1 Economic and Academic Importance

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Abstract

Allium species have been cultivated for thousands of years for its therapeutic properties, religious significance, taste and aroma. Most of the cultivated crops evolved from wild relatives that grow in central Asia. Nowadays, *Alliums* are major vegetable crops cultivated worldwide. The most important crops of this family are onion, garlic, shallot, leek and Japanese bunching onions. Worldwide the consumption of these vegetable crops is increasing, one of the reasons is consumer awareness of the potential of these vegetables to enhance health, to improve welfare and reduce the risk of diseases. In this chapter, the economic importance of the principal edible *Alliums* is described, information is given about the academic contribution to the knowledge of *Allium* crops in recent years, and also future challenges are mentioned, especially those related to plant breeding, genetics and genomics, that will contribute to increase yields, quality and to have a more sustainable production.

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1.1 *Allium* Economic Importance

Allium vegetables are the fourth most abundant group of commercially produced nonleguminous vegetables after potatoes, cassava and tomatoes according to FAO (2017) statistics. Onion, garlic, Japanese bunching onion, shallot and leek are the most crucial edible *Allium* crops. Nevertheless, over 20 other *Allium* species have been consumed by humans (van der Meer 1997). There are also *Allium* species used for ornamental purposes, such as *Allium aflatunense*. Seed production of *Allium* crops is also an important economic activity. *Allium* vegetables gross production value for 2014 was US$61,348 million (FAO 2017); about 70% of this value is for dry onion bulbs, 25% for garlic, 4% for green onions and shallots and 1% for leeks. The production of *Allium* crops, especially garlic and onion shows an important increase since 2000, in great part, this fact is explained by an increase in *per capita* consumption, one of the reasons may be that consumers are aware of the potential of these vegetables to enhance health and prevent chronic diseases.

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1.2 Onion (*Allium cepa* L.)

Onion is the most important *Allium* vegetable crop. Nearly 88 million tons per annum are worldwide produced (Table 1.1). Bulb onions are produced in different latitudes, from subarctic regions to regions close to the equator, although they are best adapted to production in temperate and subtropical areas (Brewster 2008). Onion gross production value for 2014 was US $42,743 million (FAO 2017). Due to the storage and transport facility of the crop, there is a significant international trade; about 20 million tons are traded annually (FAO 2017). Due to this global trade, and because of the many techniques for growing and storing onions for sale year-round, bulb onions are available throughout the year in most countries. The use of onion F_1 hybrids is increasing worldwide; this tendency reaches different kinds of onion germplasm, such as Granex, long-day storage and Spanish onions.

The leading producers are China (20,507,759 tons), followed by India (around 13,000,000 tons), United States of America, Egypt, Iran, Turkey, Pakistan, Brazil, Russia and Republic of Korea (Data for 2014, FAO 2017).

The leading exporters include The Netherlands, China, Mexico, India, USA, Egypt, Spain, New Zealand and Argentina. The main importers are USA, United Kingdom, Malaysia, Germany, Saudi Arabia, Japan, Canada, Czech Republic, Republic of Korea and Brazil. As an example, The Netherlands produces large quantities of long-storing, spring-sown, pungent onions which are exported between September and April, mainly to Germany and UK. In a Mediterranean country, like Spain, crops are planted in autumn and harvested during spring and summer. In large countries, like the USA, the market is supplied year-round with onions from different regions within the country and from bulbs that come from Mexico or countries from the Southern Hemisphere. The main producing areas are Idaho-eastern Oregon, California, Washington, Georgia and Texas. Countries of the Southern Hemisphere like Australia, New Zealand, Argentina and Chile have an essential export market in Europe, especially Germany and UK, and also their production is sold in Asian countries, like Japan and Malaysia, and even in USA and Canada. In the case of South America, Argentina is a vital onion exporter to Brazil (Galmarini 2001).

Onion prices tend to fluctuate widely from year to year making onion production a risky business. Since there is a global market in onion bulbs, there is little that producers in any one region can do to control the market and stabilize prices. One strategy is to add value to the production or produce particular products. An example of the latter is the sweet onion market. The production of this type of onions is very well developed in the United States, especially in Georgia and Texas. Moreover, in countries like Peru and Chile, sweet onions are produced to export to the United States market from January to May.

