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Quality and Postharvest Physiology of Rocket Leaves

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ABSTRACT

Rocket is a collective name of three main vegetable species [*Eruca sativa* Mill., *Diplotaxis tenuifolia* (L.) DC and *Diplotaxis muralis* (L.) DC] used for human consumption, in several countries of the Mediterranean region. It is a popular leafy vegetable consumed in raw salads, either alone or in a mixture with other vegetables; it is usually marketed as leaf bunches or as fresh-cut individual leaves in modified atmosphere packages. Color is the most important quality characteristic of the rocket leaves and any change of the normal green color could be a limiting factor for their marketability. The major postharvest problem of this vegetable is its rapid senescence, which is expressed primarily as yellowing, associated with chlorophyll degradation, but wilting is also a serious problem. The high perishability of rocket is a consequence of its extremely high respiration rate. Since it is a minor vegetable, very few research data are available about its postharvest features or regarding the best methods of handling, transporting and storage. A temperature of 0°C and a close to 100% relative humidity are effective storage tools, but currently the application of the above conditions is limited, since rocket usually is shipped and stored at 10°C without maintaining relative humidity at the optimum levels. Modified atmosphere packaging could be a promising postharvest handling alternative, but more research is required to answer basic questions for the postharvest physiology of this vegetable, including the further investigation of the role of ethylene. This review compiles the existed knowledge regarding the effect of the commonly applied postharvest handling procedures of rocket leaves on its quality and postharvest physiology and additionally it proposes areas requiring further study.

Keywords: arugula, ethylene, fresh-cut, minimally processed, respiration, senescence
Abbreviations: FW, fresh weight; **GSLs**, glucosinolates; **ITCs**, isothyocyanates; **MAP**, modified atmosphere packaging; **RH**, relative humidity

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INTRODUCTION

The rocket plant [also known as arugula (English), roquette (French), rucola or rughetta (Italian) and ρόκα (Greek)] has been known since the ancient times, listed in the Greek herbal of Dioscorides (*Material Medica*), written in the first century (Morales and Janick 2002). Rocket is a collective name representing some species within the *Brassicaceae*

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Fig. 1 Color rating scale of rocket leaves (1 = dark green, 2 = light green, 3 = yellowish-green, 4 = greenish-yellow, 5 = yellow). Leaves with a score of 3 or higher are considered unmarketable.

family. In the Mediterranean region, three main rocket species, used for human consumption, can be found (Pignone 1997): *Eruca sativa* Mill., an annual species frequently cultivated, as well as *Diplotaxis tenuifolia* (L.) DC and *Diplotaxis muralis* (L.) DC both being perennial species, which are mostly collected from the wild field, but in the same areas they are also cultivated. A wild type of rocket, known as *Eruca sativa* Mill. subspecies *vesicaria* (L.) Cav., is also rather well represented in the Mediterranean flora. The above-mentioned nomenclature follows the Flora of Italy, even though this is probably an incomplete classification. Although there are several significant differences among the above species regarding growing habits, leaf morphology and taste (Pignone 1997), any differences on pre- and postharvest physiology and composition among them are still unknown.

Rocket has been used as a food for a long time in several Mediterranean countries, but its popularity is now increasing remarkably, while in many countries it is regarded as a specialty food or even a delicacy. It is usually consumed fresh in salads, either alone or in a mixture with other vegetables; in some cases it is cooked as a pot-herb mixed with other vegetables for the preparation of special dishes and more recently rocket sprouts are also consumed. Besides culinary uses, rocket is also considered by some people a medicinal plant with many assumed properties.

Beyond some general references, only little specific information is available regarding quality and postharvest physiology of the rocket. To fill the existed gap of knowledge, this review compiles the currently available information on this subject and additionally it proposes some further required study.

QUALITY

The quality of rocket is a combination of characteristics, attributes and properties that give the commodity a high value for marketing. The appearance of the product is the primary criterion for purchasing. Therefore, this quality parameter is the most important aspect for judging the quality of the product along the harvest-marketing chain. Other important quality factors are the nutritional value as well as taste, flavor and aroma.

