Trends in Horticulture (2021) Volume 4 Issue 1
doi:10.24294/th.v4i1.1807

REVIEW ARTICLE

A review on the effect on phytochemical compounds relevant to human health by broccoli processing technologies

Cecilia Vázquez-González[1], Beatriz Mejía-Garibay[2], Ma. Reyna Robles-López[3], Carolina Ramírez-López[3*]

[1] *Instituto Politécnico Nacional, Universidad Tecnológica de Tecamachalco, Mexico.*

[2] *Universidad de la Américas Puebla, Mexico.*

[*3] *Instituto Politécnico Nacional, Tlaxcala 90700, Mexico. E-mail: caramirezl@ipn.mx*

ABSTRACT

Broccoli has been consumed around the world in various ways; either raw, blanched, frozen, dehydrated or fermented; however, functional foods and nutraceuticals are currently being designed and marketed from broccoli, through the extraction of compounds such as sulforaphane, which according to several studies and depending on its bioavailability has a protective effect on some types of cancer. Likewise, several food technologies are reported to seek to offer innovative foods to increasingly careful and critical consumers, ensuring that they retain their nutritional and sensory attributes even after processing and that they are also safe. In this sense, studies on the effect of processing on compounds of interest to health are of great relevance. Therefore, this article presents an overview on the study of traditionally consumed broccoli and the design of new products from the use of agro-industrial residues that, due to their high content of fiber and fitochemical compounds, can benefit the quality of life of the human population.

Keywords: Broccoli; Functional Food; Food Technologies; Sulforaphane

ARTICLE INFO

Received: 16 August 2021
Accepted: 23 September 2021
Available online: 17 October 2021

1. Introduction

The increase in the development of novel foods by the food industry is due to the convergence of several critical factors, such as: awareness of the deterioration of personal health, where busy lifestyles, poor choices in prepared foods, and sedentary lifestyles predominate. Scientific developments in nutritional research are focusing on product innovation in the area of functional foods or ingredients that provide consumers with healthier foods. Cruciferous vegetables or brassicas such as broccoli, cabbage, arugula, turnip, kale, etc., are booming due to the diffusion of the benefits they provide. There is also a high consumption worldwide due to their availability in local markets, low cost and consumer preference for ease of use as a garnish. Several studies have shown an inverse relationship between the consumption of brassica vegetables and the risk of diseases such as cancer, where the beneficial effects for human health of these cruciferous vegetables attributed to the presence of high levels of fitochemicals called glucosinolates. Broccoli is widely used in cooking in many parts of the world, also because it is a natural source of fibra and flavonoids with high antioxidant activity. However, all technological or culinary processes, whether minimal or higher grade, could cause changes in the nutritional quality of broccoli before it is ingested. For this reason, the objective of this review is to present and compare the nutritional and functional properties of broccoli when various food technologies are applied to broccoli to extend its shelf life, in addition to recognizing the importance of its consumption.

2. New concepts in food development

2.1 Functional food, nutraceutical, "superfood"

Nowadays, many people are looking for a closer relationship between their diet and their health, demanding more information about the diverse range of foods, and even more about those foods called functional foods and their bioactive compounds. Functional foods can be processed or unprocessed, and consumed as part of a daily diet, but they provide nutrients and functional substances capable of producing metabolic or fisiological effects useful for the maintenance of good physical and mental health, in addition, they can become auxiliary in reducing the risk of acquiring some chronic and degenerative disease[1–4].

Functional foods have a market estimated at $29 billion dollars a year in the United States alone, and the food industry and scientists are shifting their developments to the production of functional foods and also to proving their beneficial effects on health by their consumption, without downplaying the importance of good sensory acceptance of such foods[5].

There are also pharmaceutical presentations prepared from common foods, which can be presented as pills, capsules, formulations in the form of powders or concentrates to be added to food, and which have the medicinal character that are called nutraceutical foods[2,5,6].

In recent years, the term "superfood" is being used for those foods that can be related to the high content of nutrients of high bioavailability and bioactivity for the human body, providing health benefits. The term is mainly employed for fruits and vegetables that naturally contain a high concentration of nutrients, fitochemical compounds and antioxidants[2,7,8].

Through food science, it is possible to study and create some foods that would not normally be available, in addition to knowing how active compounds interact within the metabolism of people. **Figure 1** presents the relationship of various actors involved to preserve and understand the mechanisms of action between these types of foods[4].

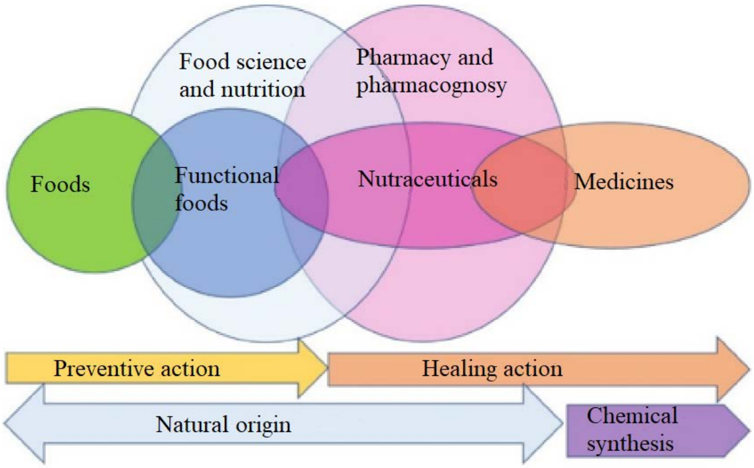

Figure 1. Stakeholder relationships for the study and development of functional and nutraceutical foods.

3. General information on broccoli and ways to consume it

3.1 Description of broccoli cultivation and its importance in Mexico

Broccoli (*Brassica oleracea* L. var. Italica) originated in the eastern Mediterranean region of Europe. A highly perishable climacteric vegetable, it is rich in minerals, vitamin C, dietary fibras and especially nutritional antioxidants, phenolic compounds and glucosinolates[9–12]. According to Cronquist[13], broccoli taxonomically falls into the following categories (**Table 1**).

Table 1. Taxonomic classification of broccoli (*Brassica oleracea* L. var italica)

Reino	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Dilleniídae
Order	Brassicales
Family	Brassicaceae
Genre	*Brassica*
Species	*Oleraceus L.*

Source: Adapted from Cronquist[13].