About 1% of the world onion cropped area is produced for the dehydration industry; nevertheless, this is an essential activity for

Table 1.1 World onion cultivated area, production, yield and consumption from 1970 to 2014

Year	Area (ha)	Production (tons)	Yield (kg/ha)	Consumption (kg/capita/year)
1970	1,334,693	16,748,643	12,549	4.15
1980	1,616,802	22,400,015	13,854	4.63
1990	1,885,700	30,609,791	16,228	5.29
2000	2,838,022	49,966,784	17,606	7.46
2010	4,174,459	78,984,889	18,921	10.53
2014	5,298,873	88,475,089	16,679	10.97

Source FAOSTAT (2017)

diversification. The production is concentrated in China, USA, India and Mexico in the Northern Hemisphere and in Argentina in the Southern Hemisphere. The industry uses cultivars that have high solids and pungent white bulbs.

Onion dry bulb production has increased through the years, mainly due to an increase in yields and the cropped area. The world average yield is about 16 t ha^{-1}. Nevertheless, there are growers that harvest more than 100 tons per hectare, due to good growing conditions, irrigation and excellent agronomic practices.

Since 1970, onion consumption has increased almost three times (Table 1.1). The average consumption is around 10 kg/capita/year, nevertheless in countries like Greece, Albania, Iran, Kuwait, Uzbekistan, and yearly onion consumption per capita is over 20 kg (FAO 2017). One reason for consumption increase may be the health-benefits that this vegetable brings to humans. The beneficial health-effects attributed to onions are essential for consumers and breeders (Galmarini 2010). Onion consumption has been associated with decreased cardiovascular events, because of their hypocholesterolemic, hypolipidemic, anti-hypertensive, antidiabetic, antithrombotic and anti-hyperhomocysteinemia effects, as well as with many other biological activities including antimicrobial, antioxidant, anticarcinogenic, antimutagenic, antiasthmatic, immunomodulatory and prebiotic activity (Corzo-Martinez et al. 2007). Garlic and onion have phytochemicals categorized as functional foods; some of them are fructans, flavonoids and organo-sulphur compounds (Galmarini et al. 2001).

Onion seed market is also important, around 50,000 tons are yearly produced (FAO 2017). Onion represents an important percentage of the total vegetable seed economic value commercialized in the world. Onion seed production is performed both in the Northern and Southern hemispheres. The main producing countries are the USA, The Netherlands, Japan, Turkey, China, Spain, Italy, France, Australia, Chile, Argentina and South Africa.

1.3 Garlic (*Allium sativum* L.)

Garlic is the second most widely cultivated *Allium* with a current worldwide production of 24.9 million tons per annum, cultivated in 1.5 million hectares (FAO 2017). Garlic gross production value for 2014 was US$15,129 million (FAO 2017). Since 1970, world garlic production has increased more than 10 times, while cultivated area increased around four times, indicating an increment in yield (Table 1.2). In addition to fresh consumption, the production of dried and processed garlic products for use in the food industry and as dietary health food supplements is an important activity.

Garlic is mainly grown in temperate areas. The garlic bulb is well adapted to storage and transportation, and there is an important international trade. The main producing and exporting country is China, which produces around 80% of the total world production. Garlic output in China exceeded the figures recorded by the world's second-largest producer, India, more than tenfold. Other important producers are South Korea, Egypt, Russia, Myanmar, Spain, USA, Uzbekistan, Argentina and Brazil. The leading exporters are China, Spain, and Argentina, while the leading importers are Indonesia, Brazil, Vietnam, Syria, USA, Pakistan, Russia, Germany, Italy and France (FAO 2017). China dominates the fresh and dehydrated garlic international market, being the leading exporter.

According to FAO (2017), the world average yield is about 16 t ha^{-1} of dry garlic; although there are countries with an average yield over 30 t ha^{-1}, due to good growing conditions, irrigation and excellent agronomic practices. Although garlic production history shows a steady increase during the past 45 years, the most dramatic increase in total production and yield has been observed in the past 15 years; the increase in yields of garlic produced in China is in great part responsible of this change.

