SOME PERSPECTIVES ON ROCKET AS A VEGETABLE CROP: A REVIEW

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Summary

Baby leaf rocket is consumed worldwide as a salad vegetable. It is usually mixed with other baby leaf crops, such as spinach and lettuce, to form a mesclun-type salad. Rocket crops have become popular due to their distinct taste and textural appearance in mixed salads. There are two common forms of rocket that are commercially cultivated, a perennial species (*Diplotaxis tenuifolia* (L.) DC.) known as perennial wall rocket and an annual species (*Eruca sativa* Mill.) known as annual garden rocket. The popularity of baby leaf crops has increased in recent years due to consumer demand for a convenient, nutritious and easily accessible product. The baby leaf salad sector is now a significant part of the leafy vegetable market, with growth in this sector estimated to continue. The leaves of cultivars of perennial wall rocket and annual garden rocket have been bred to look similar, allowing for a year-round supply of produce. Despite this, there are many differences between the species that affect their responses to abiotic factors during growth and storage. This paper aims to provide some perspectives on the historical importance, botanical classification and cultivation techniques of these economically important plants.

key words: arugula, baby leaf, botanical, glucosinolates, history, rucola, salad, vitamin C

HISTORICAL AND CULTURAL IMPORTANCE OF ROCKET

‘Rocket’ is a common name used for some species in the family Brassicaceae that have a pungent aroma and a sharp taste. They are native to the Mediterranean and Near East, and they possibly acquired their original common name from the Latin-speaking Roman citizens who inhabited this area. The common name and many of its derivatives, including rughetta, rucola, roquette and others, most likely descended from the Latin word roc, meaning harsh or rough (Pignone 1997). Common names currently used to describe these species include roquette, rucola, arugula and rocket. As with all common names, the choice of common name varies with ethnicity, location and language group.

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These differences all contribute to the confusion surrounding the correct informal labeling of these species.

Rocket has been well-documented in ancient literature, where it is called euzeleon, gargir and oroth (Yaniv et al. 1998). The leaves have been used for thousands of years to season food and oil, for the production of deodorants and cosmetics and for medicinal purposes (Blangiforti & Venora 1997, Pratap & Gupta 2009). These plants have had an interesting and turbulent journey, much of which has occurred in the last 20 years, to becoming the favored leafy greens that they are today. To effectively describe rocket’s significance and popularity as a crop, it is useful to place its recent global utilization into a historical context.

“Th’ eruca, Priapus, near thee we sow to rouse to duty husbands who are slow.” (Davenport 1869).

The above inscription appears on the base of statues of the Greek God Priapus and refers to rocket’s reputation as an aphrodisiac. Rocket’s ability to restore vigor to sexual organs is well-documented and celebrated throughout ancient literature (Davenport 1869, Fernald 1993, Barillari et al. 2005). Priapus was believed to be the protector of the reproductive productivity of livestock, plants and human male genitalia. This inscription illustrates the significance that rocket plants played in the religious beliefs of ancient civilizations of the Mediterranean region.

Publius Vergilius Maro, who is most commonly known by the Anglicized name Virgil, was a famous naturalist and poet who lived in Rome between 70-19 B.C. Virgil is known to have described rocket as follows:

“Th’ eruca, plant, which gives jaded appetite the spur.” (Stark 1980).

This description emphasizes rocket’s aphrodisiac properties concerning the sexual appetite, which was believed to be important during this period. The aphrodisiac properties of rocket plants are still regarded as excellent today (Pratap & Gupta 2009). Rocket’s extensive and continued description as an aphrodisiac subsequently led to the banning of these plants in monastic gardens, as aphrodisiac or mind-altering substances were forbidden (Stark 1980, Mascagni 1987). Despite this ban, rocket species were extensively grown in monastic herb gardens, and they were important for flavoring foods and enhancing medicinal remedies.

Throughout the Abrahamic period (500-300 B.C.), rocket was employed in a wide variety of applications. Passages of the Old Testament describe the collection of leaves from wild rocket plants, which in this period were called oroth:

“One of them went out into the field to gather oroth, and found a wild vine and gathered from it his lap full of wild gourds, and came and cut them up into the pot of pottage, not knowing what they were. And they poured out for the men to eat.” II Kings 4: 39-40.

