

Fundamental Differences between Perennial Wall Rocket and Annual Garden Rocket Influence the Commercial Year-Round Supply of These Crops

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Abstract

Perennial wall rocket (*Diplotaxis tenuifolia* [L.] DC.) and annual garden rocket (*Eruca sativa* Mill.) are cultivated around the world as salad crops and as an ingredient of condiments. From a botanical perspective these species are classified in the Rapa/Oleracea lineage, which is consistent with their similar morphological characteristics, chromosomal number and the diversity of glucosinolates. It is understandable that these species have been informally grouped together for convenience. However, the evaluation of a wide range of factors over a typical production cycle has clearly illustrated that these species should be considered distinct crops from a commercial perspective. We will demonstrate with examples why these species should be managed differently and considered commercially distinct crops.

Keywords: arugula, baby leaf, cultivation, cultivated rocket, *Diplotaxis tenuifolia*, *Eruca sativa*, glucosinolates, shelf life, wild rocket

1. Introduction

Baby leaf rocket has become a popular crop in recent years due to its taste and appearance in mesclun-type salads (Bell & Wagstaff, 2014). These crops are used globally as a salad vegetable and condiment. There are two common types of rocket grown commercially, a perennial species known as perennial wall rocket (*Diplotaxis tenuifolia* [L.] DC.) and an annual species known as annual garden rocket (*Eruca sativa* Mill.). Global growth in the consumption of baby leaf rocket is estimated to continue, yet pre- and postharvest factors affecting commercial production have not been well defined. The leaves of cultivars of these species have been bred to look similar, allowing for a year-round supply of produce (Hall et al., 2012a). Due to their similar appearance and recent commercial cultivation, growers tend to manage the growth and postharvest storage of these crops in a similar way. This generic management of species may have negative implications on yield and nutritional quality of produce. Although these species are often grouped together for convenience, there are clear similarities and differences between the plants, which can influence their responses to abiotic factors during growth and storage.

2. Similarities between the Rocket Species

2.1 Germination Characteristics

Temperature requirements for optimal germination of perennial wall rocket and annual garden rocket are similar (Hall et al., 2012b); and reflects that these species evolved in the same region under similar environmental conditions (Martín & Sánchez-Yélamo, 2000; Martínez-Laborde, 1997). This may also be influenced by the similar seasonal conditions during which germination naturally occurs; with perennial wall rocket germinating during autumn and annual garden rocket during spring (Pimpini & Enzo, 1997). These intermediate seasons share similar temperature ranges and day lengths, which may contribute to the similar optimal temperature range of 20 to 25 °C (Hall et al., 2012b).

The germination percentage for cultivars of perennial wall rocket and annual garden rocket are similar at optimal temperatures when compared to those of seeds collected from wild parental plants (Kleemann et al., 2007; Pita

Villamil et al., 2002; Sakcali & Serin, 2009); indicating the selection of both rocket species in breeding programs has not significantly improved their germination relative to wild populations.

2.2 Response to Abiotic Factors

The pattern of plant growth between species is similar during different seasonal conditions; with longer day lengths and higher temperatures resulting in the fastest growth rate for respective species (Hall et al., 2012c). The commercial yield of rocket species was therefore highest during summer conditions when greater radiant and thermal energy is received by plants. This relationship between day length and temperature has also been shown for lettuce crops, which despite being a winter crop develop faster during the summer (Dufault et al., 2009; Fallovo et al., 2009). Hall et al. (2012c) showed that nitrogen supply did not affect the yield of perennial wall rocket or annual garden rocket. This response may have been influenced by the relatively high residual nitrate levels in soil. Plant species native to the Iberian Peninsula are known to have evolved under low soil nutrient conditions (Lambers & Poorter, 2004; Pimpini & Enzo, 1997). The response of rocket species to nitrogen supply may have been influenced by the fact that both species have evolved under low nutrient conditions. The concentration of the glucosinolate glucoraphanin, which was the only common type of glucosinolate between rocket species measured, was influenced by the supply of nitrogen (Hall et al., 2015a). In both species higher levels of supply resulted in higher concentrations. The variability of these compounds between the first two harvests and seasonal conditions was very high in both species; indicating that the supply of these compounds fluctuates by as much as 50 % throughout the growing seasons. The diversity of glucosinolates in the leaves of both species changed with subsequent harvesting events, with lower concentrations recorded in the leaves of second harvested crops. This response may be due to the abrupt disruption of normal metabolic activity following harvest, which causes a change in the diversity and concentration of glucosinolates (Hall et al., 2015a). A similar relationship has been shown by Kim and Jander (2007), where aphid feeding caused physical damage similar to that caused by harvesting which resulted in a change in glucosinolate type and concentration at the site of damage.

