et al., 2013a .

Figure 2. Mean resistant starch and water-soluble prebiotic concentrations of 10 lentil genotypes grown in North Dakota, USA.

Recent discoveries show that the consumption of prebiotics can lead to multiple benefits. For example, recent studies suggest the intestinal microbiome and a prebiotic-rich, low-caloric diet could play important roles in combating obesity and related diseases (Dumas et al. 2006; Wu et al. 2011). The intestinal microbiota ferments food ingredients that cannot be digested by the host in the small gut. These ingredients include resistant starch, non-digestible carbohydrates, oligosaccharides, proteins, lignin, and mucins (Gibson 2004). Two groups of bacteria are present in the human gut: the Bacteroidetes and the Firmicutes. The relative proportion of Bacteroidetes is decreased in obese individuals compared to lean individuals; however, the relative proportion of Bacteroidetes can be improved when weight loss occurs with a prebiotic-rich, low-caloric diet. Furthermore, the consumption of prebiotics like non-digestible, fermentable carbohydrates may stimulate the growth and activity of hind gut bacteria by producing short-chain fatty acids with a variety of benefits. These include providing an energy source for colonocytes, strengthening the gut mucosal barrier, and suppressing the colonization of pathogens (Gibson and Roberfroid 1995; Gibson 2004).

The major dietary sources of prebiotics are cereals, pulses, fruits, and vegetables. Prebiotics found in cereal grain products range from 1.12 g in wheat to 0 g in rice, 0.6 g in dark rye bread, 0.11 g in oats, and 0.05 g in potato chips per 100 g per portion size. Interestingly, US-grown lentils may provide over 13 g of prebiotics per 100 g serving (Johnson et al. 2013a; Figure 2). Therefore lentils offer new opportunities to increase prebiotic intake and as a potential food to combat major non-communicable diseases.

ANTINUTRIENTS

The nutritional value of pulses depends on the nutrient and antinutrient concentrations in a given portion size. Pulses, especially lentil, are a good source of a range of nutrients, including carbohydrate, protein, fats, and micronutrients like minerals and vitamins. However, the type and level of lentil antinutrients may affect micronutrient bioavailability. This section will address the type of antinutrients that may be present in lentil and other pulses and their impact on mineral and micronutrient bioavailability.

Antinutrients could be broadly defined as natural or synthetic substances that interfere with the biological absorption of nutrients in human gut. Nutrients must be present in bioavailable form to absorb under human digestive environments. These natural and synthetic compounds interact with nutrients leading to chemical changes, forming strong complexes or destroying bioavailable forms under human digestive environments. Among antinutrients, protease/lipase/amylase inhibitors and phytic acid are the major natural antinutrients found in commonly eaten foods.

Protease inhibitors are substances that inhibit trypsin, pepsin, and other proteases in the human digestive environments. Although these substances have been recognized to inhibit protein digestions, the latest results suggest a positive role of these substances in human health. In particular, Bowman-Birk serine protease inhibitors have been shown to possess anticarcinogenic properties. The Bowman-Birk serine protease inhibitors have been isolated from field pea, lentil, and chickpea (Alfonso, Gabriella and Clare, 2011). This suggests that these foods may have additional pro-nutritional and health-promoting benefits from this type of protease inhibitor. No studies have been performed on lipase or amylase inhibitors in lentils.

Phytic acid (PA; 1,2,3,4,5,6-hexakis myo-inositol), an inositol phosphate isomer, is considered an anti-nutrient in food, agriculture, and nutritional sciences. Phytic acid is able to complex with divalent cations including iron (Fe), zinc (Zn), magnesium (Mg), and calcium (Ca), thus reducing their bioavailability. Phytic acid accounts for 1-5% of the weight of cereals, pulses, tubers, fruits, and vegetables. PA accumulates during seed development and is utilized during germination to maintain a relatively constant level of inorganic phosphorous (P). The primary functions of PA in the seed are to (1) provide storage for cations and P; (2) act as a precursor for cell wall development; (3) act as a storehouse for potential energy; (4) enable cell signaling, and (5) provide antioxidant protection against free radicals and iron.

Thavarajah et al. 2009b has reported moderate levels of phytic acid in lentil, chickpea, and field pea ranging from 0.25 to 2%.

In order to reduce the negative effects of phytic acid on mineral bioavailability, phytic acid reduction efforts have taken place. However, while phytic acid is typically viewed as a food anti-nutrient, recent inositol phosphate research shows phytic acid and other inositol phosphates may provide a range of human health benefits. Moderate intakes of phytic acid result in positive health effects for humans (Konietzny & Greiner, 2003) and several animal and epidemiological studies demonstrate beneficial effects of dietary PA, including decreased risk of heart disease, renal stone formation, and colon cancer (Fox & Eberl, 2002).

Future Research

Scientific evidence suggests lentil as a promising, nutritious whole food with the ability to supply a range of micronutrients. However, lentil's potential to deliver nutrients is faced with challenges: (1) lower grain yields in developing countries, and (2) a lack or no quality nutritional data from most lentil-producing countries. Research into increasing yields is urgently needed to increase farm productivities (hence incentives to grow lentils) and as a mean to supply anticipated future lentil demands. Further research on the nutritional quality of lentil in all lentil-producing countries will enable lentil breeding, micronutrient biofortification, consumer education, and more meaningful efforts to deliver food-based nutrition solutions to micronutrient deficiencies. Along with other legumes, lentil could prove to be a valuable crop in the development of healthy and sustainable food systems.

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