This passage illustrates that rocket was a useful forage food during this period. The mistake of the author in referring to oroth as growing from a vine is comparable to other grammatical and translation discrepancies contained in the Old Testament (Nicole 1959). Many scientists agree that the garden vegetable called oroth in
these verses is in fact rocket (Zohary 1982, Yaniv et al. 1998, Duke et al. 2008).

During the Hellenistic period (323–146 B.C.), rocket was mentioned many times, particularly in the Mishna and Talmud. These Jewish manuscripts describe rocket’s use as a spice, food and medicine (Yaniv et al. 1998). The uses of rocket recorded in these manuscripts reflect the major ways in which rocket has been used since the Hellenistic period across large geographical areas, including flavoring foods and producing medicines.

Rocket’s importance as a multi-use vegetable was primarily recorded by Caius Plinius Secundus, or Pliny the Elder, who lived during the period 23–79 A.D. Pliny, like Virgil, shared a passion for naturalist writings and identified and recorded rocket’s potential for many different medicinal uses. A total of twelve applications were recorded, an example of which includes the following:

“So agreeable is its flavour as a savouring for food, that the Greeks have given it the name of ‘euzomon’. It is generally thought that rocket, lightly bruised, and employed as a fomentation for the eyes, will restore the sight to its original goodness, and that it allays coughs in young infants.” (Bostock & Riley 1855).

Such medicinal claims are common from Pliny, who is claimed to have amassed a total of 20,000 general facts contained in 36 volumes (Fagan 2006). Nonetheless, rocket’s importance in the Mediterranean and Near East increased significantly in the first century A.D. Not only was rocket believed to be an aphrodisiac with religious significance, but it also had a wide array of medicinal properties. The uses of rocket species as salads and spices were also recorded during this period by the Roman botanist Dioscorides, in Materia Medica [therapeutic properties for healing], which was written in the first century A.D. (Gunther 1968).

Although rocket species have had a long and dubious journey to their current widespread cultivation, it is interesting to note that the surge in production did not occur until the mid-1990’s. Increased interest in these species was largely a result of the International Plant Genetic Resources Institute (IPGRI) workshops, which were held in 1994 in Lisbon, Portugal and in 1995 in Legnaro, Italy (Padulosi 1995, Padulosi & Pignone 1997). These workshops aimed to maintain genetic diversity and to promote an improved understanding of different rocket species, presenting them as viable alternative crops for use in mixed salads.

In the last quarter of a century, three major changes have occurred that lead to the rise of rocket as an attractive alternate leafy crop. First, value-added products were developed, particularly in the processed market. Second, new leafy species were introduced, particularly baby leaf crops such as rocket. Third, consumers have increasingly focused on the nutritional quality and value of the crops that they consume (Ryder 2002). These factors, combined with the unique taste and visually pleasing texture of rocket leaves, have facilitated the rise of rocket’s popularity globally. Rocket plants have had an interesting journey to their current widespread culti-
vation, and the future of these crops looks bright.

**BOTANICAL CLASSIFICATION OF ROCKET SPECIES**

The Brassicaceae family

The family Brassicaceae currently includes 3,709 species and 338 genera (Rich 1991, Warwick *et al.* 2006, 2009). Many of these species are used for fibers, oils, condiments, vegetables and salads (Gómez-Campo 1980, 1999, Gómez-Campo & Prakash 1999). Perennial wall rocket and annual garden rocket belong to this large and economically important family, with their botanical classification illustrated in Fig. 1.

![Botanical classification diagram](image)

Fig. 1. Current botanical classification of perennial wall rocket (*Diplotaxis tenuifolia* (L.) DC.) and annual garden rocket (*Eruca sativa* Mill.).

**The Brassicaceae tribe**

The tribe Brassiceae is one of the 13 to 19 disputed tribes recognized in the family Brassicaceae (Warwick *et al.* 2009). Species in this tribe are characterized by conduplicate cotyledons and/or bi-segmented fruits, which contain seeds in either one or both segments (Gómez-Campo 1999). This tribe is comprised of 46 poorly defined genera and approximately 230 species, across which a wide range of diversity is present (Warwick *et al.* 2006, Koch & Al-Shehbaz 2009).