Appearance

The appearance of rocket leaves is mainly characterized by color. Attractive are leaves with an intense and a uniform green color. Any alteration of the normal green color of rocket leaves could be a limiting factor for their marketability. The high accuracy in the determination of color, which is possible only by using a colorimeter, is generally unnecessary for the purpose of a routine quality assessment and grading; these operations could be carried out satisfactorily only by a visual observation. The visual standards in the form of colored pictures of the product are given in **Fig. 1**. The degree of yellowing is evaluated subjectively by using a scale score from 1 (no yellowing) to 5 (complete yellowing). When the leaves reach a score of 3, they conclude their shelf life, becoming unsaleable.

Apart from the color, other important quality parameters are freshness, cleanness, wilting, and freedom from decay or damage caused by insects, diseases, freezing and mechanical force.

Nutritional value

A nutritional table for the raw rocket (USDA 2006) indicates that this vegetable is low in saturated fat (0.086 g/100 g edible portion) and very low in cholesterol (0 mg/100 g edible portion). It is a good source of protein, thiamin, riboflavin, vitamin B6, pantothenic acid, zinc and copper (2.58 g, 0.044 mg, 0.086 mg, 0.073 mg, 0.437 mg, 0.47 mg and 0.076 mg/100 g edible portion, respectively) as well as it is a very good source of dietary fiber, vitamin A, vitamin C, vitamin K, folate, calcium, iron, magnesium, phosphorus, potassium and manganese (1.6 g, 2373 International Units, 15 mg, 108.6 μg, 97 μg, 160 mg, 1.46 mg, 47 mg, 52 mg, 369 and 0.321 mg/100 g edible portion, respectively).

Rocket has been reported to have a high vitamin C content; however, there is a great variation on the reported values of vitamin C from 15 (USDA 2006) to 68-80 mg/100 g fw (Koukounaras *et al*. 2007) in *E. sativa* and from 50 (Martínez-Sánchez *et al*. 2006b) to 128 mg/100 g fw (Martínez-Sánchez *et al*. 2006a). A no significant effect of leaf age on vitamin C content was observed (Koukounaras *et al*. 2007).

Lately, an increased interest has been observed for some other compounds of rocket including glucosinolates (GSLs) and flavonoids due to their andioxidant activity. The emerging evidence that vegetables of the group of *Brassica* may have anticarcinogenic effects associated with the biological activity of GSL breakdown products provides another strong motivation for a beneficial manipulation of the GSLs content of the rocket for human consumption. Most research on the antioxidative properties of the *Brassica* vegetables has been focused on *Brassica oleracea*, including broccoli, while only a few information is available for rocket. Detailed reviews on GSLs in *Brassica* vegetables and their beneficial biological activity for humans have been quite recently published by several authors (Fahey and Stephenson 1999; Mithen *et al*. 2000; Fahey *et al*. 2001; Holst and Williamson 2004; Keck and Finley 2004).

At least 120 different GSLs, a group of sulfur-containing secondary metabolites, have been identified in plants of 16 families, particularly those classified in the *Brassicaceae* family (Fahey *et al*. 2001). Hydrolysis of GSLs by the enzyme myrosinase (β-thioglucosidase; EC 3.2.3.1), which co-occurs in plants with GSLs, results in the formation of glucose and an unstable intermediate aglycone compound. This intermediate degrades to produce several products among which are a sulfate ion and a variety of some other products including isothiocyanates (ITCs), thiocyanates and nitriles (Holst and Williamson 2004; Keck and Finley 2004). It has been assumed that the ITCs are mainly responsible for the health protective effects and the sulforaphane [4-(methylsulfinyl)butyl ITC] derived from the hydrolysis of glucoraphanin [4-(methylsulfinyl)butyl GSL] is one of the most promising natural anticancer compounds (Mithen *et al*. 2000; Fahey *et al*. 2001; Holst and Williamson 2004; Keck and Finley 2004), which has been identified in *Brassica* species including rocket. Since the enzyme myrosinase is partially or completely inactivated by the conventional or microwave cooking procedures, the conversion of GSLs to ITCs cannot take place in those cases (Holst and Williamson 2004); therefore, the advantage of rocket over broccoli is that this vegetable is more often consumed fresh rather than boiled like broccoli and consequently the myrosinase activity remains at optimal levels, resulting in a significant increase of the production of ITCs, which have been reported to be six times more bioavailable than GSLs (Shapiro *et al*. 2001). Various GSLs have been isolated and identified from rocket leaves, but these results vary as to which GSLs predominate; in some studies (Bennett *et al*. 2002, 2006; Martínez-Sánchez *et al*. 2006a) with *Eruca* the predominant compound, which represented about 50% of the total content, was glucosativin [4-(mercapto)butyl GSL] with a concentration of 750-1750 µg/g fresh weight, while in other studies (Nitz and Schnitzler 2002; Songsak and Lockwood 2002) the predominant was glucoerucin [4-(methylthio)butyl GSL], with 60% of the total content. In studies with *Diplotaxis* the predominant compounds were glucosativin (Bennett *et al*. 2006) or glucoerucin, with 67% of the total content (Nitz and Schnitzler 2002).