Broccoli in Mexico is grouped in the agricultural production sector of vegetables, being a crop that is developed in regions where temperate and cold climates predominate. It is managed mainly through the irrigated agriculture modality. According to the Panorama Agroalimentario 2019 generated by SIAP in Mexico, Guanajuato accounts for more than 67% of national production, and exports broccoli to countries such as Japan, South Korea and Hong Kong[14].

3.2 Ways of consumption of broccoli

Broccoli is a vegetable that is consumed in various forms around the world, has been part of diets such as the Mediterranean diet and is usually consumed both raw and cooked. However, in both cases, it has been sought to ensure safety in the handling within the supply chain of this to avoid health risks to consumers[15].

It is estimated that, of each broccoli plant in the field, only the inflorescence is used, which constitutes about 30% of its total weight; therefore, 70% of the plant is agricultural waste consisting of heavy stems and green leaves (**Figure 2**), with the possibility of being used for the benefit of various industries such as food or pharmaceuticals[16]. On the other hand, also in broccoli packing houses, wastes are generated that, although they meet safety specifications, do not comply with minimum defects such as size or other commercial qualities (personal communication with broccoli producers in the region of Los Reyes Juárez, Puebla).

Table 2 presents some ways of consumption of broccoli or its extracts, as well as the general conditions of the process, its average shelf life and also the potential preferred market.

Figure 2. Parts of broccoli and its usable residues for obtaining functional fitochemical compounds.

4. Most important nutritional and functional components present in broccoli

Several researchers have conducted *in vivo* and *in vitro* studies[15,26], to demonstrate that bioactive compounds present in brassicas and in particular in broccoli (ascorbic acid, phenolic compounds, dietary fibra, carotenoids and glucosinolates), could be responsible in the control of chronic diseases, such as metabolic syndrome (**Figure 3**).

4.1 Phenolic compounds

Phenolic compounds are secondary plant metabolites whose molecular structures include one or more aromatic rings substituted by one or more hydroxyl groups. Phenolic compounds present in foods have attracted interest due to their benefits to health and also for their antimicrobial characteristics and impact on multiple sensory attributes in foods, including flavor, astringency, and color. Furthermore, it has been determined that polyphenols are largely responsible for the high antioxidant activity of broccoli[9].

The health benefits of phenolic compounds are increasingly recognized and are known to be partially dependent on their microbial conversion, which can occur *in situ* after cutting plant tissue, during food processing, particularly during food fermentations due to the action of gut microbiota after digestion.

Table 2. Main forms of consumption of broccoli and broccoli extracts

Form of consumption	Process conditions	Type of consumers	Shelf life	Reference
Whole raw broccoli	Pre-cooled, weighed, boxed, sealed with low density plastic film, stored at 0.8 to 12 °C.	Markets and supermarkets	Up to 1 week	Giletto et *al.*[17]
Minimally processed raw broccoli pieces.	Sorting, sectioning, disinfection, treatment from 42 to 48 °C and use of UV-C, packaging and cooling.	Supermarkets and hotel, catering, restaurant and school sectors	Up to 15 days	Lemoine *et al.*[18]
Raw broccoli chunks under passive atmosphere conditions	Sorting, sectioning, disinfection (NaClO), centrifugation, packaging in rigid polyethylene with passive atmosphere and refrigeration.	Convenience stores	Up to 21 days	Hernandez *et al.*[19]
Organic broccoli	Selection, sectioning, disinfection, packaging in low density polyethylene and refrigeration.	Supermarkets and the hotel, catering, restaurant and school sectors.	Up to 15 days	Dos Reís et *al.*[20]
Broccoli, cut and blanched	Sorting, washing, sectioning; blanching, cooling, air drying at 7 °C, packing in polyethylene, sealing and cooling.	Supermarkets and the hotel and catering sector catering, restaurants and schools	Up to 14 days	Stringer *et al.*[21]
Broccoli in juice	Reception, cutting, extraction, degassing, filtering and treatment with high intensity electric pulses (HIPEF).	Supermarkets and the hotel, catering, restaurant and school sectors	Not reported	Sánchez-Vega *et al.*[22]
Frozen broccoli	Sorting, washing, sectioning, placing in trays and freezing (-20 °C).	Supermarkets and the hotel, catering, restaurant and school sectors	Up to 12 months	Kmiecik *et al.*[23]
Bro∞li leaves in powdered form added to pancakes	Selection, washing, blanching, freeze-drying, pulverizing, packaging, sealing and storing. Dosing according to formula.	Supermarkets and celiac population and vega na	Not reported	Krupa-Kozak et *al.*[24]
Fermented broccoli stalks	Reception, separation of florets, washing, peeling, cutting, mixing with NaCI and layering for 6 h. Mixed with ingredients such as sugar, soy sauce or sesame oil, pepper. Fermented from 6 to 10 °C at least 1 day. It is marketed without refrigeration.	Traditional fermented food *yan-tsai-shin*	Not reported	Chen *et al.*[25]

Source: Authors.

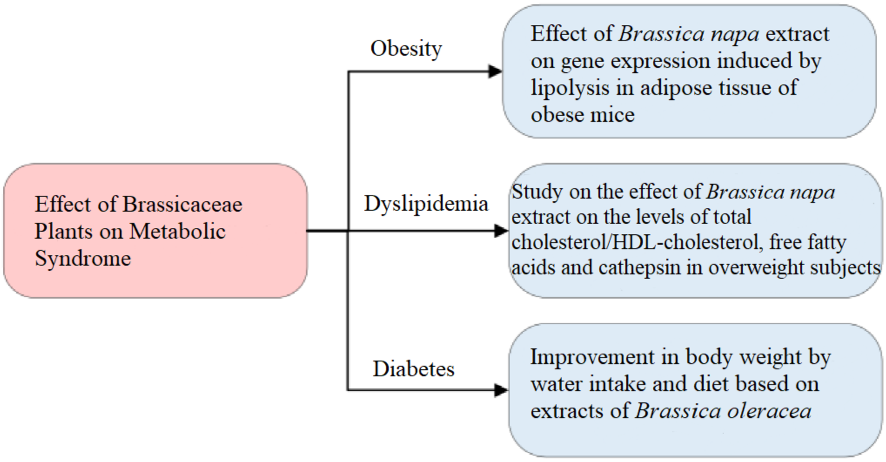

Figure 3. Main effects of consumption of Brassicaceae group in various syndromes[27–29].