The Brassicaceae tribe constitutes a natural group, and it is the most economically important and botanically distinct tribe from the Brassicaceae family (Al-Shehbaz 1985, Gómez-Campo 1999). This tribe was originally distributed around the Mediterranean region, Southwestern Asia and South Africa (Crespo *et al.* 2000). Many of the species thrive in a temperate environment and can grow successfully over a wide range of soil types, including infertile and heavily leached profiles.
Molecular markers, such as chloroplast DNA (ctDNA), have recently been used to confirm that the Brassiceae tribe does not conform to the traditional generic morphological boundaries recognized by Schulz (1936) and Gómez-Campo (1999). Some members of this tribe are monophyletic, while the majority of species form a phylogeny, as they do not share a common ancestor. Species in this grouping have been further classified into the Brassicinæ subtribe (Warwick et al. 1992, Warwick & Sauder 2005).

The Brassicinæ subtribe

The subtribe Brassicinæ has been further classified into the Rapa/Oleracea and Nigra lineages (Pradhan et al. 1992, Prakash et al. 2009). These lineages are morphologically similar and have been primarily classified using ctDNA and the diversity of glucosinolates. Perennial wall rocket and annual garden rocket have been placed into the Rapa/Oleracea lineage.

The Rapa/Oleracea lineage

Ten genera belong to the lineage Rapa/Oleracea. Four of these genera, including Brassica, Diplotaxis, Erucastrum and Eruca, are in the subtribe Brassicinæ (Warwick & Black 1997). The classification of inter-generic species is primarily based on chromosomal numbers (Warwick & Hall 2009).

The Diplotaxis genus

The name Diplotaxis originates from the Greek words ‘diplos’, which translates to double, and ‘taxis’, which translates to row; these words reflect the way in which seeds are located in the siliquae (Bianco 1995). Diplotaxis spp. originated in the Mediterranean and Near East, with a major center of diversity in the Western Mediterranean (Martínez-Labarde 1997, Eschmann-Grupe et al. 2003).

The taxonomy of Diplotaxis spp. has been revised several times and remains problematic regarding the morphological characters, molecular markers and diversity of glucosinolates used to classify species (Eschmann-Grupe et al. 2003, D’Antuono et al. 2008). There is little morphological variability between species of this genus; however, the highest level of diversity exists in the Iberian Peninsula and Northwestern Africa (Martín & Sánchez-Yélamo 2000). Some of the species extend eastward into present day Pakistan and India, with five endemic species known in the Cape Verde Islands and one in Western Nepal (Martín & Sánchez-Yélamo 2000). Until recently, the distribution of Diplotaxis spp. was restricted to the region of origin due to a lack of global interest in their commercial utilization.

In many regions, Diplotaxis spp. are weeds of economic importance. Perennial wall rocket is considered to be a weed in regions of Europe, the United States of America, Australia, New Zealand and Argentina (Kleemann et al. 2007, Pratap & Gupta 2009). Its perennial nature, combined with its capacity to produce large numbers of viable seeds, makes this species difficult to control as a weed. The Southern states of Australia, excluding Tasmania, have designated perennial wall rocket as a noxious weed (Parsons & Cuthbertson 1992, Kleemann et al. 2007), with Victoria, South Australia and Western Australia all attempting to control its spread. Although perennial wall rocket is
considered to be a weed in many areas, the commercial production of this species is permitted.

**Botanical description of perennial wall rocket**

Perennial wall rocket is an erect herbaceous plant that has elongated leaves and a deep tap root (Pratap & Gupta 2009). Under natural conditions, the mature plant can grow to a height of 80 cm. The plant possesses a coarse and woody base with retrorse hairs in the lower parts (Bianco 1995). Leaves are fleshy, oblong and deeply lobed, with pointed apexes (Fig. 2).

![Illustration of the structure and form of perennial wall rocket](image)

Fig. 2. Illustration of the structure and form of perennial wall rocket (*Diplotaxis tenuifolia* (L.) DC.). The image is presented on a scale of 3/5 the actual size (Britton & Brown 1913).

Flowers are bright yellow, medium in size and have four rounded petals 8 to 15 mm long. They are arranged in racemes with oblong or linear sepals, and they have six stamens and are tetradynamous (Pratap & Gupta 2009).

The fruits are cylindrical, ranging in length from 2 to 4 cm, and they are semi-appressed along the stems (Pratap & Gupta 2009). Seeds are light brown, with an average of 5,000 seeds per gram. They are ellipsoid in shape, slightly flattened with medium lumina, and are wingless with conduplicate cotyledons (De Leonards *et al.* 1997, Martínez-Laborde 1997). Germination occurs during the autumn, with plants forming slow growing rosettes and tap root systems. Flowering depends on seasonal conditions, but it can occur 28 days after germination (Kenigsbuch *et al.* 2009).

