REVIEW

Back to the Roots: Revisiting the Use of the Fiber-Rich *Cichorium intybus* L. Taproots

Marie-Luise Puhlmann[1,2] and Willem M de Vos[1,3]

[1]Laboratory of Microbiology, Wageningen University & Research, Wageningen, The Netherlands; [2]Division of Human Nutrition and Health, Wageningen University & Research, Wageningen, The Netherlands; and [3]Human Microbiome Research Program, Faculty of Medicine, University of Helsinki, Helsinki, Finland

ABSTRACT

Fibers are increasingly recognized as an indispensable part of our diet and vital for maintaining health. Notably, complex mixtures of fibers have been found to improve metabolic health. Following an analysis of the fiber content of plant-based products, we found the taproot of the chicory plant (*Cichorium intybus* L.) to be 1 of the vegetables with the highest fiber content, comprising nearly 90% of its dry weight. Chicory roots consist of a mixture of inulin, pectin, and (hemi-)cellulose and also contain complex phytochemicals, such as sesquiterpene lactones that have been characterized in detail. Nowaday, chicory roots are mainly applied as a source for the extraction of inulin, which is used as prebiotic fiber and food ingredient. Chicory roots, however, have long been consumed as a vegetable by humans. The whole root has been used for thousands of years for nutritional, medicinal, and other purposes, and it is still used in traditional dishes in various parts of the world. Here, we summarize the composition of chicory roots to explain their historic success in the human diet. We revisit the intake of chicory roots by humans and describe the different types of use along with their various methods of preparation. Hereby, we focus on the whole root in its complex, natural form, as well as in relation to its constituents, and discuss aspects regarding legal regulation and the safety of chicory root extracts for human consumption. Finally, we provide an overview of the current and future applications of chicory roots and their contribution to a fiber-rich diet. *Adv Nutr* 2020;11:878–889.

Keywords: chicory roots, inulin, dietary fiber, human nutrition, traditional medicine

Introduction

While the relation between nutrition and health has been studied since Hippocrates, scientific approaches focusing on what we eat and how our diets affect our body, only developed in the last century (1). Already during the early years of nutrition research, the focus shifted from the effects of whole foods towards their isolated ingredients, and from macronutrients towards micronutrients (1). Besides macro- and micronutrients, fibers are also a major component of food, and their contribution to human health and well-being has long been underestimated (2). Here, we briefly discuss the role of fibers, their contribution to our diet, and their presence in our present-day foods. We further focus on the whole roots of the chicory plant that have 1 of the highest levels of fibers and are a versatile source of fibers and other bioactive compounds.

Impact of fibers on human health and role of the colonic microbiota

Fibers are macromolecules consisting mostly of carbohydrate polymers (except lignin) with 3 or more monomeric units, linked in such a way that endogenous human enzymes in the small intestine cannot break them down, rendering them not digested or absorbed at that site (3, 4). Consequently, fibers end up in the large intestine predominantly in an undigested form, providing no direct energy, and hence have a low overall caloric load [∼2 kcal/g or 8 kJ/g (5)]. Depending on their structure and related physicochemical properties fibers can exert different effects in the gastrointestinal (GI) tract (6). Soluble and water-retaining fibers (such as pectin) contribute to bulking of the digestive chyme and thereby slow down upper GI tract transit, which increases satiety and contributes to weight management (7). In the lower GI tract, insoluble and nonfermentable fibers, such as cellulose

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Address correspondence to M-LP (e-mail: marie-luise.puhlmann@wur.nl).

Abbreviations used: AD, anno domini; BC, Before Christ; CAS Number, Chemical Abstracts Service Registry Number; GI, gastrointestinal; GRAS, Generally Recognized AS Safe; EFSA, European Food Safety Authority; EMA, European Medicines Agency; NOAEL, no-observed-adverse-effect-level.

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or psyllium husks, mechanically stimulate mucus secretion or retain water in the stool, all leading to improved defecation regularity (6). Moreover, soluble fermentable fibers, such as inulin or resistant starch, in turn, are partially degraded by human colonic microbes, collectively termed the microbiota. The colonic microbiota forms 1 of the most metabolically active parts of our body, and therefore it has been termed a "forgotten organ" (8). In recent years, the colonic microbiota has been found to include over 1000 species, notably bacterial, harboring an enormous genetic potential which vastly exceeds that of our own body. Broadly, the colonic microbiota contributes to the maintenance of health and onset of disease (9–12), which is partly a result of the colonic conversion of fibers into SCFAs, such as acetate, propionate, and butyrate. Although some of these SCFAs are known to fuel enterocytes and impact GI processes, most are also taken up into the bloodstream leading to systemic effects on metabolic and immune health (13–15). Beyond the production of SCFAs in general, the location of production and related absorption into the bloodstream have been recently found to impact health. Experimental colonic infusion studies revealed that health markers were improved when SCFA concentrations were higher in the distal compared with the proximal colon (16, 17). Based on these observations, it has been suggested that there is a need for complex fibers that are converted distally in the colon into SCFAs, which may then directly enter the systematic circulation and exert peripheral effects (18–20).