4.2 Dietary fiber

Antioxidant dietary fiber composed of grouping antioxidants and dietary fiber. The dietary fibra protects phenolic compounds from enzymes, because they spontaneously bind to cellulose, hemicellulose, lignin and pectins, making possible the release of intact phenolic compounds within the gastrointestinal tract to be utilized by the microbiota[12].

4.3 Glucosinolates, isothiocyanates and sulfurafanates

Among the most important fitochemical compounds in broccoli are glucosinolates and their breakdown products, the isothiocyanates. Broccoli is very rich in glucoraphanin, which is the precursor of sulforaphane. The isothiocyanate sulforaphane (4-methylsulfinyl-butane isothiocyanate) has been extensively studied and has been shown to have beneficial health effects such as modulation of several cancer-related events[14,30].

Glucosinolates are not biologically active until they are hydrolyzed (**Figure 4**) by the action of the endogenous enzyme myrosinase (ß-thioglucosidase, EC 3.2.3.1) when the plant tissue is ruptured as a result of mechanical damage (by cutting or chewing) or when myrosinase also present in the intestinal microflora contacts glucosinolate and releases glucose, bisulfate, and aglycone[31–33].

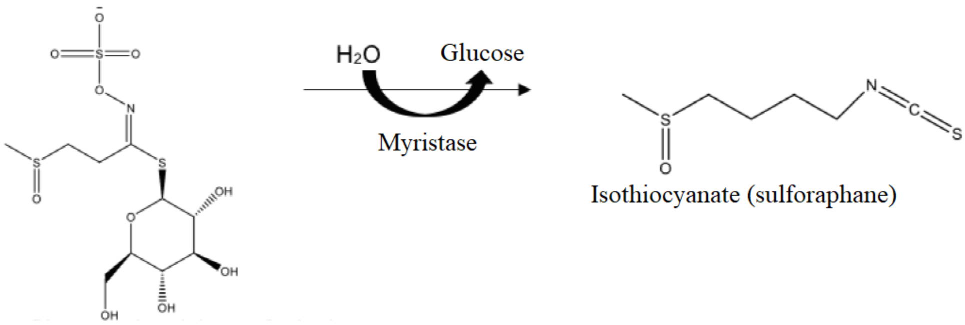

Figure 4. Formation of isothiocyanates from Glucosinolates.

The perfil and content of glucosinolates in Brassicas depends on various aspects such as crop genotype, growth stage, environmental conditions such as temperature, light, water, nutrient availability, growth stage and postharvest conditions[11]. Currently, more than 130 glucosinolates have been identified and more than 30 are always present in Brassica species. The metabolism of such complexly interacting compounds is subject to study; for example, in broccoli, it has been generally found that the glucosinolate content is higher in florets compared to other plant sections such as stems and leaves (525–556, 415–446 and 22–30 mg·kg^{-1} dry basis, respectively)[31,34–36].

5. Effect of processing technologies on broccoli nutritional and functional compounds

It is known that food processes can affect the nutritional characteristics of broccoli. In some cases they are beneficial and can improve the bioavailability of certain fitochemical substances present. However, they can also cause significant losses of nutrients. Due to the above, several studies have been conducted to demonstrate such effects as described below.

5.1 Thermal technologies in broccoli processing

To preserve broccoli, temperature reduction is frequently used, either by applying refrigeration temperatures (2 to 10 °C or freezing (-45 to -18 °C), which results in a challenge to ensure that the shelf life is maintained and at the same time the content of bioactive compounds responsible for the health benefits of consumers is preserved. Because, although the rate of reactions is lower, some reactions still take place[10,37].

In a study by Alanis-Garza *et al.*[37], a freezing process was applied to seven commercial broccoli varieties, finding that there were no relevant changes in total phenol content. However, the carotenoid content was improved (#60–300%) and the extraction capacity of glucosinolates was increased. These results suggest that in frozen broccoli, there is a higher bioavailability of bioactive compounds compared to fresh broccoli, however, the mechanisms that cause this higher yield remain to be explained.

Regarding the use of heating, a study is reported using broccoli florets sections, which consisted of blanching at 57 °C for 13 minutes, followed by incubation, to determine the ideal temperature and incubation time using response surface to maximize sulforaphane content, resulting in 38 °C for 3 hours as the best ratio. A first option the authors suggest is that sulforaphane could be isolated from broccoli to be employed with a nutraceutical or functional ingredient. A second option after achieving maximization of sulforaphane content by incubation was to dry the broccoli paste using a fluidized bed, with the objective of maintaining that concentration of sulforaphane after processing. The results showed an increase of 25% with respect to fresh broccoli[38,39].

Mahn and Rubio[40] reported the evolution of total polyphenol content and antioxidant activity in blanched (57 °C for 13 min) and unblanched florets, during storage at temperatures from -45 °C to 20 °C for more than 80 days, finding that both polyphenol content and antioxidant activity increased at the beginning of storage (-21, -1, 10 and 20 °C) and then decreased; in contrast, during storage at -45 °C, no significant changes occurred. Both blanched and fresh broccoli underwent the same reactions that caused changes in polyphenol content.

5.2 Barrier or obstacle technology applied to broccoli

Hurdle technology is a food preservation process that combines the use of one or more preservation methods to inhibit the growth of the microorganisms present. In this way, a synergy is developed with the application of various treatments, which offers advantages compared to the separate use of the individual treatment[41]. The most commonly used obstacles in food preservation are temperature (high or low), water activity (Aw), acidity (pH), oxide reduction potential, use of preservatives such as nitrites, sorbates, etc., and the use of microorganisms such as lactic acid bacteria[42–44].

At present, non-thermal processes in foods, such as the use of electric field pulses, are being studied. Another group of obstacles are the use of natural preservatives such as spices and their extracts, enzymes such as lysozyme, chitosan, bacteriocins such as nisin (E234), etc.[43].

Additionally, the application of barrier technology can improve sensory and chemical characteristics in addition to microbiological characteristics. More than 60 different types of barriers have been reported that can be used in different combinations and concentrations in food processing as presented in broccoli.