**The Eruca genus**

There is disagreement over the number of species in this genus based on the ease with which members can cross pollinate. Some authorities only accept a single species, while others recognize up to four different species (D’Antuono *et al.* 2008). In this genus, the greatest genetic variability is found in Morocco and Spain (Pratap & Gupta 2009). Species exhibit a large range of morphological variability, ranging from round leaves to heavily serrated leaves.

This genus, like the *Diplotaxis*, is native to the Mediterranean region (Pignone 1997, Pratap & Gupta 2009). Annual garden rocket has been cultivated as a salad and spice in areas of Southern Europe and Central Asia for centuries (Ryder 2002, Pratap & Gupta 2009). The name *Eruca* originates from the Latin words ‘uro’ or ‘urere’, which translates to burn and relates to the acrid taste of the leaves caused by the presence of glucosinolates (Bianco 1995).

Annual garden rocket is the most commonly grown species in this ge-
nus and is cultivated throughout the Mediterranean, Central Europe, Afghanistan, Northern India, Continental America, South Africa and Australia (Pratap & Gupta 2009). Leaves are used in mixed salads, adding a unique flavor to these dishes. Annual garden rocket is also cultivated in Pakistan and India where it is used as an industrial oil crop.

**Botanical description of annual garden rocket**

Annual garden rocket is a low-growing herbaceous plant that, under natural conditions, grows to a height of 40 cm. The lyrate-pinnatifid leaves are arranged in a rosette (Pratap & Gupta 2009). This species has a slender tap root and a rigid largely un-branched hairy stem. Leaves on upper parts of the plant are pinnatifid, with long-oblong terminal lobes, and are either coarsely toothed or lobed (Fig. 3).

![Fig. 3. Illustration of the structure and form of annual garden rocket (Eruca sativa Mill.). The image is presented on a scale of 1/2 actual size (Britton & Brown 1913).](image)

Leaves of annual garden rocket are dark green and less than 20 cm long. They range in shape from smooth and round to heavily lobed or serrated. Flowers are larger than those of *Diplotaxis* spp. and are white or light yellow with purple venations. Flowers contain four petals 15 to 20 mm long and have tetradynamous stamens (Bianco 1995). The number of flowers on a given plant is relatively low, and the flowers are borne on small terminal racemes (Fig. 3).

The siliques are ovate-oblong or oblong and range in length from 2 to 3 cm (Bianco 1995). Seeds are usually brown but can range from yellow brown to olive green (De Leonardis et al. 1997), with an average of 500 seeds per gram, making the seeds approximately ten times heavier then the seeds of perennial wall rocket.

**DIVERSITY AMONG ROCKET SPECIES**

Rocket is a common name used for both *Diplotaxis* and *Eruca* spp. (Bianco 1995, Gómez-Campo 1995, Martínez-Sánchez et al. 2007). It is used to group plants that have similar morphology and a bitter taste resulting from the presence of glucosinolates (Halkier & Gershenzon 2006). These two main factors, similar morphology and taste, are the basis for which the common name rocket and its various derivatives are used worldwide.

*Diplotaxis* spp. generally have uniform leaf morphology, while *Eruca* spp. have greater variability (Bianco 1995, Warwick 1995, Bennett et al. 2006). This natural variation has been used in the breeding programs of both perennial wall rocket and annual
garden rocket for the development of commercial baby leaf cultivars for use in the salad industry. These species hybridize with other members of respective genera through sexual reproduction, ovary culture, embryo culture and protoplast fusion (Salisbury 1989, Fahlson et al. 1997). Intergeneric hybrids have also been produced between perennial wall rocket and annual garden rocket, suggesting that there is a high level of genetic similarity between the species (Harberd & McArthur 1980, Bang et al. 2003).

Perennial wall rocket is unique among the Brassicaceae family because it is a C3-C4 intermediate. It has a low CO2 compensation point and Kranz-like leaf anatomy, where the leaf veins are surrounded by bundle-sheath cells. This characteristic is important in breeding programs because C3-C4 intermediates exhibit low photorespiration activity, and they are better able to grow under hot dry conditions than C3 plants. These plants also do not have the problem of high energy requirements associated with C4 carbon fixation. The use of perennial wall rocket in hybridization programs between wild and cultivated crops is also currently of interest, as a fertile amphidiploid (Kaneko et al. 2009).