There is some evidence of direct antioxidant activities of intact GSLs from Brassica vegetables, but this is not considered to be a major contributor to the total antioxidant activity of food plants, as compared to other common antioxidants such as vitamin C, vitamin E or some simple and complex phenolics (Plumb *et al*. 1996).

The initial total GSL content of rocket (expressed as mg potassium salt of intact GSL) was 140-170 mg K^+ GSL/100 g fw (Martínez-Sánchez *et al*. 2006a). The amount of GSL content in *Brassica* vegetables depends on the variety, cultivation conditions, harvest time and climate (Kushad *et al*. 1984; Rosa *et al*. 1997). There is a considerable variation in total amount of GSLs among species, while wild *Brassica* species accumulate high levels; it has been reported that some wild forms of *Brassica* have up to 1000-fold greater content than the cultivated ones (Mithen *et al*. 2000).

There are only a few data on rocket flavonoids and most of these are only qualitative and rarely quantitative. Moreover, some of the variation among data presented regarding concentrations and structural classes of flavonoids could be attributed to differences in cultivar analyzed or/and growing conditions, nutrient supply and especially light quality and intensity (di Venere *et al*. 2000; Arabbi *et al*. 2004; Bennett *et al*. 2006). Among flavonoids, season appears to influence particularly some quercetin and isorhamnetin glycosides; some of these compounds nearly disappeared in the summer harvested plants and *D. tenuifolia* is more sensitive than *E. vesicaria* regarding the influence of seasonal factors (di Venere *et al*. 2000).

The flavonoid content does not seem to be a major contributor to the total antioxidant capacity of the wild rocket leaves (Martínez-Sánchez *et al*. 2006b). Therefore, the antioxidant capacity of the wild rocket extract could not be explained only on the basis of its phenolic content, but in addition, it could be attributed to vitamin C or to some other compounds, such as fibers, polymeric polyphenols and other phytonutrients.

The main flavonoids are quercetin glycosides acylated with sinapic acid in *D. tenuifolia* (di Venere *et al*. 2000; Martínez-Sánchez *et al*. 2006b) and kaempferol glycosides are the ones in *E. sativa* (di Venere *et al*. 2000; Arrabi *et al*. 2004), which were further characterized by Bennett *et al*. (2006). In *D. tenuifolia,* the total content of quercetin glycosides was approximately 105 mg/100 g fw (Martínez-Sánchez *et al*. 2006b), in *E. sativa*, the leaves contained 41-118 mg/100 g fw total flavonoids, in which the largest concentration (41-104 mg/100 g fw) was kaempferol (Arrabi *et al*. 2004).

Taste, flavor and aroma

The characteristic pungent or bitter taste and flavor of vegetables belonging to the *Brassicaceae* family may be related to the presence of GSLs and their product of hydrolysis: ITCs, thiocyanates and nitriles (Mithen *et al*. 2000; Bennett *et al*. 2002), while the characteristic aroma of rocket is probably the result of 54 constituents, among the more than 60 compounds, which were detected by GC-FID and GC-MS (Jirovetz *et al*. 2002). As main compounds the following were found: 4-methylthiobutyl isothiocyanate (14.2%), *cis*-3-hexen-1-ol (11.0%), *cis*-3-hexenyl butanoate (10.8%), 5-methylthiopentyl isothiocyanate (9.3%) and *cis*-3-hexenyl 2-methylbutanoate (5.4%). Several ITCs and numerous butane, hexane, octane, and nonane derivatives were found to be of essential importance for the characteristic aroma of rocket. Both *Eruca* and *Diplotaxis* species have a characteristic flavor and odor, which is very different from the ones of other Brassica vegetables; this has been attributed to the presence of the thiol-containing GSL, glucosativin and the ITC derived from this GSL (Bennett *et al*. 2002, 2006).