Recently, biodegradable materials are being studied with the GRAS denomination to create edible films that in addition to increasing shelf life, improve food safety. Such is the case of the study of the evolution of native microorganisms (aerobic and psychrotrophic mesophilic bacteria, fungi and yeasts, lactic acid bacteria and coliforms) of an edible film made from chitosan, applied on fresh broccoli florets and stored for 20 days under refrigerated conditions. It is found that it presents a significant reduction in mesophilic and psychrotrophic bacteria compared to control samples and inhibits the growth of coliforms during the refrigerated storage time, in addition to delaying the yellowing characteristic of the product senescence[45].

Das *et al.*[46] studied the effect of three disinfectants, chlorinated water 100 μL/L free chlorine pH 7, electrolyzed water with 100 μL/L free chlorine pH 7.2 or ozonated water (O_3) 2 μL/L on fresh broccoli freshly chopped, and after treatment were bagged in 30 μm polyethylene bags. The study was analyzed on the ninth day of storage at 5 °C where the results showed no significant difference in the evaluation of color parameters (L* and hue angle), in addition, it was concluded that the application of ozone for 180 s obtained lower total aerobic and coliform bacteria counts, and ozone could be a potential disinfectant to maintain microbial quality in fresh fresh-cut broccoli.

5.3 Minimally processed food technologies in broccoli

Minimally processed broccoli should be ready for consumption, only disinfected with organic compounds such as peroxyacetic acid or natural antimicrobials such as bacteriocins and recently emerging technologies such as UV-C or ozone, among others.

However, an important problem of minimally processed broccoli is that it is very perishable due to the damage that the vegetable suffers when cut, it allows a greater availability of intracellular contents that favors the growth of pathogenic microorganisms and saprophytes, which among other things could trigger problems of low food safety, so it is also common to use refrigeration or modified atmospheres to promote its preservation[45].

Broccoli has a high respiration rate, and to maintain its quality and increase its shelf life, a study was conducted to evaluate the behavior in fresh florets, in fisicochemical, microbiological and sensory parameters. As a common postharvest treatment for pathogen control, half of them were treated with hot air at 48 °C for 3 h, then they were packed in polypropylene bags, applying a passive atmosphere and others were subjected to a modified atmosphere (5 and 10% CO_2) to be stored under refrigeration at 5 °C, a control sample was kept. The results in the use of both atmospheres did not present significant differences between them, managing to keep the product for up to 21 days compared to the control, but in practical and economic terms, the use of passive atmospheres is better[20].

Ansorena *et al.*[47] studied minimally processed broccoli through the effect of using a flexible film composed of chitosan and carboxymethylcellulose with or without the application of light thermal shocks (1.5 min at 50 °C) on broccoli stored refrigerated at 5 °C for 18 days. They found that this technology has a beneficial impact on the physical and nutritional quality of broccoli, evaluating aspects such as weight loss, texture, color (decrease in the appearance of yellowing), ascorbic acid content, total chlorophyll content, aerobic mesophilic bacteria count and sensory quality.

In another study of fresh broccoli, UV-C treatment at 10 and 14 kJ·m^{-2} was applied to delay chlorella degradation (broccoli yellowing) and also to increase the antioxidant capacity, which could be useful from a nutritional point of view and to delay broccoli senescence[48]. Likewise, in another investigation, the influence on the quality and postharvest fisiology of minimally processed broccoli of combined treatments of UV-C (5, 8 and 10 kJ·m^2 followed by hot air (42, 45 and 48 °C and stored at 20 °C for 4 days was analyzed. The combinations of 48 °C with a dose of 8 kJ·m^2 allowed delayed yellowing, lower broccoli senescence and higher level of antioxidant capacity during the storage period[18].

Many consumers today are looking for diets that provide high nutritional level, but without losing the sensory quality of food and that are practical for preparation and consumption, so it has been innovated in products such as the hybrid called kailan-broccoli and commercially known as Bimi® or Broccolini® among other names (*Brassica oleracea* Italica Group x Alboglabra Group). Currently highly consumed in northern European countries, the United States, Brazil and Australia, it has the same qualities of broccoli and retains the bioactive compounds, but with softer organoleptic characteristics in the sulfur smell, besides being slightly sweet. Another advantage of the kailan-broccoli hybrid is that it consists of elongated and thin stems making it completely edible. This product was studied to evaluate the effects on glucosinolate and vitamin C content when treated by 6 methods: boiling (100 °C for 3.5 min), low pressure steam (100 °C, 0.02 MPa for 5 min), high pressure steam (0.1 Mpa for 2 min), *sous vide* (90 °C for 15 min), grilling (280–300 °C for 3 min) and microwaving (2.5 min), and then stored for 45 days at 4 °C. Low pressure steam and microwave processes are the methods that allowed preservation of glucosinolates and vitamin C (60% and 79%, respectively), with glucoraphanin being the most thermostable glucosinolate[49].

Other studies carried out on applied technologies for broccoli utilization are summarized in **Ta-**

ble 3.