Fiber intake deficit in the Western world

With all these recent insights into the effect of fibers on human health, their reputation has changed from simply indigestible food ingredients to indispensable components of a healthy diet (21, 22). Despite this, Western diets fall below the recommended fiber intake of ≤30–40 g/d (2, 4, 23): the so-called "fiber gap" (24). One of the factors explaining this fiber gap is the limited availability of high-fiber foods in contrast to the plentiful and highly consumed refined products in the Western diet (23). An easy solution to alleviate the fiber gap is the use of fiber supplements (25). Such supplements generally comprise single types of fiber that have been isolated by disintegration of the original plant material and further purification via various processing steps. In the plant, however, fibers do not exist as isolated ingredients, but together with other fibers. The cell walls of plant material are made up of cellulose, hemicellulose, and pectin, which are intertwined in a complex network (26), encapsulating storage carbohydrates, such as glucose and fructose polymer fibers (20) (see **Figure 1**). It is this complex network of fibers, rather than the isolated ingredients, that have been traditionally consumed in our daily diet, and has been associated with improved health outcomes (2, 18, 21).

Observational and intervention studies of recent decades have addressed the health-promoting role of complex dietary fibers in the form of vegetables, fruits, and whole grains (21). High dietary fiber intake was found to be linked to decreased incidence of cardiovascular disease and related mortality, overall mortality, and type 2 diabetes (21, 27). Similarly, clinical studies reported a reduction in metabolic risk factors related to high dietary fiber intake (21). Interestingly, a dose-dependent relation between fiber intake and health outcomes was observed, suggesting a higher fiber intake of >25 g per day entails more health benefits (21). These findings make the current Western fiber intake levels of particular concern and emphasize the need for nutritional solutions to overcome the fiber gap.

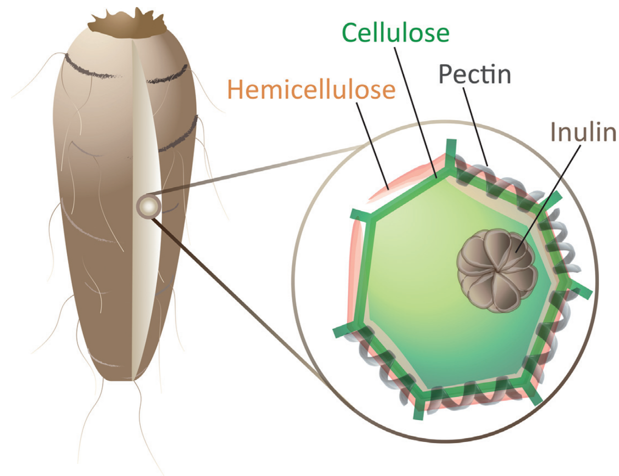

FIGURE 1 Schematic representation of fiber types in the chicory root. Visualized is the network of the cell wall fibers (cellulose, hemicellulose, and pectin) that encapsulates the storage carbohydrate inulin, which is also a dietary fiber. .

Cichorium intybus L. taproots – a fiber-rich root vegetable

Although all plants and their parts contain fibers, corresponding fiber levels vary considerably. We reviewed the food composition data of 8 food groups and selected the top 5 fiber-rich food products from each group, based on their fiber content per 100 g edible product (**Figure 2**). Certain foods clearly stand out with respect to their fiber content per weight. Seeds, nuts, and wheat bran are all high in fiber, but also contain very small amounts of water, making it difficult to compare them to water-rich foods like fruits and vegetables. Hence, it would be more appropriate to express the fiber content on a dry matter basis (Figure 2). When this is done, vegetables with the highest fiber content on a dry matter basis include chicory taproots, and, to a lesser extent, Jerusalem artichokes. Both root vegetables are rich in fiber, especially due to their high inulin content. Inulin is a storage carbohydrate, which consists mainly of fructose molecules linked via a $\beta(2 \leftarrow 1)$ linkage that cannot be broken down by human intestinal enzymes, and is therefore classified as