A content of 0.007% (w/w) of essential oils was obtained by steam distillation from the *E. sativa* leaves; GC and GC-MS analysis revealed the presence of 67 compounds, representing 96.52% of the total oil, which were identified. They included ITCs (61.40%, the main was 4-methylthiobutyl ITC), nitriles (11.53%, the main was 5-methylthiopentanonitrile), *n*-alkanes (7.04%), alcohols (4.90%), acids and ester (1.55%), amides (1.18%), aldehydes and ketones (0.86%) and others (Miyazawa *et al*. 2002).

Safety factors

Recent European outbreaks of *Salmonella* have been associated with salad rocket and head lettuce (Monaghan 2006). The above cases emphasize the need for good agricultural and preparing practices for rocket, which is to be consumed raw.

Both wild and cultivated rocket accumulates an extremely large amount of nitrates, much more than other leafy vegetables (such as lettuce and spinach), which are well known as nitrate accumulators. From two surveys on nitrate content in fresh vegetables in Italy (Santamaria *et al*. 2001), rocket has been found to be the vegetable with the highest nitrate level (up to 9300 mg/kg fw), while a 13640 mg/kg fw nitrate content has been recently reported for rocket produced in Egypt (Moussa 2006). Contrary to the above, in our experiments with rocket, a maximum nitrate content of 319 mg/kg fw has been found (Koukounaras *et al*. 2007; unpublished data).

Several genetic, environmental and agronomic factors influence nitrate absorption and accumulation in rocket. In general, nitrate accumulation is higher under low light intensity, high temperature and high NO_3-N availability in the nutrient solution; moreover, there is a significant interaction between these factors. Under conditions of low light intensity, an increase in temperature causes the increase of nitrate content when the nitrogen availability is low. Under conditions of higher light intensity, increased temperature causes the increase of nitrate content mainly when the nitrogen availability is high (Santamaria *et al.* 2001).

The Scientific Committee for Food of the Commission of the European Communities (1992) has established a maximum acceptable daily human intake of 5 mg of nitrate expressed as sodium nitrate (equivalent to 3.65 mg NO_3^-) from all sources per kg body weight. Therefore, the acceptable daily intake for an adult person of 70 kg should be lower than 255.5 mg NO_3^-, which could be covered by eating only about of 24 g of rocket, in the case of a 9300 mg/kg fw nitrate content.

Limits to maximum permitted levels of nitrates in vegetables have been set for lettuce and spinach by the EC Regulation No 194/97 and for some other vegetables (cabbage, carrot, celery, endive, lamb's lettuce, radish, red beetroot and potato) by some European countries (Austria, Belgium, Germany, Netherlands, Poland and Switzerland). Although no limits for rocket have been established in European Union, in Germany and Switzerland rocket sales contracts oblige Italian exporters to sell rocket with a nitrate content lower than 2500 mg/kg fw (Santamaria *et al.* 2001).

A number of preharvest factors affecting rocket nitrate content and their importance has been considered (Santamaria *et al.* 2001); however, no information is available on the effect of the commonly applied postharvest handling procedures and consequently this subject requires further study.

A consideration of the environmental factors affecting nitrate accumulation in plants, particularly light and temperature and especially the extremes to which plants growing in the fields might be exposed, led to the hypothesis that the nitrate content of such plants might vary considerably over a period of a few hours. If a variation of the above environmental factors does occur during each day, then adjusting harvest time helps to minimize nitrate accumulation in the harvested crops where the nitrate content is of concern, such as in rocket. However, sufficient data on the influence of harvest time on nitrate content of vegetables are limited (Siomos 2000).

Moreover, within a plant (like lettuce and spinach) usually older leaves as well as petioles accumulate more nitrates (356 and 874 mg/kg fw, respectively) than younger ones or the leaf blade (148 and 242 mg/kg fw, respectively) (Beis *et al.* 2002; Siomos *et al.* 2002). Our data for rocket (Koukounaras *et al.* 2007) showed that the fully expanded or mature leaves had a higher nitrate content (319 and 318 mg/kg fw, respectively) than the younger ones (195 mg/kg fw). Therefore, by adjusting harvesting time as well as by discarding the older leaves and petioles or by increasing the blade/petiole ratio in the harvested leaves the nitrate content of the salable produce could be reduced.