Selection techniques have been used to standardize the visual characteristics of rocket species for cultivation in the salad industry. Singh (1975) showed that crossing an annual garden rocket variant with deeply serrated leaves with a normal leaf type resulted in a F1 dominant normal leaf shape. The F2 population had a 3:1 segregation ratio of normal to deeply serrated leaves. The ease of crossing between morphologically different populations of this species has, in recent years, led to the production of cultivars of annual garden rocket that exhibit leaves resembling the heavily serrated leaves of perennial wall rocket. These cultivars are easily recognizable as rocket to consumers and have the superior vigor of the annual form.

The presence of glucosinolates in the plant kingdom is unique to the order Brassicales, with some minor exceptions (Halkier & Gershenzon 2006). The expression of glucosinolates in plants arose 10 to 15 million years ago as a result of evolutionary pressures (Windsor et al. 2005, Wheat et al. 2007). The biological role of glucosinolates is to deter herbivores and pathogens from feeding on plant parts and therefore most likely arose as part of a defense mechanism. The presence and diversity of glucosinolates in both perennial wall rocket and annual garden rocket have been well-studied and used in botanical classification systems (Daxenbichler et al. 1991, Tsukamoto et al. 1993, D’Antuono et al. 2008). The major glucosinolates found in perennial wall rocket include glucoraphanin, 4-hydroxyglucobrassicin and glucobrassicin, while in annual garden rocket they include glucoraphanin, glucobrassicin and 4-methoxygluco-brassicin (D’Antuono et al. 2008).

**IMPORTANT NUTRITIONAL COMPOUNDS FOUND IN ROCKET**

The role of glucosinolates in plants

Glucosinolates are nitrogen- and sulfur-rich compounds, with over 120 different types having been identified (Halkier & Gershenzon 2006). They are nutritionally important to humans
because they have the capacity to provide protection against carcinogens, mutagens and other forms of toxicity (Balch & Balch 2000, Ward 2002). Glucosinolates also contain toxic, growth-inhibiting and feeding-deterrent signals to a wide variety of organisms (Burow et al. 2006, Kim & Jander 2007, Hopkins et al. 2009). The induction of glucosinolates is strongly associated with biotic stress factors resulting from a range of sources including fungal pathogens, bacterial infection, insect feeding and generalist or specialist herbivores (Rostás et al. 2002, Agerbirk et al. 2009, Dam et al. 2009).

The biosynthesis of glucosinolates

Glucosinolates are formed from eight amino acids and are classified, according to their amino acid precursors, into three distinct groups: aliphatic, benzenic and indolic (Sønderby et al. 2010, Table 1).

| Aliphatic glucosinolates | Benzenic glucosinolates | Indolic glucosinolates |
|-------------------------|------------------------|-----------------------|
| L-alanine               | L-phenylalanine        | L-tryptophan          |
| L-leucine               | L-tyrosine             |                       |
| L-isoleucine            |                        |                       |
| L-valine                |                        |                       |
| Methionine              |                        |                       |

Table 1. The grouping of glucosinolate type based on their amino acid precursors.

The biosynthesis of glucosinolates occurs in three distinct phases. First, amino acids undergo chain elongation through the insertion of methylene groups into their side chains. Second, the amino acid is altered to produce the core structure of the glucosinolate. Third, the glucosinolate is modified by secondary transformations (Halkier & Gershenzon 2006). These major steps are well-known and supported by many studies of Arabidopsis.

The biosynthesis of glucosinolates is regulated by genetic and environmental factors, but the mechanisms are poorly understood (Felice et al. 2006, Zhang et al. 2006, Yan & Chen 2007). The molecular structure of glucosinolates can change in response to biotic stress caused by cellular damage, and the change increases the plant’s deterrent characteristics against further damage through direct toxicity (Kim & Jander 2007). This variability in glucosinolate formation partly explains the level of diversity in plants, with genetic factors directly influencing the type of glucosinolate that can form.

Perennial wall rocket is known to contain 11 different glucosinolates, while annual garden rocket has 14 glucosinolates (D’Antuono et al. 2008). Of these, some are indolic glucosinolates, most commonly found in the Rapa/Oleraceae lineage. The diversity of glucosinolates in rocket species is related to their botanical classification, with glucoraphanin present in the leaves of both species at high concentrations (Force et al. 2007, Kim & Ishii 2007). Most glucosinolates in these rocket species correspond to methionine-derived components, while both benzenic and indolic glucosinolates have also been identified in the leaves.

