Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

BRASSICAS AS A ROTATION CROP. POTENTIAL AND PERSPECTIVES

Eric PRENDES-RODRÍGUEZ[1], Ana FITA[1], Carla GUIJARRO-REAL[1], Caridad ROS IBAÑEZ[2]

[1]Instituto de Conservación y Mejora de la Agrodiversidad Valenciana, Universitat Politècnica de València, Camino de Vera, s/n 46022 Valencia, Spain
[2]Instituto Murciano de Investigación y Desarrollo Agrario y Ambiental, C/Mayor, s/n. 30150 La Alberca (Murcia), Spain

Corresponding author email: ejprerod@posgrado.upv.es

Abstract

Crop rotation has been one of the approaches that has most improved the efficiency of farming systems around the world as it has the potential to improve soil conditions and increase the productivity of the system. Brassica spp. and related plants have received attention in recent years for its potential use as a rotation crop due to their ability to control soilborne pathogens. The production of sulphur compounds called glucosinolates is the main, although not the only, mechanism behind the reduction of soil pathogens by Brassica spp. These compounds break down to produce isothiocyanates that are toxic to many organisms in the soil, in a process known as biofumigation. In this review, the typical characteristics of Brassica spp. which makes them a valuable option as a rotational crop are discussed, as well as examples and the perspective of its use for this purpose.

Key words: *biofumigation, Brassicas, crop rotation, glucosinolates.*

INTRODUCTION

One of the main challenges of agriculture nowadays is meeting the ever-increasing food demand and coping with the immense pressure on crop production due to the ever-rising population and changes in the climate (Abegunde, Sibanda, & Obi, 2019; Fahad et al., 2017; Gliessman, 2020; Qi et al., 2018). Maintaining soil health is a critical step to increase agricultural efficiency (Lehmann, Bossio, Kögel-Knabner, & Rillig, 2020), and in recent years there has been a growing concern over certain practices that accelerate soil erosion and nutrients depletion (Kopittke, Menzies, Wang, McKenna, & Lombi, 2019). Some calculations state that 60% of soil depletion since the 1950s is due to farming practices and other anthropogenic causes (Novotny, 1999; Uğuz et al., 2020). The role of agricultural researchers in this setting is to transform scientific knowledge into techniques that tackle the previously mentioned issues and at the same time increase farmer's understanding of the viability of their farming activities (He, Zhang, Wang, Zeng, & Zhang, 2018).

Crop rotation is one of such techniques, and it makes up one of the main approaches for sustainable farm managing that also helps to keep the soil's health. The effect of crop rotation is to disrupt the soil pathogen's life cycle and to restore the nutrients when certain plant species are introduced in the rotation scheme, which also causes agricultural systems to be less dependent on fertilizers and biocides (Costa et al., 2020). Another advantage of crop rotation is that this technique is compatible with organic agriculture and has become a cornerstone of it (Uğuz et al., 2020).

However, since worldwide agriculture has many production variables, market swings and a wide variety of levels of awareness amongst farmers, the mechanisms for diffusing, adapting, and making crop rotation adoption profitable are many, and this have been a barrier for agricultural practices (Shah et al., 2021).

In the other hand, Brassicas, whose two of their main exponents are Broccoli and Cauliflower, are traditional European crops that have become widespread in Asia in recent decades while their presence in Europe has been quite stable (Branca, 2007) The interest in these two crops has grown in recent years partly due to all the genetic improvement programs and the new opportunities offered by the food industry. The many healthy metabolites found on several

Brassicas allow them to be defined as functional foods and are also a factor towards the increase of its consumption (Dominguez-Perles et al., 2011; Favela-González, Hernández-Almanza, & De la Fuente-Salcido, 2020; Reda et al., 2021). This abundance of metabolites is strongly related also with some of the properties that make brassica crops, alongside their economic value, an interesting possibility when considering crop rotation. In this work we review the current knowledge of the characteristics that make *Brassicas* suitable crops for rotation, as well as several recent research endeavours aimed at the understanding of its potential in this sense and examples of its use.