The close botanical links between rocket species of the Rapa/Oleracea lineage means that they are likely to respond in a similar way to abiotic factors. The application of nitrogen reduced the concentration of vitamin C in the leaves of both rocket species (Hall et al., 2015b). After harvest the concentration of vitamin C was lower in the leaves of both rocket species which received higher levels of nitrogen supply; while those which received zero additional nitrogen contained higher concentrations of vitamin C. This response may be related to the higher activity of the enzyme rubisco during photosynthesis under higher nitrogen conditions. Increased activity of this enzyme in the leaves may then result in the higher production of reactive oxygen species (ROS); thereby using up greater quantities of the vitamin C sink (Lam et al., 1996).

3. Differences between the Rocket Species

3.1 Fundamental Differences

Perennial wall rocket and annual garden rocket differ in their morphology, chromosomal number, and the diversity of glucosinolates (Bell & Wagstaff, 2014; Hall et al., 2012a). These factors in combination with their perennial and annual nature and different pathways for carbon fixation, influence their response to abiotic factors during different growth phases of the commercial life cycle. Rocket species have one fundamental characteristic which influences their response to different abiotic conditions and which cannot be altered through breeding programs. This characteristic is their different perennial and annual reproductive strategies, which in turn influence the response of species to environmental conditions during growth and storage.

Survival mechanisms for perennial and annual plants are distinctly different and influence respective growth rates and investment of energy into the production of seeds. The survival of annual plants is reliant on the production of viable seeds and hence greater energy is allocated to this plant part in annual plants when compared to perennials. One obvious difference between rocket species is the size of seeds (Hall et al., 2012b). The speed of germination is much faster for annual garden rocket when compared to perennial wall rocket, due partly to its larger seed size. This species also has a wider temperature range over which optimal germination is achieved; while perennial wall rocket has a narrower optimal temperature range (Hall et al., 2012b). Again this response may be related to differences in the size of seeds between the species, as influenced by their different reproductive strategies. Differences in the germination response of different cultivars of perennial wall rocket and annual garden rocket were also noted under different temperature conditions. The level of variability between the germination of individual cultivars was highest for annual garden rocket, which may be due to the mono-specific nature of the *Eruca* genus where greater cross pollination between morphologically different plants is possible, thereby increasing the genetic transfer of characteristics in this species (D'Antuono et al., 2008;

Gómez-Campo, 1999). The level of variability identified between cultivars of individual species also has a significant effect on the plant densities of field grown crops, particularly for perennial wall rocket (Hall et al., 2012c).

Although perennial wall rocket has smaller seeds and hence less stored reserves, this does not influence the plant densities during spring and summer. The lower density of plant populations during winter would have been a temperature effect (Pignone & Ngu, 1995), and the small seed size adds to the low temperature sensitivity, particularly at temperatures < 20 °C. Annual garden rocket seeds were less sensitive to lower temperatures and negative impacts were not seen at temperature > 10 °C (Hall et al., 2012b).

3.2 Response to Abiotic Factors

The growth rate of annual garden rocket is faster than that of perennial wall rocket across all seasons. A similar relationship between the growth rate of perennial and annual plants has also been reported in lupins (Pitelka, 1977); and various grass species (Garnier & Laurent, 1994). This difference in growth rate is likely due to photosynthetic partitioning (Garnier, 1992; Pignone & Ngu, 1995), but may also be influenced by anatomical differences between reproductive strategies; with annual garden rocket having more mesophyll tissue and less sclerenchyma and vascular tissues than perennial wall rocket (Garnier & Laurent, 1994). As a result, the leaves of annual garden rocket may have fewer cell walls per unit leaf area and more of their volume occupied by mesophyll protoplast when compared to perennial wall rocket. These differences favour leaf production and hence faster growth in the annual species; while in slower growing perennial species, leaf persistence is favoured over speed of development with a higher comparative investment in this plant part (Hall et al., 2012c). This characteristic also means that annual garden rocket is not well suited to multi-harvesting events, as plants are less resistant to stress factors resulting from the abrupt disruption of energy, nutrients, and hormones during harvesting.