The glucosinolate-myrosinase system

Glucosinolates are stored in plant vacuoles, while myrosinase is localized in the cytosol and in specialized myrosin cells (Bones & Rossiter 1996, Bennett et al. 2006). In Arabidopsis, myrosinase has also been
shown to occur in S-cells and is found in the pedicel. The wide distribution of myrosinase in plants means that this substance is available for immediate degradation of glucosinolates at the site of damage.

Fig. 4. Depiction of the glucosinolate-myrosinase reaction and the various compounds produced under different conditions. ESP: epithiospecifier locus (Rask et al. 2000).

Once cellular damage occurs, the glucosinolate comes in contact with myrosinase, causing a reaction that releases glucose, sulfate and several hydrolysis products including epithionitrile, thiocyanates, nitriles, isothiocyanates, oxazolidine-thione and other less-common compounds (Rask et al. 2000, Fig. 4).

The hydrolysis products formed by this reaction are known to be dependent on the structure of the glucosinolate and the conditions under which the reaction takes place. For example, the pH during hydrolysis has been shown to be an important factor in the formation of nitriles in vitro. This reaction is most likely to occur at a pH of 4 and/or in the presence of Fe$^{2+}$ ions (Bennett et al. 2006, Fig. 4).

It is possible that variations between genetic factors of perennial wall rocket and annual garden rocket, combined with differences in their physiology, will result in a change in glucosinolate profile and concentration when grown under different conditions.

**The role of vitamin C in plants**

Another important compound found in rocket that is nutritionally important and present at high concentrations in the leaf is vitamin C. This compound is known to be effective in neutralizing reactive oxygen species (ROS), and its presence relates to the nutritional quality of crops. The term vitamin C is used to collectively refer to L-ascorbic acid (AA), L-dehydro-
ascorbic acid (DHAA) and their various derivatives. Vitamin C is a metabolite with strong antioxidant properties and is an important cofactor for enzymes. Humans cannot synthesize vitamin C because they lack the enzyme L-gulonolactone oxidase, so they must therefore obtain the vitamin from food (Nishikimi et al. 1994, Woodall & Ames 1997). Vitamin C has a direct effect on the health of skin, gums and blood vessels, and it is also known to influence collagen formation, the absorption of inorganic iron and the enhancement of the immune system (Conklin et al. 1999, Lee & Kader 2000).

Vitamin C is abundant in plants and can account for up to 10% of the total soluble carbohydrate levels (Noctor & Foyer 1998, Smirnoff & Wheeler 2000). The pathway of vitamin C biosynthesis in plants has been described and is affected by developmental triggers and environmental cues (Pastori et al. 2003). Vitamin C concentration in the leaves of rocket species is high compared to that of other leafy crops, which means that rocket has the potential to contribute high quantities of this antioxidant to the human diet (Bennett et al. 2006, Kim & Ishii 2007, Martinez-Sánchez et al. 2008).

The biochemical roles of vitamin C in plants include the elimination of ROS, ensuring that α-tocopherol remains in a reduced state so that it can be utilized, and its role as a substrate for AA peroxidase, which is involved in the production DHAA (Conklin et al. 1999, Ishikawa & Shigeoka 2008). The highest concentration of ROS is found in the chloroplasts and mitochondria of cells. If the production of these compounds is not neutralized by vitamin C, cell damage can result (Ishikawa & Shigeoka 2008). One of the most common ROS found in plants is hydrogen peroxide (H₂O₂); this compound has the ability to affect cascade reactions if not neutralized, leading to the production of more toxic molecules such as hydroxyle radicals and lipid peroxides (Noctor & Foyer 1998). AA is effective in neutralizing H₂O₂ in the L-galactose pathway, the pathway through which vitamin C is synthesized in plants (Asada 1997).

The role of vitamin C in plants has also been linked to a range of biological processes including plant growth, cell death, the response to pathogenic infection and senescence (Pignocchi & Foyer 2003, Barth et al. 2006, Linster & Clarke 2008). After senescence occurs, there is a reduction in AA concentration that is also correlated with an increase in ROS (Zimmermann & Zentgraf 2005). Vitamin C is also a protective agent against environmental factors including ozone stress, high levels of UV radiation and high temperature exposures (Conklin & Barth 2004, Gao & Zhang 2008, Linster & Clarke 2008). In Arabidopsis mutants, Larkindale et al. (2005) have shown that AA plays an important function in controlling ROS, particularly under high temperature and UV conditions. Although vitamin C is known to be influential in a wide range of biochemical reactions, the cascade of downstream reactions and enzymes are poorly understood.