BRASSICAS MAIN PHYTOCHEMICALS

Brassicaceae represents a very diverse and important family of plants which contains more than 300 genera and over 3000 species (Branca, 2007). This plant provides not only nutrients but also many heterogeneous chemical compounds (Table 1) that are adapted to a variety of functions and that are also considered as beneficial to human well-being and health (Favela-González et al., 2020)
Of all this compounds, glucosinolates are probably the most interesting ones for the purpose of crop rotation since it has been described that when released to the rhizosphere, they have biocidal effects on other organisms including plants, nematodes, insects, and fungi.

Glucosinolates

Previously called thioglucosides, this are water-soluble anions present in at least sixteen families of dicotyledonous angiosperms including many edible species. They are N-hydroxy sulfates with a sulfur-bound b-d-glucopyranose/b-thioglucose moiety and a sulfonated oxime, differing from a side chain derived from one of the amino acids, whichconstitutes the basis for their classification (Sikorska-Zimny & Beneduce, 2021), that is conformed by three main groups:

- Aliphatic group, from Met, Ala, Leu, Ile and Val
- Indolic group, from Trp
- Aromatic group, from Phe and Tyr

This is not the only classification for this compound, being an alternative system the one proposed by Romeo, Iori, Rollin, Bramanti & Mazzon (2018).

Table 1. Main bioactive compounds present in Brassica plants. From Favela-González et al. (2020)

Phytochemical class	Major constituent	Constituent types
Glucosinolates (β-thioglucoside-N-hydroxysulfates)	(β-thioglucoside-N-hydroxysulfates) Water soluble organic anions share a basic structure	**Aliphatic** Dehydroerucin, Epiprogoitrin Glucoalyssin, Glucoerucin, Glucobrassicanapin, Glucoiberin, Glucocapparin, Glucoerysolin, Glucohirsutin, Glucoibervirin, Glucolepidin, Gluconapin, Gluconapoleiferin, Glucoraphanin, Glucoputranjivin Glucoraphenin, Glucorerysolin Glucosiberin, Progoitrin, Sinigrin **Indolic** 4-Hydroxyglucobrassicin, Neoglucobrassicin 4-Methoxyglucobrassicin, Glucobrassicin, **Aromatic** Glucobarberin, Gluconasturtiin, Glucosibarin, Glucosinalbin, Glucotropaeolin
Phenoles	Hydroxycinnamic acids, Flavonoids, Anthocyanins	Caffeic, ferulic, sinapic and p-coumaric acids, Flavonols with quercetin, kaempferol and isorhamnetin Cyanidin-3-sophoroside-5-glucoside
Tocopherol (vitamin E) and carotenoids	α- δ- and γ-tocopherols α- carotenoids with lutein, β- carotene	Precursors of vitamin A (2S)-2,5,7,8-tetramethyl-2-[(4S,8S)-4,8,12-trimethyltridecyl]-3,4-dihydro-2H-chromen-6-ol

In *Brassica* species glucosinolates are accumulated in intact plants but are released when the plant is injured. At this point, the enzyme myrosinase (β-thioglucosidase glucohydrolase, E.C.3.2.3.1) hydrolyses the glucosinolates and this reaction yields breakdown produces like isothiocyanates, nitriles, thiocyanates, epithionitriles, and oxazolidinethiones (Cartea & Velasco, 2008; Favela-González et al., 2020).

The ability of both glucosinolates and glucosinolates hydrolysis products (GHPs) for having a positive effect in reducing soil pathogens is well documented (Agrawal & Kurashige, 2003; J.w, A.t, & P, 2001; Rahmanpour, Backhouse, & Nonhebel, 2009; Sotelo, Lema, Soengas, Cartea, & Velasco, 2015) and different authors have tested this hypothesis in both soil and *in vitro* assays. Bending & Lincoln (2000) was one of the first attempts to properly investigate the toxic effect of GHPs in soilborne pathogens, resulting in a limitation of the growth of bacteria, fungus, and nematodes. Other research like Lazzeri & Manici (2001) and Motisi, Montfort, Doré, Romillac, & Lucas (2009) have corroborated this and also have shown differences in the effect strength and duration depending in the specific compound. In Aires et al. (2009) and Sotelo et al. (2015) the in vitro effect of glucosinolates and GHPs on six plant pathogenic bacteria and two pathogenic bacteria and two fungi respectively was evaluated, showing that both glucosinolates and its hydrolysis produces coming from *Brassica* extracts can have the potential to be used in biofumigation for the control of multiple diseases.