POSTHARVEST PHYSIOLOGY

Respiration

The respiration rate is related to the temperature of the product and is usually a fairly good indication of the postharvest quality loss. At harvest, a respiration rate of 21-80, 58-135, 107-192 and 198 mg CO_2/kg·h at 0, 5, 10 and 20°C, respectively, have been reported for rocket leaves (**Table 1**). These differences should be attributed to cultivar, preharvest crop management practices and climatic conditions, leaf physiological age, postharvest handling conditions, time elapsed after harvest and other factors. However, only few of the above factors have already been studied. Young leaves had a higher respiration rate (489 mg CO_2/kg·h) than the fully expanded and mature ones (371 and 367 mg CO_2/kg·h, respectively) (Koukounaras *et al.* 2007). The respiration rate significantly decreased within the first 2 days of storage, with a minimal change thereafter (Koukounaras *et al.* 2007).

At harvest, the respiration rate of rocket increases linearly with temperature in the 0-10°C (Peiris *et al.* 1997; Koukounaras *et al.* 2007) or 0-20°C temperature range (Peiris *et al.* 1997), while during storage, the respiration rate increases exponentially with temperature in the 0-10°C range (Koukounaras *et al.* 2007). Considering the classification of horticultural commodities based on their respiration rate at 5°C (Kader and Saltveit 2003) rocket should be classified as a commodity with an extremely high respiretion rate.

The respiration rate of wild rocket was 11.6 mg CO_2/kg·h after 24 h at 4°C and it increased throughout storage to reach 53.8 mg CO_2/kg·h at day 14 (Martínez-Sánchez *et al.* 2006b).

The respiratory quotient (Q_{10}) of rocket in the 0-10°C temperature range was 2.42, as an average of the entire storage period (Koukounaras *et al.* 2007). In the same storage temperature range, Q_{10} ranged from 1.90 to 5.05 for 18 specialty vegetables, with rocket having the highest one. The corresponding values for Chinese chives leaves and methi leaves and tender shoots were 1.91 and 2.75, respectively (Peiris *et al.* 1997).

Table 1 Respiration rate of rocket leaves at four storage temperatures.

Reference	Temperature			
	0°C	5°C	10°C	20°C
Peiris *et al.* 1997	21.1 ± 5.3	58.1 ± 12.3	106.6 ± 12.4	198.1 ± 11.7
Koukounaras *et al.* 2007	80.3 ± 5.6	134.5 ± 4.8	192.1 ± 20.5	nd
Wright 2004	42.0	113.0	nd	nd

nd= not determined

Ethylene production

At harvest, the young leaves had the highest C_2H_4 production (2.68 µl/kg·h), while the mature ones had the lowest one (1.44 µl/kg·h) (Koukounaras *et al.* 2007). In leaves of all ages, C_2H_4 production reached a maximum during the first day of storage (5.32, 3.94 and 3.22 µl/kg·h in young, fully expanded and mature leaves, respectively) and it decreased rapidly until the 4th day of storage, when it approached values of about 32, 21 and 12% of the maximum ones observed in young, fully expanded and mature leaves, respectively. The young leaves had a higher C_2H_4 production than the fully expanded and mature ones during the entire storage period (Koukounaras *et al.* 2007). The higher C_2H_4 production by the young leaves in comparison to the fully expanded and mature ones during the entire storage period was not accompanied by a higher chlorophyll loss or more yellowing in those leaves, suggesting a minimal role of endogenous C_2H_4 in the yellowing process, caused by chlorophyll degradation.

As an average of the entire storage period, C_2H_4 production of rocket leaves at 10°C was 1.00 µl/kg·h, while the correspondent value at 20°C is expected to be higher. Considering the classification of horticultural commodities according to their C_2H_4 production rate at 20°C (Kader and Saltveit 2003) rocket should be classified as a commodity with a moderate C_2H_4 production rate. In contrast to our data, rocket has been classified by Cantwell (2001) as a commodity with a very low C_2H_4 production rate (<0.1 µl/kg·h).