Table 3. Studies on the nutritional aspects of broccoli utilization in the world

Study material	Study conducted	Relevant result	Reference
Broccoli florets	To study the effects of pretreatment and freezing on glucosinolate content and antioxidant capacity.	The current method of industrial freezing is good practice for preserving the main antioxidant nutrients. Pretreatments such as blanching can be improved.	Cai *et al.*[10]
Broccoli florets	To evaluate the effect of cooking methods (boiling, steaming and microwave) on glucoraphanin degradation and bioaccessibility in a simulated gastrointestinal digestion model.	The steamed treatment had only 11.87% loss of glucoraphanin and the boiled one 47.03%. The steamed broccoli presented lower bioaccessibility (94.59%).	Cuomo *et al.*[26]
Broccoli sprouts and seeds	To measure the effect of temperature on glucoraphanin, sulforaphane and myrosinase content and distribution in the sprout.	The content of glucoraphanin and the formation of glucoraphanin decreases with the growth of the sprouts. More sulforaphane is present in ungerminated seeds.	Guo *et al.*[50]
Organic and conventional whole fresh broccoli	To compare the effect of ozonated and chlorinated water as sanitizers on antioxidant properties.	Cultivation method has an effect on polyphenols, vitamin C and total chlorophyll content. Flavonoid content and antioxidant capacity is higher in organic broccoli. The use of ozone favors chlorophyll preservation.	Lima *et al.*[51]
Fresh broccoli	To evaluate the use of ethanol to extend shelf life and determine antioxidant activity.	The use of ethanol can extend shelf life and increase antioxidant activity. It could also retard broccoli yellowing.	Xu *et al.*[52]
Broccoli florets with green bean chunks	To determine the effect of blanching with hot water (20 to 52 °C) and storage from 7 to 10 °C and to simulate post process of contamination (inoculation of *Listeria monocytogenes, Bacillus cereus* and *E. coli* O157:H7.	The method improves appearance and reduces the endogenous microbial population but may also allow the growth of contaminating and pathogenic organisms.	Stringer et *al.*[21]
Broccoli florets	To evaluate the effect of household practices such as refrigeration, freezing and cooking on vitamin C retention and its relationship with sulforaphane.	When refrigerated at 6 °C and 95% R.H. there was a high loss of vitamin C and sulforaphane. Freezing was a good technique to preserve the vitamin and the concentration of sulforaphane did not change in the product.	Galgano *et al.*[62]
Broccoli seeds	To evaluate the glucosinolate content and antioxidant activity in seeds of several broccoli varieties grown in Thailand.	The concentration of glucosinolates varies among the four broccoli seed varieties. Methanol and water are the best solvents for extraction in the determination of antioxidants.	Chuanphongpanich *et al.*[32]

Source: Authors.

5.4 Application of fermentation to broccoli

Fermented foods are consumed all over the world, playing important roles in the nutrition of the population, such as food preservation due to the formation of metabolites such as lactic acid, acetic acid, propionic acid or formic acid, ethanol, bacteriocins, etc. In addition, they improve food safety due to the decrease of enterobacteria due to pH changes. They also improve the nutritional value, organoleptic quality of food and generally increase digestibility[54,55].

There are various processes in the world to carry out fermentation of fruits and vegetables, regions of Europe, Asia, America and Africa, such as Vietnam, Taiwan, Philippines, China, etc. (**Figure 5**). Such processes can be described in a general way as presented by Manas *et al.*[55].

The stems of broccoli florets are usually discarded, however, they can also be used to make fermented broccoli stems (yan-tsai-shim), which are traditionally sold without refrigeration in Taiwanese markets. Broccoli stalks are washed, peeled and cut, layered with NaCl in a vat for 6 hours, then the ex-

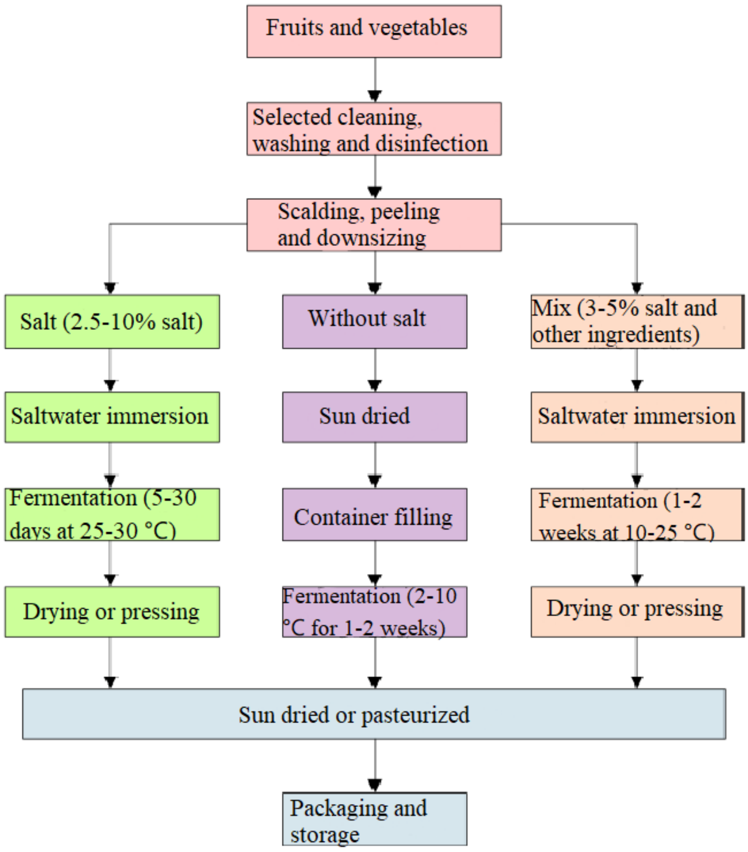

Figure 5. Overall fermentation process for fruits and vegetables.

Source: Adapted from Manas *et al.*[55].

udate is removed and sugar, soy sauce and sesame oil are added and left to ferment for 24 hours at a temperature of 6 to 10 °C. This food has been studied to describe the great variety of lactic acid bacteria (LAB) in both fresh and fermented products, as well as the presence of antimicrobial substances produced during fermentation[25].

Filannino *et al.*[9] studied the metabolism of phenolic acids and flavonoids during fermentation of cherry juice and broccoli puree to be a potential food source of phenolic compounds with biogenic properties. Broccoli is a major source of flavonoids, mainly acylated derivatives derived from synaptic, ferulic, caffeic, caffeic, and p-coumaric acids.

6. Use of broccoli residues to obtain phytochemicals

Currently, several studies are being carried out in Mexico for the utilization of broccoli agricultural residues, seeking to obtain bioactive products through the fermentation of these residues. An investigation carried out by Campas-Baypoli *et al.*[53], consisted of evaluating the chemical composition and sulforaphane content in fermented broccoli residues; three treatments of crushed broccoli were established for fermentation, adding 1% NaCl powder in all cases and leaving it to stand for 20 minutes; to treatment 1, 33% water was added to obtain a fermentation with native microbiota; to treatment 2, 33% inoculum of lactic bacteria previously activated from a commercial probiotic of immobilized cells, and for treatment 3, a scalding at 60 °C for 5 minutes was previously applied and 33% of previously activated inoculum was added.