Product category	Fiber (g/100 g product)	Water (g/100 g product)	Fiber ($\%_{dm}$)
Seeds and nuts			
Linseeds	34.8	2.2	35.6
Chia seeds dried	34.4	5.8	36.5
Poppy seeds	24.0	5.2	25.3
Almonds with skin unsalted	10.2	4.6	10.7
Pecan nuts unroasted unsalted	9.6	3.5	9.9
Legumes			
Beans soya boiled	13.2	45.1	24.0
Beans white boiled	9.9	67.0	30.0
Beans kidney red boiled	9.8	66.0	28.8
Peas marrowfat boiled	8.9	64.0	24.7
Peas chick boiled	8.8	64.0	24.4
Grains			
Wheat bran	45.0	8.3	49.1
Wheat germ	16.0	6.1	17.0
Oat bran	15.4	6.6	16.5
Muesli with fruit	8.5	11.0	9.6
Oatmeal	7.3	12.0	8.3
Vegetables			
Chicory root raw	17.5	80.0	87.6
Jerusalem artichoke raw	17.4	78.0	79.3
Tomato sun-dried	12.3	14.6	14.4
Beans broad tinned	5.3	84.1	33.3
Celeriac boiled	4.9	88.0	40.8
Fruits			
Prunes dried	16.1	36.9	25.5
Apricots dried	14.4	25.0	19.2
Goji berries dried	13.0	7.5	14.1
Olives ripe in brine tinned/glass	12.5	68.5	39.7
Figs dried	9.8	30.1	14.0
Bread and crackers			
Crispbread	11.9	5.8	12.6
Bread linseed	9.6	31.5	14.0
Bread brown/wholemeal with sunflowerseeds	8.7	34.0	13.2
Bread rye	8.2	46.2	15.2
Bread brown/wholemeal with pumpkinseeds	7.8	37.3	12.4
Starchy roots			
Tannia prepared without fat	7.2	69.8	23.8
Taro boiled	3.0	72.9	11.1
Potato sweet boiled	2.3	74.7	9.1
Potatoes boiled with skin	1.8	81.0	9.5
Potatoes without skin boiled	1.6	78.0	7.3
Others			
Seaweed nori dried	36.3	6.5	38.8
Cocoa powder	34.0	15.4	40.2
Almond/imitation paste	8.6	14.2	10.0
Cocoa powder sweetened	6.0	6.2	6.4
Yeast extract Marmite	3.1	39.2	5.1

FIGURE 2 Fiber content of foods. An overview is presented of the fiber content of foods based on 100 g edible product and on a dry matter basis by correcting for water content. Data were retrieved from the Dutch Food Composition Database NEVO-online (28) and for inulin-containing vegetables from the FoodData Central of the USDA (29) as referred to by van Loo et al. 1995 (30). $\%_{dm}$, percentage on a dry matter basis.

a dietary fiber (31). Chicory inulin has been instrumental in the discovery and subsequent definition of prebiotics, which are substrates that are selectively utilized by GI microorganisms and confer a health benefit (32). The health benefits of chicory inulin-type fructans on the composition and activity of the gut microbiota have been addressed in a great number of studies, and have recently been reviewed (33). These include the well-known stimulatory effect of inulin on potentially beneficial bifidobacteria, increased production of SCFA, and improved stool frequency and consistency (33, 34). Moreover, systemic effects of inulin consumption on satiety and insulin sensitivity in relation to obesity have also been documented (35).

Chicory taproots are, however, much more than just inulin. Besides inulin, chicory roots also contain the cell-wall fibers pectin, cellulose, and hemicellulose that have been studied and acknowledged for their health-promoting effects, such as the reduction of cholesterol or glycemic response by pectins (36–38). Within cell walls, inulin is trapped as a storage carbohydrate (Figure 1). This mix of dietary fibers in the chicory root results in a total fiber content of 15–20% wet weight and ≤90% on a dry weight basis (39, 30, 40). Consequently, chicory roots outscore other commonly consumed vegetables, fruits, seeds, or nuts for fiber content.

Chicory taproots are by no means new to human consumption. They have a long history of use in the Western world, and were consumed in Ancient Egypt, Ancient Greece, and the Roman Empire (41). Chicory roots are the taproots of the plant *Cichorium intybus* L., which belongs to the Asteraceae (or Compositae) family. The plant is easily recognizable due to its blue flowers and can be found as a wild or cultivated plant in numerous regions around the world, with various local names (42, 43). The cultivated plant is either grown for its leaves (leaf chicory) or its white fleshy taproots (root chicory) (43). Leaf chicory can have, depending on the variety of *C. intybus* L., either green leaves (sugarloaf), red leaves (radicchio), or white chicons (Belgian endives also known as witlof or witloof) (41, 43). The latter is produced by forcing chicory roots indoors in the dark, which results in blanched tasteful shoots (41). Root chicory is cultivated for the production of root vegetables and inulin (41).

Beside fibers, chicory taproots also contain various micronutrients such as potassium and calcium, as well as many phytochemicals (44). The major phytochemicals are sesquiterpene lactones [≤0.81% per dry weight (45)], a group of well-known bitter compounds with medicinal activities (46), for which several structures have been elucidated (47, 48). Other phytochemicals include polyphenols, such as chlorogenic acid, coumarins, like cichoriin, and other organic acids (44), which are known to have various health-protective effects (49, 50). All these fiber and phytochemical components of chicory roots have been exploited by humanity for medicinal, culinary, and other uses. Some of these uses are still well-known, such as the consumption of chicory root coffee, whereas others are less well-known or have been forgotten.

In this review, we re-examine the use of *C. intybus* L. taproots, hereafter referred to as chicory roots, for human intake. We reconstruct the historical uses of chicory from Ancient Egypt to the beginning of the 21st century. Thereafter, we review safety issues and assessment by legal authorities. We end by detailing the current uses of the components of chicory roots and an outlook for the future applications of the whole chicory root.

Historical Use of Chicory Roots

C. intybus L. is believed to be 1 of the oldest cultivated vegetables in human history (51, 52). One of the first descriptions of chicory root cultivation dates from around the 3rd century before Christ (BC) when the Greek Theophrastus, a student of Aristotle and 1 of the first botanists, described chicory and its growth (51). Beside botanists, physicians, cooks, and even poets have also written about the chicory plant, which indicates that the plant enjoyed great popularity.