Regarding consumption, in some countries like the Republic of Korea 10 kg/capita/year

Table 1.2 World garlic cultivated area, production and yield from 1970 to 2014

Year	Area (ha)	Production (tons)	Yield (kg/ha)
1970	416,385	2,854,876	6856
1980	619,410	4,251,797	6864
1990	811,519	6,463,996	7965
2000	1,082,515	11,086,692	10,241
2010	1,336,544	22,557,355	16,877
2014	1,547,381	24,939,965	16,117

Source FAOSTAT (2017)

have been reported. In the USA, the consumption is around one kg/capita/year. Garlic consumption rose from 1.6 kg/capita/year to almost 3 kg/capita/year, in the last decades (Cavagnaro and Galmarini 2007); one of the reasons, as was mentioned for onion, is the consumer awareness of health benefits associated with garlic intake (Gonzalez et al. 2009). Different types of garlic, hard neck, soft neck, Asian, Mediterranean or Russian types are grown and consumed around the world (Burba 2013a, b). Growers and consumers' preferences vary with geographic region, cultural background and end-use. Although fresh intact bulbs are the usual form of garlic traded in commerce, fresh garlic preparations (e.g. chopped, sliced or minced), as well as dehydrated forms of condiments, are common in several countries. In parts of Asia and North Africa, garlic leaves are marketed. Garlic preparations for the nutraceutical industry are also necessary (Cavagnaro and Galmarini 2007).

1.4 Shallot (*Allium cepa* L. Aggregatum Group)

Shallots are of much less economic importance than onion and garlic. Shallot gross production value for 2014 was US$2505 million (FAO 2017). The worldwide production is about 4 million tons in about 200 thousand hectares (Table 1.3). This production can be overestimated since FAO statistics add to shallots other *Alliums*. Shallots are mainly produced by small-scale growers. There are noticeable differences between shallots in many countries. Some differences are linked to traditions or local customs. In Asia, shallots are predominantly small and round with a deep red colour, while in France, Europe's major shallot producer prefers shallots that are more elongated and reddish brown in colour. In the Netherlands and Belgium, yellow-skinned shallots used to be very common, but they are almost only grown by hobby gardeners and on allotments (Brewster 2008).

The major production regions are France, The Netherlands, the United States, New Zealand and Great Britain for the so-called "long day varieties". These varieties grow slower and firmer, and therefore can be stored for longer. They are available all year-round.

Other important production regions can be found in South East Asia and Africa. China, Taiwan, Korea, Indonesia, Thailand, Turkey, Tunisia and Nigeria are important shallot producers. In America, the production is important in Mexico and Ecuador. These are tropical cultivars that grow with fewer hours of daylight and humid environments, and also have pest and disease resistance to grow in those environments (Brewster 2008).

1.5 Leek (*Allium ampeloprasum* L.)

This vegetable, unlike an onion, is indifferent to day-length, and the same genotype can be grown and produce economic yield over a wide range of latitudes (De Clercq and Van Bockstaele 2002). Leeks are well adapted to cool conditions and are harvested through the winter in Western Europe. Leek gross production value for 2014 was US$971 million (FAO 2017). Worldwide

Table 1.3 World shallots cultivated area, production and yield from 1970 to 2014

Year	Area (ha)	Production (tons)	Yield (kg/ha)
1970	103,783	1,329,878	12,814
1980	125,642	1,924,840	15,320
1990	162,870	2,509,379	15,407
2000	193,808	3,359,098	17,332
2010	230,052	4,129,546	17,950
2014	219,367	4,165,600	18,989

Source FAOSTAT (2017)

Table 1.4 World leek and other *Alliums* cultivated area, production and yield from 1970 to 2014

Year	Area (ha)	Production (tons)	Yield (kg/ha)
1970	61,205	835,974	13,658
1980	57,425	741,939	12,920
1990	81,708	1,499,235	18,349
2000	99,748	1,625,155	16,293
2010	130,202	2,122,492	16,302
2014	133,433	2,236,771	16,763

Source FAOSTAT (2017)

production is around 2 million tons in about 130,000 ha (Table 1.4); nevertheless, this production can be overestimated because FAO statistics add to leek other alliums.