The results showed that all fermented broccoli improved its nutritional composition due to the action of lactic acid bacteria (LAB), obtaining an increase in protein (21.4 to 24.5%), lipid (1.6 to 2.6%) and ash (14.5 to 17.9%) content compared to unfermented broccoli shreds (time zero). Regarding sulforaphane, it presented an increase and remained stable for a longer time in treatment 3 where blanching was applied, with the best content in a range of 109 to 376 μg/g dry matter, because authors such as Fuller *et al.*[54] and Chen *et al.*[25], have reported that lactic acid bacteria (LAB) possess enzymes with activity similar to myrosinase, responsible for the conversion of glucosinolate glucoraphanin to sulforaphane.

Sánchez-Machado *et al.*[55], conducted a study on the biochemical composition and fisicochemical properties of different flours prepared from agroindustrial residues of broccoli parts (florets, stems and leaves), proposing that they can be a good source of nutrients with potential use for food supplements. The overall process consisted of convective drying at 60 ℃ for each section, then pulverized and sieved for analysis. The florete flours had the highest protein content (22.41 g/100 g dry weight) and the stems presented the highest crude fibra content. The amino acid perfil of the flours revealed high concentrations of tyrosine, aspartic acid, glutamic acid, proline, and valine.

Within the research conducted to determine the bioconversion and viability of glucosinolates to sulforaphane, Alvarez-Jubete *et al.*[3] conducted a study to compare the effect of microwave processing on the content of isothiocyanate and total sulforaphane in a ready-to-eat commercial Knorr® soup, which was separately enriched with two products; on the one hand, a powder obtained from lyophilized floretes and another containing lyophilized broccoli stems. Finding that the content of isothiocyanates and total sulforaphane was higher in both cases, with respect to the control, but was significantly higher in floretes (0.29 and 0.21 μmol/g of soup) with respect to the stems (0.09 and 0.11 μmol/g). On the other hand, it is recognized that the fibra contribution is higher in the latter, which implies that broccoli stems represent an attractive alternative in the formulation and development of new food products, since they are currently considered as a by-product of broccoli cultivation.

7. Conclusions

It is evident that broccoli and its extracts possess high functional properties for the benefit of human health, due to the presence of bioactive compounds (glucosinolates, sulforaphane, flavonoids, vitamin C, fibra etc.). The review presented on various broccoli research strongly suggests that, all factors within the vegetable supply chain, including the form of culinary preparation or industrial processing, will determine the content of phytochemical compounds and their bioavailability. Adding value to broccoli by-products by obtaining functional ingredients and bioactive nutrients could benefit the food and pharmaceutical industry, contributing to the prevention of chronic degenerative diseases. It is important for the scientific community to carry out confirmation of the effects of broccoli processing, as well as the dissemination of its nutritional quality to the population. Hopefully, in the near future the development and inclusion of functional foods will be available and accessible in supermarkets with established sections for the prevention of specific chronic diseases.

Acknowledgments

The authors would like to thank the Instituto Politécnico Nacional (IPN) and the Universidad Tecnológica de Tecamachalco (UTTECAM) for their support in carrying out the project. Also, the company Agroindustria de Brócoli Poblano (Agroibpsa S.A. de C.V.) gave support the author Cecilia Vázquez González for the realization of this work in the framework of the PhD Program in Productive Biotechnology of the Center for Applied Biotechnology Research (CIBA-IPN Tlaxcala).

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Hasler CM. Functional foods: Benefits, concerns and challenges—A position paper from the American Council on Science and Health. The Journal of Nutrition 2002; 132(12): 3772–3781. doi: 10.1093/jn/132.12.3772.
2. Keservani R, Kesharwani R, Vyas N, *et al*. Nutraceutical and functional food as future food: A review. Der Pharmacia Lettre 2010; 2(1): 106–116.
3. Alvarez-Jubete L, Valverde J, Kehoe K, *et al*. Development of a novel functional soup rich in bioactive sulforaphane using broccoli (*Brassica oleracea* L. ssp. *italica*) florets and by-products. Food Bio-

process Technology 2014; 7(5): 1310–1321. doi: 10.1007/s11947-013-1113-9.