Chicory roots have been historically used for 3 purposes: *1*) as a food product for culinary vegetable dishes and later for the production of ingredients, *2*) as a medicinal plant prepared either as a whole or as a base for extraction, and *3*) for miscellaneous use, such as cosmetic applications and spiritual intentions (for an overview see **Figure 3**).

Historical use of chicory roots and their ingredients as food

The first application of chicory roots for any type of intake seems to relate to their culinary use. Whether they were first used for the production of leaves or as a root vegetable is unclear. Most of the very early references do not specify the plant part that was used. Only Theophrastus specifically mentioned that the leaves were used as food (51). This is also what Horatius, a Roman poet living 2 centuries later, most likely refers to when he cherishes chicory in his ode to Apollo (53). The first record of the culinary use of chicory dates back to the 1st century anno domini (AD), in the ancient Roman cookbook *Apicius–De re coquinera* (54). During harvesting time, the vegetables were preserved with oil and onions, and during winter consumed with honey and vinegar. Celsus, a Greek writer living in the 1st century AD, also mentioned in his *De Medicina* a roasted version of chicory (55). This preparation was consumed alone or together with other foods. The bitter taste of the vegetable was also well-known in both the wild and cultivated plant, as described by the Greek physician Galenus in the 2nd century AD (56).

More detailed information on the culinary use of chicory started to appear in the Renaissance and includes a well-cited 1614 cookbook of the Italian, Giacomo Castelvero (57). He appraised 2 seasonal vegetable dishes made from chicory roots. In spring, the leaves together with the young roots were harvested and served raw with oil, vinegar, and salt. In autumn, the roots were boiled, cut, seasoned, and eaten with raisins to neutralize the bitter taste. The tradition of eating the cooked root in the autumn months still exists in Italy, where these are considered a regional specialty (41, 58). Contemporaries of Castelvero, such as the German,

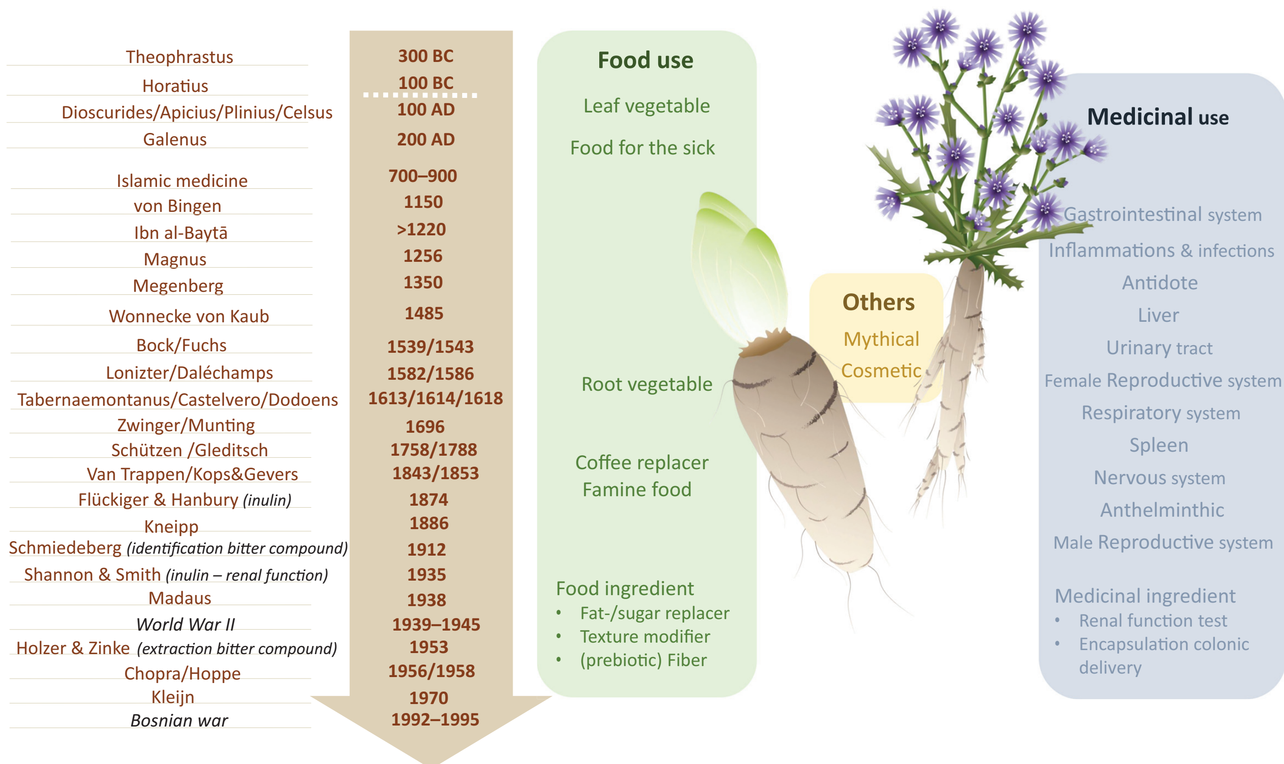

FIGURE 3 Historical overview of chicory use. An overview is presented of the use of roots from both the wild and cultivated *C. intybus L.* since ancient times in culinary, medicinal, or other applications. AD, anno domini; BC, before Christ.