The main producers are Indonesia, Turkey, Belgium, France, China, Republic of Korea, Poland and Germany. It is an important crop in Europe were about 30,000 ha are grown. France is an important European Community (EC) producer with nearly 9 thousand ha yielding about 200,000 tons. The average yield is 16.7 t ha^{-1} (Table 1.4). The monetary value of the crop is quite high due to the high price per unit weight.

1.6 Japanese Bunching Onion (*Allium fistulosum* L.)

The production of this vegetable is important in East Asia. The annual production of Japanese bunching onion in Japan is about 500,000 tons in a cultivated area of 23,000 ha, in South Korea, there is around 27,000 ha that produced around 723,000 tons, and in China, 545,000 ha produce 20,754,000 tons (Park 2012). The main production areas are distributed in the southern part of Japan, South Korea and China. In South America, Colombia has a considerable production of Japanese bunching onion for domestic consumption.

Data on annual consumption per person shows a marked difference in the consumption of Japanese bunching onion; in Korea 6.6 kg/capita/year are consumed, in Japan 1.7 kg/capita/year and in China 5.1 kg/capita/year (Park 2012).

1.7 Other Minor Edible Alliums

Rakkyo (*Allium chinense* G. Don) and Chinese chives (*Allium tuberosum* Rottl.) are also crops of commercial importance in East Asia. Annual Japanese production of rakkyo is about 30,000 tons; a high proportion of this production is used for pickles. The annual Chinese chive production is about 66,000 tons (Brewster 2008).

Chives (*Allium schoenoprasum* L.) are widely grown by small farmers for use as a flavouring herb. The total world area of commercial production is about 1000 ha with large areas in Denmark, New Zealand and Germany (Brewster 2008).

1.8 *Allium* Academics

Since the publication of the book Onions and their Allies in 1963 by Jones and Mann (1963), there has been great advances in scientific and agronomical knowledge of *Alliums*. The book of Jones and Mann contributed to agronomical, physiological and breeding of Alliums. In 1985, Fenwick and Hanley (1985), published a review focused on food science aspects and uses of *Allium* crops. Five years later Rabinowitch and Brewster (1990a, b, c) edited a three-volume book, Onions and Allied Crops. This book provided a very good review of aspects such as: genetic resources, anatomy, pollination biology, sulfur biochemistry, medicinal values and physiology, among others, of Allium crops. A great contribution to summarize *Allium* knowledge was James Brewster´s book Onions and other Vegetable Alliums published in 1994 and updated in 2008. Dr. Brewster, passed away in 2015, the *Allium* community should recognize his contribution to *Allium* science, not only for his book, which is a reference book for students and agronomist all over the world and has been translated to several languages, but also for his studies about onion physiology. Although Dr. Brewster is usually thought of like an onion physiologist, his passion for knowledge extended into the genetics and breeding of the onion crops. His book relates the production and utilization of *Allium* crops to many aspects of plant science underpinning their production and storage technologies. It covers species and crop types, plant structure, genetics and breeding, physiology of growth and development as well as pests and diseases, production agronomy, storage after harvest and the biochemistry of flavour, storage carbohydrates and colour and how this relates to nutritional and health benefits. It provides many examples where scientific knowledge helps to explain and improve agronomic practice. This book is still the standard reference work for many people. In 2002, the book *Allium* Crop Science: Recent Advances, edited by Rabinowitch and Currah (2002) made a great contribution to review the advances occurred since the publication of Onions and Allied Crops in 1990. Aspects such as genome organization, exploitation of wild and cultivated relatives for breeding purposes, fertility and seed production of garlic; genetic transformation of onions; molecular markers in *Alliums*; detection of garlic viruses and the propagation of virus-free crops; bacterial and fungal diseases of the Alliums; strategies of integrated pest management, among other aspects were covered.