4. Yeung A, Mocan A, Atanasov A. Let food be thy medicine and medicine be thy food: A bibliometric analysis of the most cited papers focusing on nutraceuticals and functional foods. Food Chemistry 2018; 269(15): 455–465. doi: 10.1016/j.foodchem.2018.06.139.
5. Tripathi YB, Tripathi P, Arjmandi B. 2005. Nutraceuticals and cancer management. Frontiers in Bioscience 2005; 10: 1607–1618. doi: 10.2741/1644.
6. Kalra EK. Nutraceutical-definition and introduction. AAPS Pharmaceutical Science 2003; 5(3): 27–28. doi: 10.1208/ps050325.
7. De Ancos B, Fernández-Jalao I, Sánchez-Moreno C. Functional compounds in IV and V range products. Revista Iberoamericana de Tecnología Postcosecha 2016; 16(1): 8–17.
8. Proestos C. Superfoods: Recent data on their role in the prevention of diseases. Current Research in Nutrition and Food Science Journal 2018; 6(3): 576–593. doi: 10.12944/CRNFSJ.6.3.02.
9. Filannino P, Bai Y, Di Cagno R, *et al*. Metabolism of phenolic compounds by *Lactobacillus spp.* during fermentation of cherry juice and broccoli puree. Food Microbiology 2015; 46: 272–279. doi: 10.1016/j.fm.2014.08.018.
10. Cai C, Miao H, Qian H, *et al*. Effects of industrial pre-freezing processing and freezing handling on glucosinolates and antioxidant attributes in broccoli florets. Food Chemistry 2016; 210: 451–456. doi: 10.1016/j.Godchem.2016.04.140.
11. Bhandari SR, Kwak JH, Jo JS, *et al*. Changes in phytochemical content and antioxidant activity during inflorescence development in broccoli. Chilean Journal of Agricultural Research 2019; 79(1): 36–47. doi: 10.4067/S0718-58392019000100036.
12. Berndtsson E. Dietary fibre and phenolic compounds in broccoli (*Brassica oleracea* Italica group) and kale (*Brassica oleracea* Sabellica group). A literature study about the potential uses of side streams. Alnarp: Sveriges lantbruksuniversitet; 2019.
13. Cronquist AL. An integrated system of classification of flowering plants. New York: Columbia University Press; 1981.
14. SIAP (Servicio de Información Agroalimentaria y Pesquera). El brócoli, casi un “Súper alimento” (Spanish) [Broccoli, almost a “Superfood”] [Internet]. 2020. Available from: https://www.gob.mx/siap/articulos/el-brocoli-casi-un-super-alimento.
15. Raiola A, Errico A, Petruk G, *et al*. 2017. Bioactive compounds in brassicaceae vegetables with a role in the prevention of chronic diseases. Molecules 2017; 23(1): 1–10. doi: 10.3390/molecules23010015.
16. Domínguez-Perles R, Martínez-Ballesta MC, Carvajal M, *et al*. Broccoli- derived by-products-a promising source of bioactive ingredients. Journal of Food Science 2010; 75(4): C383–C392. doi: 10.1111/j.1750-3841.2010.01606.x
17. Giletto C, Losada C, Cacace J. Brócoli envasado en polietileno de baja densidad y policloruro de vinilo (Spanish) [Broccoli packaged in low density polyethylene and polyvinyl chloride]. Revista Facultad de Agronomía 2001; 21(3): 191–198.
18. Lemoine M, Civello P, Chaves A, *et al*. Effect of combined treatment with hot air and UV-C on senescence and quality parameters of minimally processed broccoli (*Brassica oleracea* L. var. Italica). Postharvest Biology and Technology 2008; 48(1): 15–21. doi: 10.1016/j.postharvbio.2007.09.016.
19. Hernández P, Ayuso-Yuste M, González-Gómez D, *et al*. Behaviour of fresh cut broccoli under different modified atmosphere conditions. Emirates Journal of Food and Agriculture 2017; 29(3): 188–197. doi: 10.9755/ej&2016-07-907.
20. Dos Reis LC, de Oliveira VR, Hagen ME, *et al*. Effect of cooking on the concentration of bioactive compounds in broccoli (*Brassica oleracea* var. Avenger) and cauliflower (*Brassica oleracea* var. Alphina F1) grown in an organic system. Food Chemistry 2015; 172: 770–777. doi: 10.1016⁄j.foodchem.2014.09.124.
21. Stringer S, Plowman J, Peck MW. The microbiological quality of hot water-washed broccoli florets and cut green beans. Journal of Applied Microbiology 2007; 102(1): 41–50. doi: 10.1111/j.1365-2672.2006.03065.x.
22. Sánchez-Vega R, Garde-Cerdán T, Rodríguez-Roque MJ, *et al*. 2020. High-intensity pulsed electric fields or thermal treatment of broccoli juice: The effects of processing on minerals and free amino acids. European Food Research Technology 2020; 246: 539–548. doi: 10.1007/s00217-019-03420-y.
23. Kmiecik W, Slupski J, Lisiewska Z. Comparison of amino acid content and protein quality in raw broccoli and in broccoli after technological and culinary processing. Journal of Food Processing and Preservation 2010; 34(s2): 639–652. doi: 10.1111⁄j.1745-4549.2009.00422.x.
24. Krupa-Kozak U, Drabinska N, Rosell CM, *et al*. Broccoli leaf powder as an attractive by-product ingredient: Effect on batter behaviour, technological properties and sensory quality of gluten-free mini sponge cake. International Journal of Food Science and Technology 2019; 54: 1121–1129. doi: 10.1111/ijfs.13972
25. Chen Y-S, Liou M-S, Ji S-H, *et al*. Isolation and characterization of lactic acid bacteria from *Yan-tsai-shin* (fermented broccoli stems), a traditional fermented food in Taiwan. Journal of Applied Microbiology 2013; 115(1): 125–132. doi: 10.1111/jam.12199.
26. Cuomo V, Fernando BL, Meca G, *et al*. Bioaccessibility of glucoraphanin from broccoli using an *in vitro* gastrointestinal digestion model. CyTA–Journal of Food 2015; 13(3): 361–365. doi: 10.1080/19476337.2014.984337.