Tabernaemontanus, described the culinary use of chicory in 1613 and mentioned, similar to Castelvero's recipes, that both the chicory roots and the chicory leaves were consumed in salads (59). Moreover, chicory was prepared in mushes, cooked and served as a vegetable dish alone, or used as a condiment in meat and chicken dishes. He concluded his elaboration on the culinary practices by stating that the leaves and the root can be prepared for food use in any way desired (59). After the Renaissance, chicory roots continued to be used culinarily in salads and soups in Germany until the beginning of the 19th century (60, 61). Chicory roots even found their way onto confectioners' shelves, where they were sold as confected and candied sweets (60). In the south west of the Netherlands (Province of Zeeland) chicory roots were also consumed frequently until the end of the 19th century, prepared with vinegar, syrup, or sugar (62).

In the second half of the 18th century, the use of chicory roots as a food product started to change, as did the general image of chicory roots. They were still used in vegetable dishes, although the dishes were prepared more out of need in periods of food shortage, and chicory roots thereby became known as a famine food. Chicory roots were 1 of the few foods available during wartime, for instance during World War II (63), and the more recent Bosnian War (64). Aside from the cooked versions, chicory roots also started to be dried and ground to powder, which was used as flour replacement for breadmaking (65, 66). The chicory root powder eventually also found its way into a new food application: chicory drinks, which were made by roasting the root powder and infusing it with hot water, either with or without real coffee (61, 67). It is likely that such a drink was known for a longer period of time, but it gained popularity at the end of the 18th century when Frederick the Great prohibited coffee import into Germany (68, 69). In the ensuing years, chicory roots were increasingly cultivated for the production of chicory coffee in Europe (67). Eventually, the food use of the chicory root changed completely at the end of the 19th and beginning of the 20th century when inulin was discovered (70), together with its versatile physicochemical properties as a food ingredient. Consequently, chicory roots started to be used mainly as a source for inulin production, and their use as a root vegetable became less common, apart from certain regions, notably in Italy (41).

Medicinal historical use of chicory roots and their extracts

Similar to its use as food products, chicory roots also have a long-standing use in medicinal preparations. Beginning in the 1st century AD, the Greek physician, Dioscurides, and the Roman physician, Plinius, mentioned chicory as a medicinal plant (52, 71). The sites of application and the types of preparation described in their work laid the foundation of today's core medicinal uses of chicory roots, which predominantly concern the GI tract, the liver, and their anti-inflammatory properties. The same medicinal uses and preparations of chicory were described in the following centuries in various Islamic medicine books, e.g., by the influential Persian physician, Rhazes, in the 9th century AD, and were later summarized by the Andalusian pharmacologist, Ibn al-Bayā (72). Based on the documentation, in the Middle Ages, various European religious authorities expanded the portfolio of chicory's medicinal applications, as described by von Bingen (73), Magnus (74), and Megenberg (75). However, it was only in the Renaissance that detailed descriptions of ingredient ratios, preparation methods (e.g., cooking time), and dosing began to be documented as precise recipes in medicinal books. Chicory is mentioned in almost every pharmacopeia written in the 16th and 17th centuries by influential botanists and physicians of the time (76–80) (Figure 3). In their recipes, all plant parts were used: roots, leaves, stems, flowers, seeds, and the milky juice. The most impressively detailed documentations of chicory as a medicinal plant were those of the German, Tabernaemontanus, and his Dutch contemporary, Dodoneaus, followed by the Swiss, Zwinger (81), and the Dutch, Munting (82).

As a medicinal plant, chicory was historically used mainly in 3 ways: *1*) as a preparation of "food for the sick," for consumption by ill or weakened individuals; *2*) as a medicinal preparation for internal use to treat specific organs or diseases; and *3*) as a medicinal preparation for external use. "Food for the sick" mainly included a cooked version of the vegetable that was consumed with vinegar to help a malfunctioning GI tract ("weak stomach," bowel movements) (52, 71). Later in the Middle Ages, eating the crushed leaves and drinking the juice from the whole plant was also advised for liver and spleen ailments (72, 75). Many more specific preparations existed for the internal treatment of various organs (52, 59, 71, 73, 75–79, 81–83) as summarized in Figure 3. These medicinal preparations were mostly based on decoctions made from the roots and leaves in water, vinegar, and/or wine, the extracts of which were consumed alone or with wine (52, 59, 71, 73, 76, 78, 79). In the Middle Ages, the first preserved medicinal preparations were described. Dried, powdered chicory was mixed with fermented honey and salt to produce a drink (73). Later, in the Renaissance, the juice and leaves were cooked to syrup, the roots were conserved, and flowers confected (59, 77–79). Another application included the consumption of the roots with dried cherries but does not specify whether they were cooked or eaten raw (80). Finally, distillates were also made from the roots, flowers, or a mix of roots and leaves (77). There was even a sugar aromatized with chicory flowers that was used as a universal remedy (81).