The different reproductive mechanisms of rocket species influence their nitrogen utilization during the growth phase. Leaf nitrogen levels in perennial wall rocket were consistently higher than the annual species, despite identical levels of nitrogen supply. This may be due to the C₃-C₄ carbon fixation in perennial wall rocket (Hall et al., 2012a); C₃ and C₄ represent different types of carbon binding during photosynthesis. C₄ plants are known to accumulate nitrogen in higher quantities when compared to C₃ plants, such as annual garden rocket (Ehleringer & Monson, 1993). This relationship between higher nitrogen uptake efficiency in C₄ plants has also been reported in many grass species (Beale & Long, 1997; Rubio et al., 2010); and occurs due to the higher energy requirements of C₄ carbon fixation, particularly with regards to rubisco activity during photosynthesis which becomes saturated with CO₂ (Carmo-Silva et al., 2010; Ghannoum et al., 2005).

3.3 Leaf Nutrients and Postharvest Stability

Vitamin C is an important plant metabolite directly involved in photosynthesis and the elimination of ROS, which are toxic by-products of this process. The concentrations of vitamin C in the leaves of rocket species were affected by nitrogen supply. The faster growth and larger photosynthetic area of leaves of annual garden rocket may have resulted in a larger variation in the concentration of vitamin C between treatments of this species (Hall et al., 2012c, 2015b). The concentration of vitamin C in leaves of perennial wall rocket was constant across these conditions; while the concentration of vitamin C for annual garden rocket varied greatly across cultivar and nitrogen treatments (Hall et al., 2015b). This may have occurred due to this species synthesising more vitamin C to counteract higher oxidative stress resulting from faster growth and increased photosynthesis (Bergquist et al., 2007; Lester et al., 2010).

An important nutritional consideration of rocket species is the concentration of leaf glucosinolates, which relates to both the nutritional value of crops and their close botanical classification (Singh & Hall, 2013). The concentration of glucosinolates in the leaves of rocket species can vary greatly across the seasons (Hall et al., 2015a). Mild temperature conditions in spring resulted in the highest concentration in the leaves of perennial wall rocket; while lower temperature conditions in winter resulted in higher concentrations in the leaves of annual garden rocket (Hall et al., 2015a). Perennial wall rocket had the highest overall concentration of glucosinolates, which is consistent with the slower growth rate allowing more time for these compounds to accumulate in the leaves of the perennial species (Porter et al., 1991).

Postharvest storage did not affect glucosinolate levels in perennial wall rocket, but glucosinolate levels increased during storage in annual garden rocket, especially at higher temperature storage (Hall et al., 2015a). This response is similar to that reported in broccoli, where the glucosinolate concentration increased during storage, particularly when stored at a high postharvest temperature (Hansen et al., 1995; Jones et al., 2006). This response may have to do with the higher activity of myrosinase in plant parts when produce is stored at higher postharvest

temperatures, as its activity is less retarded than at lower temperature storage.

4. The Cultivars of These Species Should Not Be Considered Botanically Similar

The classification of the *Diplotaxis* and *Eruca* genera was primarily done using morphological characters first proposed by Schulz (1936) with further contributions by Gómez-Campo (1999). This method of classification is similar to that which has been used for the wider plant kingdom. Some of the morphological characters used to classify species in these genera are: the size, shape, and characteristics of the beak of siliques; the leaf shape and type of attachment to the stem; and the shape, venation, and colour of petals (D'Antuono et al., 2008; Martínez-Laborde, 1997).

More recently the chromosomal number of individual species in respective genera has been used to group similar species, in combination with the previously identified morphological characters (Martínez-Laborde, 1997). The classification of species has further been combined with the diversity of glucosinolates which are found in plant species of these genera (D'Antuono et al., 2008; Martín & Sánchez-Yélamo, 2000; Sánchez-Yélamo, 2009). The consideration of the diversity of these compounds is important, particularly that these genera are thought to be of similar phylogeny and the similarities of glucosinolates are thought to reflect the conditions under which plants evolved (Warwick & Black, 1997; Warwick & Sauder, 2005).