In addition glucosinolates and their by-products are also widely recognized as defensive compounds against herbivores and are likely to be involved in the defence against insects and other plagues (Rask et al., 2000) but at the same time evidence also suggest that in some cases this compounds might act also as feeding cues for some insects, which are differently stimulated to fed by various glucosinolates (Renwick, Radke, Sachdev-Gupta, & Städler, 1992).

It is interesting also to mention that the biocidal activity of glucosinolates is not only specific for plant pathogens, and activity against numerous human pathogens has been described (J.w et al., 2001), as well as an effect in reducing as much as a 50% in the relative risk for cancer in certain sites (Kune, Kune, & Watson, 1987), being this probably some of the reasons why many Brassicas like cabbage and mustard have been used as poultices and antitumoral agents for centuries.

Another interesting property of glucosinolates and GPHs is their activity as allelochemicals (Rehman et al., 2019), which implies their potential use of glucosinate-rich plants extracts in biological weed control, something that several studies like Awan, Rasheed, Ashraf, & Khurshid (2012) and Turk & Tawaha (2003) have confirmed.

Phenoles

Phenolic extracts from several species of Brassicas have proven to have also allelopathic effects in other plant species (Haddadchi & Gerivani, 2009). The main components of phenolic substances in Brassicas are caffeic and sinapic acids. The other phenolic acids and their esters, such as salicylic, o-coumaric, ferulic, syringic and cinnamic acid, are minor substitutes in *Brassica* species (Zukalova & Vasak, 1998). Interference with plant-water balance appears to be one mechanism of action of phenolic acids causing a reduction in plant growth although phenolics compounds might also decrease decreased seed germination, ion uptake, leaf expansion, chlorophyll content, photosynthesis and electron transport (Colpas, Ono, Rodrigues, & Passos, 2003).

BRASSICAS IN CROP ROTATION SYSTEMS

Although an direct relationship between the presence of phytochemicals and the benefits of Brassicas has generally being observed, when used as a rotation crop, Brassicas have been shown to supress diseases also through effects on soil microbial communities and development of suppressive conditions, that are separate from the biofumigation response (Larkin & Lynch, 2018). In Larkin & Honeycutt (2006) it was observed that in rotations with canola and rapeseed (*Brassica napus* L.) distinct microbial community characteristics from non-Brassica rotations were exhibited, and these rotations resulted in reduced incidence and severity of *Rhizoctonia* disease in potatoes, even when the rotations were not incorporated as green manures.

Disease suppression in some cases has not been consistently associated with high glucosinolate-producing crops, and it has been observed that in some cases this suppression is completely independent of the glucosinolate content (Cohen, Yamasaki, & Mazzola, 2005; Larkin &

Griffin, 2007). It is very important to notice that disease benefits are not the only ones considered when having Brassicas as rotation crops, in McGuire (2003) it is shown that many other characteristics such as increased porosity and organic matter content, which may lead to lower disease levels as well as increased crop yields, are present when Brassicas crops are used.

Even if the potential of Brassicas to reduce disease and improve overall soil condition has been proven, it is not yet clear which crops are best for which diseases and how to manage these crops for an effective disease reduction, and how to best implement these crops into a rotation and production system. In this case, it is necessary to perform a detailed study of each case. In Larkin & Lynch (2018) they evaluated six different *Brassica* crops and standard rotation crops (ryegrass and buckwheat) as green manure and rotation crops alongside with potato, showing a similar performance for all *Brassica* crops compared to that of ryegrass and buckwheat.