External applications of the leaves, roots, and juice of the plant were used to alleviate pain (77–79), to treat infections of the eye and skin (52, 71, 75–78), and as an antidote against animal bites (59, 75–77). For this purpose, bandages made with the plant material or its extracts, and ointments made from the juice and oily substances were prepared.

Following these extensive documentations of chicory as a medicinal plant around the 17th century, the development of new medicinal recipes ceased. Similar to the developments of its food use, chicory's use as a medicinal plant began to change in the 18th century. On the one hand, chicory entered pharmacies and pharmacognosy handbooks as a herbal drug (84–86), while on the other hand, chicory-derived products became increasingly recognized as folk medicine, which they currently still are in Europe (60, 61, 87), as well as Asia and Africa (88, 89). Finally, at the beginning of the 20th century, the medicinal focus shifted completely from the whole root to the isolated ingredients, due to the discovery of inulin as an agent for the testing of renal function (90), and the identification (91) and extraction (92) of the first chicory root phytochemicals.

Other historical applications of chicory roots

Beside its food and medicinal use, chicory was also used for various other purposes. The milky juice that is secreted from the root was applied externally for cosmetic reasons, e.g., to prevent hair loss of the eyebrows (77) or to provide skin-firming properties for the female décolleté (82).

As the plant was part of folk medicine for centuries, mythical properties were also attributed to it, such as attracting people (52) or repelling them (73). Over the years, beliefs surrounding the power of the chicory plant entered many sagas and traditions in various countries (42, 60, 61, 93, 94). All in all, chicory roots have been part of everyday human life for many centuries, and have been used to feed, heal, and rejuvenate the human body.

Safety and Legal Aspects of Chicory Root Use

As indicated above, chicory roots have evidently had a long history of safe use, and are still being consumed in raw and processed forms as part of normal diets in various parts of the world. With the shift away from the use of whole roots toward the extracted, concentrated components of chicory, safety concerns have also arisen over the last century.

Allergies to the chicory plant

A rare allergy to the chicory plant has been documented in $\sim$20 cases over the last 100 y. Most of these cases occurred in adults who were in contact with chicory due to their occupation (95–103), and only a single case involved a child reacting to inulin (104). Allergic reactions to the chicory plant have miscellaneous clinical explanations, being either immediate [IgE-mediated (type 1)] or delayed [T-cell mediated (type 4)], or sometimes both (98, 105, 106). Depending on the individual, allergic symptoms can be systemic and/or local, ranging from rhinoconjunctivitis, to asthma and anaphylactic reactions, to contact dermatitis. As individual as the allergic reactions are, the chicory preparations and routes of exposure are also unique and varied. There are only 2 cases where fresh chicory roots topically induced an allergic reaction (100, 101). The majority of reactions occurred in response to leaves (raw and cooked) after skin contact or inhalation (96–101). Sometimes, reactions were also caused by the inhalation of dried chicory roots and inulin (100, 102, 103), consumption of inulin-containing products (107, 108), and once by intravenous inulin administration during a standard renal function test (109).

It is not yet clear exactly how allergic reactions to chicory are triggered. Proteins from chicory or newly formed inulin-protein compounds (arising during production) (98, 108), as well as sesquiterpene lactones could be potential allergens (105, 106). Sensitization might arise from repeated exposures (98, 106) or from cross-sensitization with birch pollen (103, 110) or lettuce (96, 101). Due to all this ambiguity, the general advice is that people with allergies or occupational exposure to Asteraceae family members, people with birch-pollen allergies (110), and people with atopic dermatitis should be cautious when coming into contact or consuming chicory- and inulin-containing foods (106).

Toxicological assessments of chicory root extracts

Since the intake of concentrated root extracts may pose a health risk, several safety and toxicological evaluations have been performed in recent years on chicory root inulin, its phytochemical extracts, and chicory root coffee. The toxicological safety of inulin was tested in several in vitro and animal models and summarized 20 y ago to pose no toxicity in the amounts administered (111). Human data from clinical studies indicated that inulin has been safely administered intravenously as a renal function agent for nearly 100 y (90), even in pregnant women (112). As a prebiotic fiber, inulin has been tested up to an intake of >50 g per day (113) and concluded to be safe (111). The only concerns comprised GI symptoms (such as flatulence and diarrhea), that appeared to be dose- and individual-dependent, but generally arose at doses of 20–30 g per day (111).

The safety of phytochemicals from chicory roots has mainly been evaluated based on concentrated ethanolic extracts of chicory roots using in vitro and animal models. Sesquiterpene lactones extracted from chicory roots did not reveal any mutagenic effect in an Ames test, nor any toxicological adverse effects in a rat model, establishing a no-observed-adverse-effect-level (NOAEL) of 1000 mg/(kg∗d) (114). One human study included the safety of a sesquiterpene-rich chicory extract in a 1-mo phase I trial on osteoarthritis (115). Only 1 of the participants receiving the highest dose (1800 mg/d) reported adverse effects, headaches, and diarrhea. The other 24 subjects in the intervention group showed no adverse change (115). Consequently, it was concluded that there are no safety concerns in the clinical use of chicory root extracts (115). Additionally, the external application of sesquiterpene lactones for human use has recently been studied in skincare formulations and found to be safe (116).