Although cultivars of rocket species have been selectively bred for commercially desirable traits, they still retain distinctive differences with regards to floret structure, leaf arrangement and branching from the stem. These morphological characters are used to define individual species and have not been altered through breeding. Although the harvested leaves of species visually look similar, the anatomy of perennial wall rocket and annual garden rocket plants remains different between the species. It is also known that the diversity of glucosinolates in the leaves are different between rocket species (Bell & Wagstaff, 2014; Hall et al., 2015a); indicating that selection techniques have not produced cultivars of these species with similar glucosinolate profiles. The chromosomal number between rocket species remains different; with perennial wall rocket having 13 and annual garden rocket 11 (Gómez-Campo, 1995; Sánchez-Yélamo, 2009). Although cultivars of perennial wall rocket and annual garden rocket have similar leaf shapes the three major factors of morphology, chromosomal number, and glucosinolate diversity, used to differentiate species in the *Diplotaxis* and *Eruca* genera are still distinctly different between the species. Therefore although cultivars of rocket species share many similar characteristics they also have important physical and chemical differences and should remain botanically isolated species.

5. Differences between the Species Impact on Commercial Production

The plant density of rocket species was influenced by seasonal conditions with perennial wall rocket falling below commercially acceptable densities during winter (Hall et al., 2012c). This season also corresponded to a 40 % reduction in yield when compared to the seasonal average. The production of perennial wall rocket during winter conditions is likely to result in reduced yield. For this reason annual garden rocket should be cultivated during winter as this species achieved a yield 2.7 times higher than that of perennial wall rocket during this season (Hall et al., 2012c).

Annual garden rocket has a higher germination and growth rate when compared to perennial wall rocket. The yields of first harvested crops of annual garden rocket were around 50 % higher than perennial wall rocket across all seasonal conditions; however, the yield of this species decreased from first to second harvest (Hall et al., 2012c). Commercially, annual garden rocket crops needs to be sown again after the second harvest, with further harvesting not commercially viable. Although the total yield of annual garden rocket was higher across seasons when compared to perennial wall rocket, a greater number of harvests per seeding are possible for the perennial as yield increases from the first to second harvested crops (Hall et al., 2012c). This characteristic makes perennial wall rocket better suited to commercial utilisation as it is more efficient per cultivation with lower seed and labour costs. Mild growing environments similar to Mediterranean conditions under which these species evolved (J. M. Baskin & C. C. Baskin, 1995; Thanos et al., 1995), are optimal for commercial production. These conditions will allow for the year-round supply of rocket leaves with lower volumes of production experienced during winter, which is influenced by a slowdown in the growth rate of plants during this season.

Nutritionally, perennial wall rocket has consistently higher levels of vitamin C under different levels of nitrogen supply and a higher combined glucosinolate concentration than annual garden rocket, making this species of greater nutritional value (Hall et al., 2015a, 2015b). The leaves of perennial wall rocket maintain visual quality for a longer period of time, i.e., they have a longer shelf life (Hall et al., 2013). Both species of rocket supply much higher vitamin C than lettuce which is the main leafy salad vegetable consumed worldwide (Llorach et al., 2008; Martínez-Sánchez et al., 2008); meaning that regardless of species or storage conditions rocket crops represent superior nutritional value when compared to more traditional lettuce types.

6. Further Understanding and Improvement of Rocket Species

Future work on rocket species should concentrate on selecting perennial wall rocket cultivars with improved germination characteristics, particularly under lower temperature conditions. This would enable this species to achieve a commercially acceptable level of crop establishment during winter conditions, thereby increasing the growing season of this species. Improvements in supply chain management systems are also required particularly with regards to low temperature storage of leaves; the implementation of changes in the current system is needed to obtain storage temperatures as close to 0 °C as possible as this has been shown to better maintain the visual and nutritional quality of produce during storage. Breeding programs should focus on reducing the variability in cultivars of annual garden rocket, particularly in relation to the biosynthesis of vitamin C. Further work should also clarify the health benefits of glucosinolates in humans, to help support a nutrient health claim. These factors will help to improve the nutritional value and consistency of the year-round supply of leaves to consumers.