The synthesis of vitamin C in plants

The pathway for vitamin C formation in plants is the L-galactose pathway (Wheeler et al. 1998,
Giovannoni 2007), which converts GDP-D-mannose to L-ascorbate through four successive intermediates that are enabled by six enzymes, as described in Fig. 5.

D-mannose 1-phosphate

\[ \Downarrow \] GTP-mannose pyrophosphorolase

GDP-D-mannose

\[ \Downarrow \] GTP-mannose-3,5-epimerase

GDP-L-galactose

\[ \Downarrow \] L-galactose guanyltransferase

L-galactose 1-phosphate

\[ \Downarrow \] L-galactose-1-P phosphatase

L-galactose

\[ \Downarrow \] L-galactose dehydrogenase

L-galactose-1,4-lactone

\[ \Downarrow \] L-galactono-1,4-lactone dehydrogenase

L-ascorbate

Fig. 5. Depiction of the L-galactose pathway of ascorbate synthesis in plants. Pathway metabolites from D-mannose-1-phosphate through L-ascorbate are shown with the enzymes associated with the formation to the right of the pathway. Figure adapted from Giovannoni (2007).

The factors that control the distribution and accumulation of vitamin C in plant tissue are poorly understood, particularly concerning vitamin C accumulation in non-photosynthetic and storage tissue (DeBolt et al. 2007). The synthesis of AA in plants occurs in the cytosol of cells (Loewus 1999). The AA is then translocated to the chloroplast, vacuole and apoplast (Rautenkrantz et al. 1994). Franceschi & Tarlyn (2002) have shown that the accumulation of AA in plant organs is likely to follow localized synthesis and that translocation of AA from source to sink occurs via phloem (DeBolt et al. 2007). A similar relationship has also been reported by Tedone et al. (2004) in potato tubers. The transport of vitamin C occurs across a steep gradient, indicating the use of co-transport. The methods of transport around the plant are poorly understood, with the majority of work focusing on AA, which makes up the largest component of vitamin C in plants.

SUMMARY OF THE DIFFERENCES BETWEEN ROCKET SPECIES

Both species of rocket share characteristics consistent with their close botanical classification, including similarities in morphology, origin and the diversity of glucosinolates. It is understandable that informally, these species have been historically grouped together for convenience.

Breeding programs for annual garden rocket have targeted cultivars for use in the baby leaf salad market and have primarily focused on the increased expression of heavily serrated leaves, which closely resemble those of perennial wall rocket. This has enabled the commercial production of annual garden rocket during seasons of plant growth that do not favor perennial germination and growth. The combination of similarities between cultivars of different rocket species creates a problem because different cultivars look the same but do not respond equally to abiotic factors.
Table 2. Illustration of the main differences between perennial wall rocket (*Diplotaxis tenuifolia* (L.) DC.) and annual garden rocket (*Eruca sativa* Mill.).

| Variable            | Perennial wall rocket | Annual garden rocket |
|---------------------|-----------------------|----------------------|
| Form                | Perennial             | Annual               |
| Seed size           | 5,000 seeds/g         | 500 seeds/g          |
| Uses                | Salad, condiment      | Salad, condiment, oil, pesticide |
| Carbon fixation     | C₃-C₄ intermediate    | C₃                   |
| Root system         | 30 to 40 cm           | 10 to 20 cm          |
| Growth rate (summer)| 30 to 40 days to harvest | 20 to 30 days to harvest |
| Glucosinolates      | 11 known types        | 14 known types       |

The major differences between perennial wall rocket and annual garden rocket are summarized in Table 2. When compared to perennial wall rocket, the seeds of annual garden rocket are approximately 10 times heavier (Table 2). This difference influences the germination of rocket species, as larger seeds contain greater stored reserves than smaller seeds (Hall et al. 2012). Annual species are also known to develop more rapidly than perennial species (Pitelka 1977, Jackson & Roy 1986), because they divert more energy into the production of reproductive structures and less into vegetative growth (Bazzaz et al. 1987, Hancock & Pritts 1987, Garnier 1992). The root system of perennial plants is deeper than annual plants, which is relevant to a crop that is harvested multiple times by the removal of above-ground vegetation. Therefore, the amount of stored reserves in the root system may be a critical factor dictating the successful regrowth of leaves after harvest.