Another crop in which Brassicas' potential as a rotation crop have been investigated is pepper. In Ros et al. (2016), several cultivars from *Raphanus sativus*, *Brassica juncea* and *Sinapis alba* were evaluated for its suitability as a rotation crop and as a green amendment during the process of biosolarization. They have shown that the joint action of the non-multiplier effects of the brassicas and biosolarization reduced the damage to the roots of the following pepper crop during the first months, which translated into an improvement in production compared to the control. These results are relevant for soil management and pepper production systems, but more trials under different conditions and sowing dates of brassicas will be necessary in order to recommend the use of Brassicas as a crop for biosolarization of pepper greenhouses, both in organic farming and in conventional production.

The study by Tiwari et al., (2021) is another example of research where *Brassica* crops, in this case *Brassica carinata*, was used for diversifying crop rotation and its potential to improve integrated weed management evaluated. Their research objective was to evaluate the influence of *B. carinata* on weed population dynamics of several cropping systems. As a result, they found an interesting synergistic effect of both a reduction in the weed emergence and an increase in *B. carinata* biomass when rotating this crop with peanut (*Arachis hypoge*a L.) indicate that *B. carinata* can enhance integrated weed management strategies at the rotational level for summer crops by reducing seed banks of summer weed species, in addition to its potential as a winter biofuel crop.

This previous example shows another advantage of the use of Brassicas as rotation crops, which is the added value that most *Brassica* species have, either as food, or biofuel and many other applications. This is very important since one factor of particular importance to growers is whether a full-season rotation crop is needed to achieve disease control. The disadvantage of rotation crops is that it takes the field out of any kind of production for that season. The use of a Brassica cover crop, such as condiment mustard or cauliflower, with an high value produce that can also be effective in reducing disease, and also if the *Brassica* crop can be effective as a fall cover crop implemented after a regular seasonal rotation crop, would give growers more flexibility in how to effectively implement Brassicas for disease control into their production system (Larkin & Lynch, 2018).

Just as important as figuring out the specific benefits of using Brassicas as rotation crops, it is important to define any probable negative interaction with other crops. Some *Brassica* species, when included in crop rotation, caused inhibiting of germination and seedling growth of succeeding small-grain crops (Bialy, Oleszek, Lewis, & Fenwick, 1990). Most of the studied cases are related to the harmful effect on small-grained crops (Oleszek, 1987; Vera, McGregor, & Downey, 1987) so, the evaluation of this negative effect is very important when studying the inclusion of *Brassica* in rotation systems with cereals.

CONCLUSIONS

While the use of chemical herbicides, pesticides, and synthetic growth regulators is generally unavoidable in crop production, ecological alternatives such as crop rotation may aid in the long-term sustainability of global food security. Exploring the potential of *Brassica* as a rotation crop as a means of increasing productivity without jeopardizing environmental safety could be fruitful in this sense. However, this field of study is still in its early stages, and its full potential has yet to be realized. So far, research has shown that *Brassica* species have a lot of potential, which may be exploited in a variety of ways to enhance crop output in the face of climate change.

To improve the allelopathic potential of major Brassica crops, plant breeders and molecular biologists should collaborate with agronomists. Phytochemical genes should be identified in more allelopathic cultivars and then introduced into non-allelopathic or less allelopathic crops and cultivars. It's also possible to find growth-regulating secondary metabolites to boost crop yields in both normal and stressful situations. This will not only reduce the cost of production but will also reduce the environmental hazards caused by chemical pollution, helping towards achieving the goal of sustainable crop production without compromising the environmental safety.

ACKNOWLEDGEMENTS

The authors would like to thank the Polytechnic University of Valencia for its PAID-10-20 contract for Access to the Spanish Science, Technology and Innovation System and for the GRISOLIAP/2021/062 grant.