27. An S, Han JI, Kim MJ, *et al*. Ethanolic extracts of *Brassica campestris spp. rapa* roots prevent high-fat diet-induced obesity via beta(3)-adrenergic regulation of white adipocyte lipolytic activity. Journal of Medicinal Food 2010; 13(2): 406–414. doi: 10.1089/jmf.2009.1295.
28. Jeon SM, Kim JE, Shin SK, *et al*. Randomized double-blind placebo-controlled trial of powdered Brassica rapa ethanol extract on alteration of body composition and plasma lipid and adipocytokine profiles in overweight subjects. Journal Medicinal Food 2013; 16(2): 133–138. doi: 10.1089/jmf.2012.2249.
29. Shah MA, Sarker MMR, Gousuddin M. Antidiabetic potential of *Brassica oleracea* var. Italica in Type 2 diabetic Sprague dawley (sd) rats. International Journal Pharmacognosy and Phytochemical Research 2016; 8(3): 462–469.
30. Bueno-Solano C, Martinez D, Camacho-Gil F, *et al*. Contenido de sulforafano (1-isotiocianato-4-(metilsulfinil)-butano) en vegetales crucíferos (Spanish) [Sulforaphane (1-isothiocyanate-4-(methylsulfinyl)-butane) content in cruciferous vegetables]. Archivos Latinoamericanos de Nutrición 2009; 59(1).
31. Aires A, Carvalho R, Rosa E. Glucosinolate composition of brassica is affected by postharvest, food processing and myrosinase activity. Journal of Food Processing and Preservation 2012; 36(3): 214–224. doi: 10.1111/j.1745-4549.2011.00581.x.
32. Chuanphongpanich S, Phanichphant S, Bhuddasukh D, *et al*. Bioactive glucosinolates and antioxidant properties of broccoli seeds cultivated in Thailand. Songklanakarin Journal of Science and Technology 2006; 28(1): 55–61.
33. Fahey JW, Holtzclaw WD, Wehage SL, *et al*. Sulforaphane bioavailability from glucoraphanin-rich broccoli: Control by active endogenous myrosinase. PLoS One 2015; 10(11): e0140963. doi: 10.1371/journal.pone.0140963.
34. Alpuche-Solís A, Paredes-Lopez O. Assessment of glucosinolates in broccoli by three different methodologies. Journal of Food Biochemistry 1992; 16(5): 265–275. doi: 10.1111/j.1745-4514.1992.tb00451.x.
35. Abdull R, Ahmad F, Noor N. Cruciferous vegetables: Dietary phytochemicals for cancer prevention. Asian Pacific Journal of Cancer Prevention: APJCP 2013; 14(3): 1565–1570. doi: 10.7314/APJCP.2013.14.3.1565.
36. Bhandari SR, Jo JS, Lee JG. Comparison of glucosinolate profiles in different tissues of nine Brassica crops. Molecules 2015; 20(9): 15827–15841. doi: 10.3390/molecules200915827.
37. Alanís-Garza P, Becerra-Moreno A, Mora-Nieves J, *et al*. Effect of industrial freezing on the stability of chemopreventive compounds in broccoli. International Journal of Food Sciences and Nutrition 2015; 66(3): 1–7. doi: 10.3109/09637486.2015.1007451.
38. Mahn A, Pérez C. Optimization of an incubation step to maximize sulforaphane content in pre-processed broccoli. Journal of Food Science Technology 2016; 53(11): 4110–4115. doi: 10.1007/s13197-016-2386-6.
39. Mahn A, Pérez C, Reyes A. Effect of the drying conditions in a pulsed fluidized bed dryer on the sulforaphane content of broccoli. Información Tecnológica 2017; 28(4): 17–28. doi: 10.4067/S0718-07642017000400004.
40. Mahn A, Rubio M. Evolution of total polyphenols content and antioxidant activity in broccoli florets during Storage at Different Temperatures. Journal of Food Quality 2017; 1–9. doi: 10.1155/2017/3742183.
41. Abdullahi N. Critical review on principles and applications of hurdle technology in food preservation. Annals. Food Science and Technology 2016; 17: 485–491.
42. Alzamora S, Guerrero N, Nieto A, *et al*. Conservación de frutas y hortalizas mediante tecnologías combinadas. Manual de capacitación (Spanish) [Conservation of fruits and vegetables by combined technologies. Training manual]. Servicio de Tecnologías de Ingeniería Agrícola y Alimentaria (AGST). Dirección de Sistemas de Apoyo a la Agricultura (AGS); FAO; 2004.
43. Leistner L. Hurdle technology. In: Barbosa-Cánovas GV (editor). Food Engineering-Vol III. Encyclopedia of Life Support Systems. Oxford: EOLSS Publishers; 2009.
44. Rostami Z, Ahmad M, Khan M, *et al*. Food preservation by hurdle technology: A review of different hurdle and interaction with focus on foodstuffs. Journal of Pure and Applied Microbiology 2016; 10(4): 2633–2639. doi: 10.22207/JPAM.10.4.20.
45. Moreira M, Roura S, Ponce A. Effectiveness of chitosan edible coatings to improve microbiological and sensory quality of fresh cut broccoli. LWT–Food Science and Technology 2011; 44(10): 2335–2341. doi: 10.1016/j.lwt.2011.04.009.
46. Das B, Kim J. Microbial quality and safety of fresh-cut broccoli with different sanitizers and contact times. Journal of Microbiology and Biotechnology 2010; 20(2): 363–369. doi: 10.4014/jmb.0907.07009.
47. Ansorena M, Marcovich N, Roura S. Impact of edible coatings and mild heat shocks on quality of minimally processed broccoli (*Brassica oleracea* L.) during refrigerated storage. Postharvest Biology and Technology–Postharvest Biology Technology 2010; 59(1): 53–63. doi: 10.1016/j.postharvbio.2010.08.011.
48. Costa M, Vicente A, Civello P, *et al*. UV-C treatment delays postharvest senescence in broccoli florets. Postharvest Biology and Technology 2006; 39(2): 204–210. doi: 10.1016/j.postharvbio.2005.10.012.
49. Martínez-Hernández B, Artés-Hernández F, Gómez P, *et al*. Induced changes in bioactive compounds of kailan-hybrid broccoli after innovative processing and storage. Journal of Functional Foods 2013; 5(1):

133–143. doi: 10.1016/j.jfE2012.09.004.
50. Guo L,Yang R, Wang Z, *et al*. 2014. Glucoraphanin, sulforaphane and myrosinase activity in germinating broccoli sprouts as affected by growth temperature and plant organs. Journal of Functional Foods 2014; 9: 70–77. doi: 10.1016/j.jff.2014.04.015.
51. Lima GPP, Machado TM, Oliveira LM, *et al*. Ozonated water and chlorine effects on the antioxidant properties of organic and conventional broccoli during postharvest. Scientia Agricola 2014; 71(2): 151–156. doi: 10.1590/S0103-90162014000200010.
52. Xu F, Chen X, Jin P, *et al*. Effect of ethanol treatment on quality and antioxidant activity in postharvest broccoli florets. European Food Research Technology 2012; 235: 793–800. doi: 10.1007/s00217-012-1808-6.
53. Galgano F, Favati F, Caruso M, *et al*. The influence of processing and preservation on the retention of health-promoting compounds in broccoli. Journal of Food Science 2007; 72(2): S130–S135. doi: 10.1111/j.1750-3841.2006.00258.x.
54. Bourdichon R, Casaregola S, Farrokh C, *et al*. Food fermentations: Microorganisms with technological beneficial use. International Journal of Food Microbiology 2012; 154(3): 87–97. doi: 10.1016/j.ijfoodmicro.2011.12.030.
55. Manas RS, Marimuthu A, Ray RC, *et al*. Fermented fruits and vegetables of Asia: A potential source of probiotics. Biotechnology Research International 2014; 1–19. doi: 10.1155/2014/250424.
56. Campas-Baypoli ON, López-Cervantes J, Sánchez-Machado DI. Alternativas para el aprovechamiento de los residuos agrícolas de brócoli (Spanish) [Alternatives for the utilization of broccoli agricultural residues]. Revista La Sociedad Académica 2012; 39: 15–23.
57. Fuller Z, Louis P, Mihajlovski A, *et al*. Influence of cabbage processing methods and prebiotic manipulation of colonic microflora on glucosinolate breakdown in man. British Journal of Nutrition 2007; 98(2): 364–372. doi: 10.1017/S0007114507709091.
58. Campas-Baypoli ON, Sánchez-Machado DI, Bueno-Solano C, *et al*. Biochemical composition and physicochemical properties of broccoli flours. International Journal of Food Sciences and Nutrition 2009; 60(4): 163–173. doi: 10.1080/09637480802702015.