The carbon fixation cycle is different between the different species; perennial wall rocket is a C₃-C₄ intermediate plant and annual garden rocket is a C₃ plant (Table 2). This difference affects the range of environmental conditions under which respective species can continue to metabolize and grow, with perennial wall rocket better able to photosynthesize at higher temperatures than annual garden rocket. The diversity of glucosinolates is also different between rocket species, with 11 known glucosinolates in perennial wall rocket and 14 in annual garden rocket (Table 2).

The utilization of rocket species is similar for both perennial wall rocket and annual garden rocket, both of which are extensively used around the world in salads (Table 2). Annual garden rocket is also used as an industrial oil and pesticide base due to its annual nature and large oil yield capacity.

**CULTIVARS OF PERENNIAL WALL ROCKET AND ANNUAL GARDEN ROCKET**

Selective breeding of cultivars from wild plants is performed to improve the expression of desirable traits for commercial production (Chahal & Gosal 2002, Acquaah 2007). These traits may include higher production and productivity, stress resistance and uniformity of growth (Kalia 2006). The breeding of cultivars for commercial use invariably alters the response of species to environmental conditions because plants...
have been selected to remove natural variation in the resulting population (Acquaah 2007). This means that, between individual plants in the resulting cultivar, very little variation is experienced. The uniformity among plants allows for better crop management and superior plants for cultivation compared to the wild plants from which they were bred. Leaves of both species are usually harvested once they reach a commercial size specification of 10 to 15 cm, further necessitating the need for uniformity between plants.

In the last 20 years, with increased interest in rocket species for use in the salad market, many seed companies have included perennial wall rocket and annual garden rocket in their respective breeding programs. The breeding of plants for appearance, commercial quality, shelf life, nutritional quality and other qualities is commonly performed during cultivar development. These traits have therefore been considered in the breeding of rocket species. It is impossible to estimate the number of cultivars for respective rocket species because seed companies hold many more cultivars than they commercially sell and are reluctant to provide such information.

CONCLUSION

Through the detailed description of perennial wall rocket and annual garden rocket, it is clear that these species share many similarities, as reflected by their close botanical classifications and similar uses. However, it is also clear that these species cannot be considered similar from an agronomic perspective. These differences between the species mean that, although they have been bred to look similar, these crops need to be managed commercially in different ways. In response to differences in plant responses to abiotic factors resulting from differences in carbon systems, habits and reproductive cycles. These species clearly represent plants with important historical significance and high nutritional value for modern diets. If cultivation of these crops is to be improved, it is necessary to view the management of these crops separately so that improvements in yield, quality and nutrition can result.

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**ROKIETTA JAKO ROŚLINA WARZYWNA: PRZEGLĄD**

**Streszczenie**

Młoda rokietta liściasta spożywana jest na całym świecie jako warzywo sałatkowe. Mieszając się z innymi młodymi warzywami liściastymi, takimi jak: szpinak i sałata, by otrzymać sałatkę typu mesclun. Rośliny rokietty stały się popularne ze względu na ich specyficzny smak i wygląd w sałatkach mieszanych. Istnieją dwa powszechnie spotykane rodzaje rokietty, które są uprawiane komercyjnie: gatunek wieleletni – dwurząd wąskolistny (*ang. perennial wall rocket*) (*Diplotaxis tenuifolia* (L.) DC.) i gatunek jednoroczny – rokietta siewna (*ang. garden rocket*) (*Eruca sativa* Mill.). Popularność młodych roślin liściastych wzrosła w ostatnich latach ze względu na zapotrzebowanie konsumentów na pożywne i łatwo dostępne produkty. Sektor sałatek z młodych liści stanowi już znaczącą część rynku warzyw liściastych i spodziewany jest dalszy rozwój w tym sektorze. Liście odmian uprawnych dwurządu wąskolistnego i rokietty siewnej wyhodowano tak, że są do siebie podobne, co pozwala na dostawę tego produktu przez cały rok. Pomimo tego, istnieje wiele różnic między tymi gatunkami, które mają wpływ na ich reakcje na czynniki abiotyczne w okresie wzrostu i przechowywania. Niniejszy artykuł ma na celu przedstawienie historycznego znaczenia, klasyfikacji botanicznej i techniki uprawy tych ważnych gospodarczo roślin.

ROKIETTA JAKO ROŚLINA WARZYWNA: PRZEGLĄD