REFERENCES

Abegunde, V. O., Sibanda, M., Obi, A. (2019). The dynamics of climate change adaptation in sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers. *Climate*, *7*(11). https://doi.org/10.3390/cli7110132

Agrawal, A. A., Kurashige, N. S. (2003). A role for isothiocyanates in plant resistance against the specialist herbivore Pieris rapae. *Journal of Chemical Ecology*, *29*(6), 1403–1415. https://doi.org/10.1023/A:1024265420375

Aires, A., Mota, V. R., Saavedra, M. J., Monteiro, A. A., Simões, M., Rosa, E. A. S., & Bennett, R. N. (2009). Initial *in vitro* evaluations of the antibacterial activities of glucosinolate enzymatic hydrolysis products against plant pathogenic bacteria. *Journal of Applied Microbiology*, *106*(6), 2096–2105. https://doi.org/10.1111/j.1365-2672.2009.04181.x

Awan, F. K., Rasheed, M., Ashraf, M., & Khurshid, M. Y. (2012). Efficacy of brassica, sorghum and sunflower aqueous extracts to control wheat weeds under rainfed conditions of pothwar, Pakistan. *Journal of Animal and Plant Sciences*, *22*(3), 715–721.

Bending, G. D., & Lincoln, S. D. (2000). Inhibition of soil nitrifying bacteria communities and their activities by glucosinolate hydrolysis products. *Soil Biology and Biochemistry*, *32*(8–9), 1261–1269. https://doi.org/10.1016/S0038-0717(00)00043-2

Bialy, Z., Oleszek, W., Lewis, J., & Fenwick, G. R. (1990). *Allelopathic potential of glucosinolates (mustard oil glycosides) and their degradation products against wheat Author (s): Z . BIALY , W . OLESZEK , J . LEWIS and G . R . FENWICK Published by : Springer Stable URL : www.jstor.org/stable/429372*. *129*(2), 277–281.

Branca, F. (2007). Cauliflower and Broccoli. *Vegetables I*, 151–186. https://doi.org/10.1007/978-0-387-30443-4_5

Cartea, M. E., & Velasco, P. (2008). Glucosinolates in Brassica foods: Bioavailability in food and significance for human health. *Phytochemistry Reviews*, *7*(2), 213–229. https://doi.org/10.1007/s11101-007-9072-2

Cohen, M. F., Yamasaki, H., & Mazzola, M. (2005). Brassica napus seed meal soil amendment modifies microbial community structure, nitric oxide production and incidence of Rhizoctonia root rot. *Soil Biology and Biochemistry*, *37*(7), 1215–1227. https://doi.org/10.1016/j.soilbio.2004.11.027

Colpas, F. T., Ono, E. O., Rodrigues, J. D., & Passos, J. R. D. S. (2003). Effects of some phenolic compounds on soybean seed germination and on seed-borne fungi. *Brazilian Archives of Biology and Technology*, *46*(2), 155–161. https://doi.org/10.1590/S1516-89132003000200003

Costa, M. P., Chadwick, D., Saget, S., Rees, R. M., Williams, M., & Styles, D. (2020). Representing crop rotations in life cycle assessment: a review of legume LCA studies. *International Journal of Life Cycle Assessment*, *25*(10), 1942–1956. https://doi.org/10.1007/s11367-020-01812-x

Dominguez-Perles, R., Martinez-Ballesta, M. C., Riquelme, F., Carvajal, M., Garcia-Viguera, C., & Moreno, D. A. (2011). Novel varieties of broccoli for optimal bioactive components under saline stress. *Journal of the Science of Food and Agriculture*, *91*(9), 1638–1647. https://doi.org/10.1002/jsfa.4360

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., … Huang, J. (2017). Crop production under drought and heat stress: Plant responses and management options. *Frontiers in Plant Science*, *8* (June), 1–16. https://doi.org/10.3389/fpls.2017. 01147

Favela-González, K. M., Hernández-Almanza, A. Y., & De la Fuente-Salcido, N. M. (2020). The value of bioactive compounds of cruciferous vegetables (Brassica) as antimicrobials and antioxidants: A review. *J Food Biochem*. https://doi.org/https://doi.org/10.1111/jfbc.13414

Gliessman, S. R. (2020). Transforming food and agriculture systems with agroecology. *Agriculture and Human Values*, *37*(3), 547–548. https://doi.org/10.1007/s10460-020-10058-0

Haddadchi, G. R., & Gerivani, Z. (2009). Effects of Phenolic Extracts of Canola (Brassica napus L.) on Germination and Physiological Responses of Soybean

(Glycine max L.) Seedlings. *Angewandte Chemie International Edition, 6(11), 951–952*, 10–27.