Another important contribution was the review regarding genome mapping and molecular breeding made by Cavagnaro and Galmarini for garlic and McCallum for onion in 2007 in the book Genome Mapping and Molecular Breeding in Plants edited by Kole.

For garlic research advances, there is a comprehensive review in Spanish, edited by Burba (2013a, b) in a five-volume book where aspects of garlic crop situation, cultivars and seed production, agronomy and post harvest are summarized.

Important contributions to divulge academic and agronomic advances of *Allium* Science are the Symposia organized by Edible Alliaceae Working Group, established in 1994 by the International Society for Horticultural Sciences (ISHS). The Proceedings of these Symposia, published in Acta Horticulturae, provide a good coverage not only of scientific and agronomic advances but also economic and marketing information about edible *Allium* crops (Amstrong 2001; Burba and Galmarini 1997; Gokce 2016; Guangshu 2005; Wako and Shigyo, 2012). The first Symposium was hosted in Mendoza (Argentina) in 1994, and then were hosted at Adelaide (Australia) in 1997, Athens (United States) in 2000, Beijing (China) 2004, Dronten (The Netherlands) in 2007, Fukuoka (Japan) in 2012, and the last one took place at Nigde (Turkey) in 2015. The Symposia have allowed opportunities for international scientists, growers, seed companies, among others, to meet and discuss the present and future developments of Edible *Allium* crops. Important items like Molecular Breeding and Genomics, Growth Physiology, Cultivation Techniques, Storage and Processing, Pest and Diseases, Secondary Metabolites and Phytochemicals and Genetic Resources are discussed in these Symposia.

A brief analysis of the contributions made in the last four Symposia indicates that 55% deal with onion, 30% with garlic, 3% are related to leek and 12% to other *Alliums*. These results suggested that there are few groups working with leek, shallot and other minor *Allium* crops and that most of the research is concentrated in onion and garlic. A disciplinary analysis indicates that 24% of the contributions are related to genetic and plant breeding, 22% to plant physiology, 21% to agronomy aspects of *Allium* crops, 15% to plant protection, 12% to genetic resources and 6% of the contributions are related to crop situation and economical value. This disciplinary analysis indicates a relatively balanced situation among the different approaches.

In recent years, there has been an outstanding contribution to *Allium* knowledge. Perhaps the field where more advances has been produced is Genetics, Genomics and Breeding. Important research groups like Dr. Mike Havey's group at the University of Wisconsin-Madison, Dr. Chris Kik's group at Wageningen, Dr. John McCallum in New Zealand, Dr. Masayoshi Shigyo at Yamaguchi University in Japan, Dr. Ludmila Khrustaleva, from the University of Moscow, Dr. Colin Eady in New Zealand, Dr. Borut Bohanec in Slovenia, among others, have made relevant contributions.

In onion physiology it was already mentioned the contribution of Dr. J. Brewster. Dr. Brian Thomas group at the University of Warwick (UK) has contributed to understand the physiology and genetic control bulbing in *Allium* species in response to day-length. Regarding garlic physiology, genetics and agronomy outstanding contributions were made by Dr. C. Messiaen from France, Dr. José Luis Burba, from Argentina, Dr. Takeomi Etoh from Japan, Dr. P. Simon from USA, and Dr. Rina Kamenetsky from the Volcani Center of Israel, among others.

Dr. Olga Scholten from Wageningen has contributed to study genetic aspects of *Allium* diseases. Also, the work of Dr. Astley in the UK and Dr. Keller in Germany has been very important to the conservation and characterization of *Allium* genetic resources.

All the recent advances have contributed to an increase not only the knowledge, but also yields and to have a more sustainable production.