References

- Baskin, J. M., & Baskin, C. C. (1995). Variation in the annual dormancy cycle in buried seeds of the weedy winter annual *Viola arvensis*. *Weed Research*, 35, 353-362. <http://dx.doi.org/10.1111/j.1365-3180.1995.tb01630.x>
- Beale, C. V., & Long, S. P. (1997). Seasonal dynamics of nutrient accumulation and partitioning in the perennial C4 grasses *Miscanthus x giganteus* and *Spartina cynosuroides*. *Biomass Bioenergy*, 12, 419-428. [http://dx.doi.org/10.1016/S0961-9534\(97\)00016-0](http://dx.doi.org/10.1016/S0961-9534(97)00016-0)
- Bell, L., & Wagstaff, C. (2014). Glucosinolates, myrosinase hydrolysis products, and flavonols found in rocket (*Eruca sativa* and *Diplotaxis tenuifolia*). *Journal of Agricultural and Food Chemistry*, 62, 4481-4492. <http://dx.doi.org/10.1021/jf501096x>
- Bergquist, S. A. M., Gertsson, U. E., Nordmark, L. Y. G., & Olsson, M. E. (2007). Ascorbic acid, carotenoids, and visual quality of baby spinach as affected by shade netting and postharvest storage. *Journal of Agricultural and Food Chemistry*, 55, 8444-8451. <http://dx.doi.org/10.1021/jf070396z>
- Carmo-Silva, E. A., Keys, A. J., Andralojc, J. P., Powers, S. J., Arrabaca, C. M., & Parry, M. A. J. (2010). Rubisco activities, properties, and regulation in three different C4 grasses under drought. *Journal of Experimental Botany*, 61, 2355-2366. <http://dx.doi.org/10.1093/jxb/erq071>
- D'Antuono, L. F., Elementi, S., & Neri, R. (2008). Glucosinolates in *Diplotaxis* and *Eruca* leaves: Diversity, taxonomic relations and applied aspects. *Phytochemistry*, 69, 187-199. <http://dx.doi.org/10.1016/j.phytochem.2007.06.019>
- Dufault, R. J., Ward, B., & Hassell, R. L. (2009). Dynamic relationships between field temperatures and romaine lettuce yield and head quality. *Scientia Horticulturae*, 120, 452-459. <http://dx.doi.org/10.1016/j.scienta.2009.01.002>
- Ehleringer, J. R., & Monson, R. K. (1993). Evolutionary and ecological aspects of photosynthetic pathway variation. *Annual Review of Ecology and Systematics*, 24, 411-439. <http://dx.doi.org/10.1146/annurev.es.24.110193.002211>
- Falovo, C., Roupahel, Y., Cardarelli, M., Rea, E., Battistelli, A., & Colla, G. (2009). Yield and quality of leafy lettuce in response to nutrient solution composition and growing season. *Journal of Food, Agriculture and Environment*, 7, 456-462. <http://world-food.net/yield-and-quality-of-leafy-lettuce-in-response-to-nutrient-solution-composition-and-growing-season/>
- Garnier, E. (1992). Growth analysis of congeneric annual and perennial grass species. *Journal of Ecology*, 80, 665-675. <http://dx.doi.org/10.2307/2260858>
- Garnier, E., & Laurent, G. (1994). Leaf anatomy, specific mass and water content in congeneric annual and perennial grass species. *New Phytologist*, 128, 725-736. <http://dx.doi.org/10.1111/j.1469-8137.1994.tb04036.x>
- Ghannoum, O., Evans, J. R., Chow, W. S., Andrews, J. T., Conroy, J. P., & Caemmerer, S. V. (2005). Faster Rubisco is the key to superior nitrogen-use-efficiency in NADP-Malic enzyme relative to NAD-Malic enzyme C4 grasses. *Plant Physiology*, 137, 638-650. <http://dx.doi.org/10.1104/pp.104.054759>
- Gómez-Campo, C. (1995). An introduction to the diversity of rocket (*Eruca* and *Diplotaxis* species) and their natural occurrence within the Mediterranean region. In S. Padulosi (Ed.), *Rocket Genetic Resources Network* (pp. 20-21). International Plant Genetic Resources Institute, Lisbon, Portugal.