He, K., Zhang, J., Wang, X., Zeng, Y., & Zhang, L. (2018). A scientometric review of emerging trends and new developments in agricultural ecological compensation. *Environmental Science and Pollution Research*, *25*(17), 16522–16532. https://doi.org/10.1007/s11356-018-2160-6

J.w, F., A.t, Z., & P, T. (2001). The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry*, *56*.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International*, *132*(July), 105078. https://doi.org/10.1016/j.envint.2019.105078

Kune, S., Kune, G. A., & Watson, L. F. (1987). Case-Control Study of Dietary Etiological Factors: The Melbourne Colorectal Cancer Study. *Nutrition and Cancer*, *9*(1), 43–56. https://doi.org/10.1080/01635588709513909

Larkin, R. P., & Griffin, T. S. (2007). Control of soilborne potato diseases using Brassica green manures. *Crop Protection*, *26*(7), 1067–1077. https://doi.org/10.1016/j.cropro.2006.10.004

Larkin, R. P., & Honeycutt, C. W. (2006). Effects of different 3-year cropping systems on soil microbial communities and rhizoctonia diseases of potato. *Phytopathology*, *96*(1), 68–79. https://doi.org/10.1094/PHYTO-96-0068

Larkin, R. P., & Lynch, R. P. (2018). Use and effects of different brassica and other rotation crops on soilborne diseases and yield of Potato. *Horticulturae*, *4*(4), 1–16. https://doi.org/10.3390/horticulturae4040037

Lazzeri, L., & Manici, L. M. (2001). Allelopathic effect of glucosinolate-containing plant green manure on Pythium sp. and total fungal population in soil. *HortScience*, *36*(7), 1283–1289. https://doi.org/10.21273/hortsci.36.7.1283

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth and Environment*, *1*(10), 544–553. https://doi.org/10.1038/s43017-020-0080-8

McGuire, A. M. (2003). Mustard Green Manures Replace Fumigant and Improve Infiltration in Potato Cropping System. *Crop Management*, *2*(1), 1–6. https://doi.org/10.1094/cm-2003-0822-01-rs

Motisi, N., Montfort, F., Doré, T., Romillac, N., & Lucas, P. (2009). Duration of control of two soilborne pathogens following incorporation of above- and below-ground residues of brassica juncea into soil. *Plant Pathology*, *58*(3), 470–478. https://doi.org/10.1111/j.1365-3059.2008.02017.x

Novotny, V. (1999). Diffuse pollution from agriculture - A worldwide outlook. *Water Science and Technology*, *39*(3), 1–13. https://doi.org/10.1016/S0273-1223(99)00027-X

Oleszek, W. (1987). Allelopathic effects of volatiles from some Cruciferae species on lettuce, barnyard grass and wheat growth. *Plant and Soil*, *102*(2), 271–273. https://doi.org/10.1007/BF02370715

Qi, X., Fu, Y., Wang, R. Y., Ng, C. N., Dang, H., & He, Y. (2018). Improving the sustainability of agricultural land use: An integrated framework for the conflict between food security and environmental deterioration. *Applied Geography*, *90*(August 2017), 214–223. https://doi.org/10.1016/j.apgeog.2017.12.009

Rahmanpour, S., Backhouse, D., & Nonhebel, H. M. (2009). Induced tolerance of sclerotinia sclerotiorum to isothiocyanates and toxic volatiles from brassica species. *Plant Pathology*, *58*(3), 479–486. https://doi.org/10.1111/j.1365-3059.2008.02015.x

Rask, L., Andréasson, E., Ekbom, B., Eriksson, S., Pontoppidan, B., & Meijer, J. (2000). Myrosinase: Gene family evolution and herbivore defense in Brassicaceae. *Plant Molecular Biology*, *42*(1), 93–114. https://doi.org/10.1023/A:1006380021658