1.9 Lessons Learnt and Challenges for the Future

Although recent advances, especially in plant breeding and genetics, have contributed to increase yields and also to have a more sustainable production; the demand for high-quality *Allium* vegetables will continue to increase in the future. Vegetable production will be done using less agrochemical products, so a great effort should be made to introduce resistance to pests and diseases into *Allium* crops, especially important are resistance against soil-borne pathogens and nematodes. Water will be used less wastefully, not only its quantity but also its quality (e.g. salinity) will be important; so the introduction of resistances to abiotic stress should be a priority. The production of *Allium* cultivars with better health-benefits will also be required by consumers. Perhaps, higher garlic productivity and quality will come from work on fertile garlics (Etoh and Simon 2002; Simon and Jenderek 2003). In addition, the market for oriental vegetables, such as Chinese chives, blanched Japanese bunching onions is likely to increase. More efforts should be made to study the so-called "minor edible *Allium* crops".

Breeding strategies will need a multidisciplinary approach to solve *Allium* production problems in the coming years. A team where breeders work together with agronomists, geneticists, molecular biologists, physicians, plant pathologists, biochemists, nutritionists and food science experts will be required. This strategy will contribute to increasing competitiveness of *Allium* agro-industrial chain, to diversify varietal offer to access new markets, increase consumption and also to adopt production strategies that allow better yields, quality and sustainability. In the near future, genetics will have a very important role in the economic value of *Allium* crops incorporating biotechnology tools to plant breeding, such as: haploidy using gynogenesis, molecular markers and *Allium* transformation (Eady 2001). The generated knowledge will help for example to establish integrate control systems toward the management of soil-borne diseases. This teamwork will require a very good communication with growers and industry.

A big challenge is to incorporate in a practical way basic genetic and genomic knowledge to breeding programs. *Allium* species are notable for their very large genomes, typically in the range 10–20 Gbp (Ricroch et al. 2005), which have complicated genomic studies and precluded genome sequencing to date. Genetic map development in onion and other *Allium* has been limited by difficulty in developing, maintaining and exchanging genetic stocks, high degrees of heterozygosity and a dearth of sequence data (McCallum 2007).

Comparative genomic approaches have been widely used and proven in crop genetics, and are of growing interest as improved sequencing technologies enable ever broader and more detailed surveys of germplasm. Online databases integrating genetic map, marker, sequence and germplasm are now key tools for exploiting such data. Due to *Allium* economic significance, there is a clear and pressing need for such resources.

Despite the rapid advances in sequencing technologies, the enormous size of *Allium* nuclear genomes will preclude full sequencing in the short term. As large-scale DNA sequencing technologies become more efficient and less costly, the genomic DNAs of more and more plants are being sequenced, assembled and annotated. These complete sequences are extremely valuable for the identification of specific genes associated with important phenotypes. In the case of onion, I certainly agree with Havey (2016), who proposed an efficient strategy for an international effort to sequence the onion nuclear DNA and provide the sequences and annotations on a freely accessible website. Deep transcriptome sequencing is already underway. Reduced representation approaches can be used to select against repetitive DNAs and enrich for more unique regions of the onion genome. These genomic reads can be aligned against expressed sequences of the transcriptome to identify promoter and intronic regions. Dr. Havey suggests that the international community should select and focus on one doubled haploid line as the common reference material for collaborative sequencing efforts. A publically accessible website should provide unrestricted access to the sequence and annotations. These resources will enable translational genomics of onion by providing researchers with tools to more efficiently select for important traits in onion improvement.

References

Amstrong J (ed) (2001) Proceedings of the second international symposium on edible *Alliaceae*, Adelaide, South Australia, 10–13 November 1997. Acta Horticulturae 555, 304 p

Brewster JL (2008) Onions and other vegetable Alliums, 2nd edn. CAB International, Wallingford, UK, p 454

Burba JL (2013a) Grupos Ecofisiológicos (GE), de ajos en Argentina y su equivalencia internacional. In 100 temas sobre producción de ajo. Mejoramiento genético y producción de semillas de ajo. Ediciones INTA, La Consulta, Mendoza, Argentina, vol 2, pp 8–16

Burba JL (ed) (2013b) 100 temas sobre producción de ajo. Ediciones INTA, La Consulta, Mendoza, Argentina, vol 1–5, 500 p

Burba JL, Galmarini CR (eds) (1997) Proceedings of the first international symposium on edible Alliaceae, Mendoza, South Argentina, 14–18 March 1994. Acta Horticulturae 433, 652 p