- Gómez-Campo, C. (1999). Taxonomy. In C. Gómez-Campo (Ed.). *Biology of Brassica Coenospecies* (pp. 3-32). Elsevier, Amsterdam.
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2012a). Some perspectives on rocket as a vegetable crop: a review. *Vegetables Crops Research Bulletin*, *76*, 21-41.
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2012b). The germination of perennial wall rocket (*Diplotaxis tenuifolia* (L.) DC.) and annual garden rocket (*Eruca sativa* Mill.) under controlled temperatures. *Plant Breeding and Seed Science*, *65*, 15-28.
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2012c). Factors affecting growth of perennial wall rocket and annual garden rocket. *International Journal of Vegetable Science*, *18*, 393-411. <http://dx.doi.org/10.1080/19315260.2012.660565>
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2013). Influence of storage temperature on the seasonal shelf life of perennial wall rocket and annual garden rocket. *International Journal of Vegetable Science*, *19*, 83-95. <http://dx.doi.org/10.1080/19315260.2012.716387>
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2015a). Variations in the most abundant types of glucosinolates found in the leaves of baby leaf rocket under typical commercial conditions. *Journal of the Science of Food and Agriculture*, *95*, 552-559. <http://dx.doi.org/10.1002/jsfa.6774>
- Hall, M. K. D., Jobling, J. J., & Rogers, G. S. (2015b). Effect of nitrogen supply and storage temperature on vitamin C in two species of baby leaf rocket, and the potential of these crops for a nutrient claim in Australia. *Journal of Plant Nutrition*, *38*, 246-259. <http://dx.doi.org/10.1080/01904167.2013.873465>
- Hansen, M., Møller, P., Sørensen, H., & de Trejo, M. C. (1995). Glucosinolates in broccoli stored under controlled atmosphere. *Journal of the American Society for Horticultural Science*, *120*, 1069-1074.
- Jones, R. B., Faragher, J. D., & Winkler, S. (2006). A review of the influence of postharvest treatments on quality and glucosinolate content in broccoli (*Brassica Oleracea* var. *italica*) heads. *Postharvest Biology and Technology*, *41*, 1-8. <http://dx.doi.org/10.1016/j.postharvbio.2006.03.003>
- Kim, J. H., & Jander, G. (2007). *Myzus persicae* (green peach aphid) feeding on *Arabidopsis* induces the formation of a deterrent indole glucosinolate. *Plant Journal*, *49*, 1008-1019. <http://dx.doi.org/10.1111/j.1365-313X.2006.03019.x>
- Kleemann, S. G. L., Chauhan, B. S., & Gill, G. S. (2007). Factors affecting seed germination of perennial wall rocket (*Diplotaxis tenuifolia*) in Southern Australia. *Weed Science*, *55*, 481-485. <http://dx.doi.org/10.1614/WS-06-197.1>
- Lam, H. M., Coschigano, K. T., Oliveira, I. C., Melo-Oliveira, R., & Coruzzi, G. M. (1996). The molecular-genetics of nitrogen assimilation into amino acids in higher plants. *Annual Review of Plant Physiology and Plant Molecular Biology*, *47*, 569-593. <http://dx.doi.org/10.1146/annurev.arplant.47.1.569>
- Lambers, H., & Poorter, H. (2004). Inherent variation in growth rate between higher plants: a search for physiological causes and ecological consequences. *Advances in Ecological Research*, *34*, 283-362. [http://dx.doi.org/10.1016/S0065-2504\(03\)34004-8](http://dx.doi.org/10.1016/S0065-2504(03)34004-8)
- Lester, G. E., Makus, D. J., & Hodges, D. M. (2010). Relationship between fresh-packaged spinach leaves exposed to continuous light or dark and bioactive contents: effects of cultivar, leaf size, and storage duration. *Journal of Agricultural and Food Chemistry*, *58*, 2980-2987. <http://dx.doi.org/10.1021/jf903596v>
- Llorach, R., Martínez-Sánchez, A., Tomás-Barberán, F. A., Gil, M. I., & Ferreres, F. (2008). Characterization of polyphenols and antioxidant properties of five lettuce varieties and escarole. *Food Chemistry*, *108*, 1028-1038. <http://dx.doi.org/10.1016/j.foodchem.2007.11.032>
- Martín, J. P., & Sánchez-Yélamo, M. D. (2000). Genetic relationships among species of the genus *Diplotaxis* (Brassicaceae) using inter-simple sequence repeat markers. *Theoretical and Applied Genetics*, *101*, 1234-1241. <http://dx.doi.org/10.1007/s001220051602>
- Martínez-Laborde, J. B. (1997). A brief account of the genus *Diplotaxis*. In S. Padulosi & D. Pignone (Eds.), *Rocket: A Mediterranean crop for the world* (pp. 13-22). International Plant Genetic Resources Institute, Legnaro, Italy.
- Martínez-Sánchez, A., Gil-Izquierdo, A., Gil, M. I., & Ferreres, F. (2008). A comparative study of flavonoid compounds, vitamin C, and antioxidant properties of baby leaf Brassicaceae species. *Journal of Agricultural and Food Chemistry*, *57*, 2330-2340. <http://dx.doi.org/10.1021/jf072975+>