Two trials evaluated the safety of a combination of inulin and phytochemicals in chicory coffee. It should be noted that the composition of chicory coffee is different from raw chicory roots since inulin and phytochemicals are partly broken down during the roasting process forming new chemical compounds (117, 118). The effect of chlorogenic acids on thrombosis prevention was tested in 27 subjects who consumed 20 g of chicory coffee in 300 mL for 1 wk. They did not observe any negative side effects during this short time period and found some, but variable, effects on the measured thrombosis markers (118). Similarly, the effect of inulin on GI tolerance was tested in chicory coffee with a higher inulin content produced by a new method (117). Short-term (6 d) consumption of ≤500 mL chicory coffee containing ≤7.8 g inulin, as well as long-term (4 wk) consumption of 500 mL chicory coffee containing 5 g inulin, did not lead to any adverse GI symptoms in any of the 35 subjects.

Legal status of chicory root extracts

From a legal perspective, chicory inulin obtained from *C. intybus* L. has been assigned the status of generally recognized as safe (GRAS) by the FDA in their list of Substances Added to Food (119). GRAS is a status given to food components that have been proven to be safe due to a long history of consumption in a meaningful number of people. The FDA also lists a chicory root extract [Chemical Abstracts Service Registry Number (CAS Number) 68650-43-1] with GRAS status as a coloring and flavoring agent (120). The European Food Safety Authority (EFSA) has approved a health claim for unfractionated chicory root inulin obtained from *C. intybus* L. (called "native chicory inulin") at a dosage of 12 g per day in relation to stool regularity (121). The European Medicines Agency (EMA) provided an assessment of the traditional medicinal use of chicory roots in Europe (122), and concluded that the traditional use of chicory roots for the treatment of GI complaints and to stimulate appetite is supported by scientific evidence and does not pose any safety risk. Nevertheless, based on the scientific data included in this assessment, it was not recommended to enter chicory root as a medicinal product, due to insufficient scientific information (122). Nevertheless, chicory root is still regarded as folk medicine in several European countries, such as Germany, France, and the Czech Republic, and is listed by their respective governmental authorities as a medicinal substance (123–125).

Contemporary Uses of Chicory Roots

Presently, chicory inulin-based ingredients and root coffees are the most recognized applications of chicory roots. However, new methods of using chicory roots seem to be evolving, fueled by the combined interest in the nutritive and medicinal value of chicory roots, as well as increasing demand for autochthonous, traditional, and natural foods (126, 127).

Food use in the 21st century

As mentioned earlier, chicory roots are currently mainly used for the production of inulin, which is a highly versatile food ingredient and is generally extracted by a hot water process (128). After extraction, inulin is purified in a rather intense process, and can then be further refined based on its chain lengths, requiring additional solvents like ethanol, methanol, or acetone (129, 130). Inulin of different chain lengths has different physicochemical properties and, hence, can be added to food products for various purposes (129), which can be generally categorized into sugar replacement (short-chain inulin), fat replacement (long-chain inulin), or texture modification (long-chain inulin) (131). Besides changing the sensory properties of a product, inulin can also be added to a food product to increase its prebiotic dietary fiber content, or consumed as a food supplement (31). Due to its importance as a food ingredient, optimization and sustainability of the, until now, energy- and time-consuming extraction process of inulin from chicory roots is an ongoing research topic (130). In addition, the cell wall fibers in chicory pulp, which emerge as waste during inulin production are currently being examined for their potential as a food ingredient (132) or fiber supplement (133). Chicory pulp was reported to increase satiety in vivo (133) and is rapidly fermented in vitro (134).

Besides using chicory roots in the isolated form of inulin, they are also still used for the production of chicory coffee, which is valued today as a caffeine-free alternative to coffee (135). It is also often used to add a characteristic flavor to coffee or alcoholic beverages (44), such as beer or vodka. For its use in beverages, chicory is dried and roasted (135). During the roasting process, depending on the conditions used, different flavor compounds can be formed, the characterization of which is a developing research area (136).

Today, the use of whole fresh roots is limited to areas where these have been traditionally consumed. Despite this, efforts have been made to preserve genetic resources and revive the culinary use of *C. intybus L.* roots, for instance in Italy where contemporary consumption in Sicily, Liguria, and Lombardy has been noted (137, 138). Of interest, an annual festivity for chicory roots (Sagra delle Radici) is organized in autumn in Socino, in the Lombardy region (58). Furthermore, various recipe ideas are promoted on websites of organizations and hobby cooks. More than 25,000 tons of chicory are still produced in Italy annually for consumption of the roots (58). It is likely that chicory roots are still traditionally consumed in other countries, but it is not broadly known or described due to their existence as a regional specialty.