Cavagnaro PF, Galmarini CR (2007) Garlic. In: Kole, C (ed) Genome mapping and molecular breeding in plants, vegetables, vol 5. Springer, Berlin, 375, pp 349–365

Corzo-Martinez M, Corzo N, Villamiel M (2007) Biological properties of onions and garlic. Trends Food Sci Technol 18:609–625

De Clercq H, Van Bockstaele E (2002) Leek: advances in agronomy and breeding. In: Rabinowitch HD, Currah L (eds) *Allium* crop science: recent advances. CABI Publishing, New York, USA, pp 431–458

Eady CC (2001) *Allium* transformation. In: Learmonth R, Khachatourians GG (eds) The handbook of transgenic plants. Marcel Dekker, New York, pp 655–671

Etoh T, Simon P (2002) Diversity, fertility and seed production of garlic. In: Rabinowitch HD, Currah L (eds) *Allium* crop science: recent advances. CABI Publishing, New York, USA, pp 101–107

FAO. 2017. FAOSTAT. http://www.fao.org/faostat/en/#data

Fenwick GR, Hanley AB (1985) The genus *Allium*, part 1. CRC Crit Rev Food Sci Nutr 22:199–271

Galmarini CR (2001) Onion Crop Situation in the Mercosur. Acta Hort 555:269–274

Galmarini CR, Havey MJ, Goldman IL (2001) Genetic analyses of correlated solids, flavor, and health related traits in onion (*Allium cepa* L.). Mol Genet Genomics 265:543–551

Galmarini CR (2010) Mejoramiento de hortalizas para incrementar sus propiedades funcionales. Horticultura Brasileira 28(2):S32–S38

Gokce AF (ed) (2016) Proceedings of the VII international symposium on edible Alliaceae, Nidge, Turkey, May 2015. Acta Horticulturae 1143, 352 p

Gonzalez R, Soto V, Sance M, Camargo A, Galmarini CR (2009) Variability of solids, organosulfur compounds, pungency and health-enhancing traits in garlic (*Allium sativum* L.) cultivars belonging to different ecophysiological groups. J Agric Food Chem 57:10282–10288

Guangshu L (ed) (2005) Proceedings of the IV international symposium on edible Alliaceae, Beijing, China, April 2004. Acta Horticulturae 688, 370 p

Havey MJ (2016) Lessons from 25 years of genetic mapping in onion, where next? Acta Hort 1143:1–6

Jones HA, Mann LK (1963) Onions and their allies. InterScience, New York, p 286

McCallum J (2007) Onion. In: Kole C (ed) Genome mapping and molecular breeding in plants, vegetables, vol 5. Springer, Berlin, 375 pp 331–347

Park H (2012) Food system of *Allium* vegetables in east Asia. Acta Hort 969:23–40

Rabinowitch HD, Brewster JL (eds) (1990a) Onions and allied crops, I: botany, physiology and genetics. CRC Press, Boca Raton, Florida, p 273

Rabinowitch HD, Brewster JL (eds) (1990b) Onions and allied crops, II: agronomy, biotic interactions, pathology and crop protection. CRC Press, Boca Raton, Florida, p 320

Rabinowitch HD, Brewster JL (eds) (1990c) Onions and allied crops, III: biochemistry, food science and minor crops. CRC Press, Boca Raton, Florida, p 265

Rabinowitch HD, Currah L (eds) (2002) *Allium* crop science: recent advances. CABI Publishing, New York, USA, p 515

Ricroch A, Yockteng R, Brown S, Nadot S (2005) Evolution of genome size across some cultivated *Allium* species. Genome 48:511–520

Simon PW, Jenderek MM (2003) Flowering seed production and the genesis of garlic breeding. In: Janick J (ed) Plant breeding reviews, vol 23. Wiley, New York, pp 211–244

Van Der Meer QP (1997) Old and new crops within edible *Alliums*. Acta Hort 433:17–31

Wako T, Shigyo M (eds) (2012) Proceedings of the VI international symposium on edible Alliaceae, Fukuoka, Japan, May 2012. Acta Horticulturae 969, 327 p