- Pignone, D., & Ngu, M. A. (1995). Collection and conservation of rocket genetic resources: The Italian contribution. In S. Padulosi (Ed.), *Rocket Genetic Resources Network* (pp. 35-57). International Plant Genetic Resources Institute, Lisbon, Portugal.
- Pimpini, F., & Enzo, M. (1997). Present status and prospects for rocket cultivation in the Veneto region. In S. Padulosi & D. Pignone (Ed.), *Rocket: A Mediterranean crop for the world* (pp. 61-62). International Plant Genetic Resources Institute, Legnaro, Italy, 13-14 December, 1996.
- Pita Villamil, J. M., Pérez-García, F., & Martínez-Laborde, J. B. (2002). Time of seed collection and germination in rocket, *Eruca vesicaria* (L.) Cav. (Brassicaceae). *Genetic Resources and Crop Evolution*, 45, 47-51. <http://dx.doi.org/10.1023/A:1013875614186>
- Pitelka, L. F. (1977). Energy allocation in annual and perennial lupines (Lupinus: Leguminosae). *Ecology*, 58, 1055-1065. <http://dx.doi.org/10.2307/1936925>
- Porter, A. J. R., Morton, A. M., Kiddle, G., Doughty, K. J., & Wallsgrove, R. M. (1991). Variation in the glucosinolate content of oilseed rape (*Brassica napus* L.): I. Effects of leaf age and position. *Annals of Applied Biology*, 118, 461-467. <http://dx.doi.org/10.1111/j.1744-7348.1991.tb05647.x>
- Rubio, G., Gutierrez Boem, F. H., & Lavado, R. S. (2010). Responses of C3 and C4 grasses to application of nitrogen and phosphorus fertilizer at two dates in spring. *Grass and Forage Science*, 65, 102-109. <http://dx.doi.org/10.1111/j.1365-2494.2009.00728.x>
- Sakcali, M. S., & Serin, M. (2009). Seed germination behaviour of *Diplotaxis tenuifolia*. *EurAsian Journal of BioSciences*, 3, 107-112. <http://dx.doi.org/10.5053/ejobios.2009.3.0.14>
- Sánchez-Yélamo, M. D. (2009). Relationships in the *Diplotaxis-Erucastrum-Brassica* complex (Brassicaceae) evaluated from isoenzymatic profiles of the accessions as a whole. Applications for characterisation of phylogenetic resources preserved ex situ. *Genetic Resources and Crop Evolution*, 56, 1023-1036. <http://dx.doi.org/10.1007/s10722-009-9423-5>
- Schulz, O. E. (1936). Cruciferae, 17B:227-658. In A. Engler & H. Harms (Ed.), *Die natürlichen Pflanzenfamilien*. Verlag von Wilhelm Engelmann. Leipzig, Germany.
- Singh, A., & Hall, M. (2013). Update on the current understanding of biosynthesis, biology and transport of glucosinolates in Brassica plants. *International Journal of Agriculture and Food Science Technology*, 4, 37-50.
- Thanos, C. A., Kadis, C. C., & Skarou, F. (1995). Ecophysiology of germination in the aromatic plants thyme, savoury and oregano (Labiatae). *Seed Science Research*, 5, 161-170. <http://dx.doi.org/10.1017/S0960258500002786>
- Warwick, S. I., & Black, L. D. (1997). Molecular phylogenies from theory to application in *Brassica* and allies (tribe Brassiceae, Brassicaceae). *Opera Botanica*, 132, 159-168.
- Warwick, S. I., & Sauder, C. (2005). Phylogeny of tribe Brassiceae (Brassicaceae) based on chloroplast restriction site polymorphisms and nuclear ribosomal internal transcribed spacer and chloroplast trnL intron sequences. *Canadian Journal of Botany*, 83, 467-483. <http://dx.doi.org/10.1139/b05-021>

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