Medicinal use in the 21st century

Chicory inulin, similar to its food use, also forms the main application of chicory roots for medicinal purposes. Chicory inulin is still used for the measurement of renal function (glomerular filtration rate), and for the colonic delivery of drugs. Chicory's inulin suitability as an agent for renal function tests originates in its low molecular weight, being neither absorbed nor metabolized by the kidney but readily excreted (111, 139). As a colonic delivery medium, inulin can be chemically modified to carry or encapsulate drug compounds. Drugs that would be absorbed on their own, early in the GI tract, are now transported to the colon, where inulin is broken down by gut bacteria and the compound is released (131, 139).

Besides chicory inulin, the relevance of the phytochemical compounds in chicory roots has also been increasingly recognized in recent years. There is a large body of research on the medicinal effects ascribed to the phytochemicals of chicory roots, which have been recently reviewed (140–143). The majority of those studies are based on in vitro or animal models (143). A single human intervention study has been reported that assessed the anti-inflammatory potential of chicory sesquiterpene lactones in patients with osteoarthritis (115). All 3 tested dosages (600, 1200, and 1800 mg/d) led to an improvement of pain, stiffness, and general functionality assessment, with the highest improvement in the highest dose group, albeit without reaching statistical significance (115). The medicinal field is still evolving, and present interest is focused on reproducing effects in humans and elucidating the underlying mechanisms.

Other uses of chicory roots in the 21st century

Besides human food use, chicory roots are also still used for cosmetic purposes. Although the juice of chicory roots was advised in the 17th century to be a skin-firming agent, chicory root extract has recently been rediscovered as a protective and regenerative component in skincare formulations (144).

In recent years, the health benefits of inulin have also been discovered and proven in animals, and consequently chicory inulin is nowadays added into feed for domestic and companion animals (145). For an even longer time, chicory pulp has been added to animal feed formulations as a cheap, fiber-rich ingredient (146). Recently, the use of whole chicory roots has also been evaluated for nutritive and medicinal benefits for animals (147, 148). For instance, in trials with companion animals it has been shown that dried whole chicory roots, as a source of prebiotic fibers, provided health benefits and contributed to longevity (149, 150). Consequently, whole chicory roots are now also tested in studies with domestic animals for their potential as nutritive and health-promoting feed components (151–154).

Future Use of Chicory Roots for Human Intake

Although isolated chicory root compounds are still widely investigated for their functionality, studies have started emerging that focus on the whole vegetable instead of the isolated ingredient, with the aim of increasing the intake of multiple fibers and exploiting the bioactive potential of the phytochemicals present in the chicory root. One report focused on the prebiotic effect of inulin in combination with probiotic feta cheese on lipid metabolism (155). However, instead of consuming inulin, participants drank a watery extract made from a decoction of raw chicory roots. The consumption of this combination led to a significant reduction in total and LDL cholesterol, as well as a reduction in serum triglyceride concentrations, which the probiotic cheese alone did not achieve (155). Another report studied the effect of inulin from roasted chicory roots on glucose and lipid metabolism and intestinal health (156). For this purpose, chicory coffee, instead of conventional inulin supplementation, was used. A significant improvement of glycated hemoglobin (HbA1c) and stool frequency was found, however, no improvements in fasting glucose or insulin concentrations and lipid metabolism were observed. Chicory coffee was also used in relation to its phenolic acid content (chlorogenic acids), which was thought to beneficially affect thrombosis prevention, as was previously demonstrated in vitro and in vivo in mice using synthesized compounds (118). In the human intervention, it was found that the in vivo effects were far lower than expected and blood values remained unchanged. Despite this, chicory coffee had a positive effect on whole blood and plasma viscosity, as well as RBC deformability (118). Furthermore, a very recent preliminary report mentioned the use of dried and ground chicory roots to replace fat in burgers. Interestingly, a replacement of 75% of the fat could be achieved, which improved water retention during cooking. This also affected sensory properties, although within an acceptable range (157). No study has yet examined the effect of whole chicory roots on human health. One very recent study investigated the effect of inulin-containing vegetables instead of isolated inulin on food intake and GI health (158), but did not include chicory roots. It was observed that a 2-wk intake of, on average, 15 g/d inulin via whole foods increased fecal bifidobacteria and satiety ratings, similar to the effects of isolated inulin, without leading to negative effects on GI tolerability (158). Consequently, it was concluded that the inclusion of inulin-rich whole foods in the diet might be a health-benefitting food-behavior strategy.

Conclusion

Chicory roots have a long history of traditional use for human consumption. Although they have enjoyed broad popularity for >2000 y, chicory roots have become increasingly connoted as a famine food over the last 3 centuries, and have today been nearly forgotten as a food source apart from their use in some regional specialties, notably in Italy. With the recent recognition of the importance of dietary fiber for the improvement and maintenance of human health, the fiber-rich chicory roots offer an attractive option to close the gap between fiber recommendations and consumption. Moreover, chicory roots meet consumer interest in being minimally processed, autochthonous, and natural foods. The mix of cell wall fibers and the phytochemical content, in addition to the inulin content of chicory roots, offer interesting nutritional options for improving human health. Revisiting chicory roots in the 21st century as a rich and versatile source of complex dietary fibers opens up opportunities to combat a range of chronic metabolic diseases originating in the current fiber-poor Western diet.

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