Reda, T., Thavarajah, P., Polomski, R., Bridges, W., Shipe, E., & Thavarajah, D. (2021). Reaching the highest shelf: A review of organic production, nutritional quality, and shelf life of kale (Brassica oleracea var. acephala). *Plants People Planet*, *3*(4), 308–318. https://doi.org/10.1002/ppp3.10183

Rehman, S., Shahzad, B., Bajwa, A. A., Hussain, S., Rehman, A., Cheema, S. A., … Li, P. (2019). Utilizing the Allelopathic Potential of Brassica Species for Sustainable Crop Production: A Review. *Journal of Plant Growth Regulation*, *38*(1), 343–356. https://doi.org/10.1007/s00344-018-9798-7

Renwick, J. A. A., Radke, C. D., Sachdev-Gupta, K., & Städler, E. (1992). Leaf surface chemicals stimulating oviposition by Pieris rapae (Lepidoptera: Pieridae) on cabbage. *Chemoecology*, *3*(1), 33–38. https://doi.org/10.1007/BF01261454

Romeo, L., Iori, R., Rollin, P., Bramanti, P., & Mazzon, E. (2018). Isothiocyanates: An overview of their antimicrobial activity against human infections. *Molecules*, *23*(3), 1–18. https://doi.org/10.3390/molecules23030624

Ros, C., Sánchez, F., Martínez, V., Lacasa, C. M., Hernández, A., Torres, J., … Lacasa, A. (2016). El cultivo de brásicas para biosolarización reduce las poblaciones de Meloidogyne incognita en los invernaderos de pimiento del sudeste de España. *ITEA Informacion Tecnica Economica Agraria*, *112*(2), 109–126. https://doi.org/10.12706/itea.2016.008

Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified Crop Rotation: An Approach for Sustainable Agriculture Production. *Advances in Agriculture*, *2021*. https://doi.org/10.1155/2021/8924087

Sikorska-Zimny, K., & Beneduce, L. (2021). The glucosinolates and their bioactive derivatives in Brassica: a review on classification, biosynthesis and content in plant tissues, fate during and after processing, effect on the human organism and interaction with the gut microbiota. *Critical Reviews in Food Science and Nutrition*, *61*(15), 2544–2571. https://doi.org/10.1080/10408398.2020.1780193

Sotelo, T., Lema, M., Soengas, P., Cartea, M. E., & Velasco, P. (2015). In vitro activity of Glucosinolates and their degradation products against Brassica-pathogenic bacteria and fungi. *Applied and Environmental Microbiology*, *81*(1), 432–440. https://doi.org/10.1128/AEM.03142-14

Tiwari, R., Reinhardt Piskáčková, T. A., Devkota, P., Mulvaney, M. J., Ferrell, J. A., & Leon, R. G. (2021). Growing winter Brassica carinata as part of a diversified crop rotation for integrated weed management. *GCB Bioenergy*, *13*(3), 425–435. https://doi.org/10.1111/gcbb.12799

Turk, M. A., & Tawaha, A. M. (2003). Allelopathic effect of black mustard (Brassica nigra L.) on germination and growth of wild oat (Avena fatua L.). *Crop Protection*, *22*(4), 673–677. https://doi.org/10.1016/S0261-2194(02)00241-7

Uğuz, H., Goyal, A., Meenpal, T., Selesnick, I. W., Baraniuk, R. G., Kingsbury, N. G., … Rodriguez-Villegas, E. (2020). Intensive Agriculture, Nitrogen Legacies, and Water Quality: Intersections and Implication. *Environmental Research Letters*, *2*(1), 0–31.

Vera, C. L., McGregor, D. I., & Downey, R. K. (1987). Detrimental effects of volunteer Brassica on production of certain cereal and oilseed crops. *Canadian Journal of Plant Science*, *67*(4), 983–995. https://doi.org/10.4141/cjps87-135

Zukalova, H., & Vasak, J. (1998). Natural antioxidants in winter rape (Brassica napus L) seed. *Rostlinna Vyroba*, *44*(3), 97–101.