Our data (Koukounaras *et al.* 2006, 2007) suggest a minimal role of endogenous C_2H_4 in the yellowing process of rocket, caused by chlorophyll degradation; on the other hand exogenous C_2H_4 at a concentration of 1 µl/l found to be involved in the yellowing of rocket leaves. A prestorage treatment with the C_2H_4 action inhibitor 1-MCP (0.5 µl/l for 4 h at 10°C) could be a useful tool for slowing down the rate of the C_2H_4-induced yellowing and consequently the shortening of shelf life.

INFLUENCE OF POSTHARVEST CHANGES ON QUALITY

A large number of changes are observed in harvested rocket leaves that influence quality, but only a few of them have been described in detail. The initial bright green color tend to decrease due to chlorophyll degradation (Koukounaras *et al.* 2006; Martínez-Sánchez *et al.* 2006a; Koukounaras *et al.* 2007), which is a serious problem for all leafy vegetables, while yellowing is a common symptom of their senescence process. Furthermore, rocket is highly susceptible to postharvest water loss resulting not only in a direct loss of salable weight, but it causes also wilting and shriveling. All above changes result in a loss of freshness and in a deterioration of the appearance quality.

After harvest, stem browning and decay were the most detrimental defects observed in wild rocket leaves leading to a decrease in the overall visual quality, even though they kept their characteristic aroma throughout storage (Martínez-Sánchez *et al.* 2006b).

Moreover, ascorbic acid (50 mg/100 g fw), phenolic (109.3 mg/100 g fw), GSL (162.3 mg K^+ GSL/100 g fw), sinapic acid derivatives (3.7 mg/100 g fw) and flavonoid content (105.2 mg/100 g fw) as well as the antioxidant capacity (60.8 Trolox equivalent/100 g fw of wild rocket is decreased after storage for 14 or 15 days at 4°C (24 mg/100 g fw, 56.3 mg/100 g fw, 122.9 mg K^+ GSL/100 g fw, 0.8 mg/100 g fw, 55.6 mg/100 g fw and 19.9 Trolox equivalents/100 g fw, respectively) (Martínez-Sánchez *et al.* 2006a, 2006b), resulting in the deterioration of both nutritional and organoleptic quality.

EFFECTS OF POSTHARVEST CONDITIONS ON QUALITY

Temperature and storage duration

Improper temperature control is known to be a critical constraint in the successful storage and shipping of many fresh vegetables. For rocket, little information is available on storage requirements and the effect of temperature on the respiratory rate, although such information is available for all major vegetable crops. Rocket leaves can be stored successfully at 0°C with a maximum storage life of 16 days, while at 5°C a slight quality deterioration was observed and the shelf life was reduced by 3 days. At 10°C rocket leaves deteriorated rapidly and their shelf life was only 8 days (Koukounaras *et al.* 2007). The effect of storage temperature on the yellowing of rocket leaves, resulting in quality deterioration, is shown in **Table 2**.

Rocket leaves stored at 10°C showed a slight yellowing by the 4th day, while a progressive increase of yellowing was observed thereafter resulting in a shelf life of about 10 days (Koukounaras *et al.* 2006). The visual quality of the stored wild rocket decreased bellow the limit of salability after 10 days at 4°C, while at the end of the storage period (14 days) a 10% of weight loss was observed (Martínez-Sánchez *et al.* 2006b).

There is only limited information regarding the influence of storage conditions on the total or individual GSL content of *Brassica* vegetables (Mithen *et al.* 2000), while no such information is available for rocket. Further research is required on this field, since both storage temperature and duration are important factors determining the optimum storage conditions for minimizing GSLs loss in rocket.

Table 2 The effect of storage temperature on the yellowing score and the hue angle decline/day of rocket leaves stored for 14 days.

Storage temperature (°C)	Yellowing score[1]	Hue angle decline/day[2]
0	2.69	0.02
5	3.14	0.16
10	4.92	1.25

[1] Yellowing was scored using a scale from 1 to 5. Leaves with a score of 3 or higher are considered unmarketable
[2] Hue angle was calculated from *a** and *b** values taken with a chromameter. Hue angle decline indicates a color change from green to yellow.
Source: Adopted from Koukounaras *et al.* 2007

Ethylene

Although it has been reported that rocket is highly sensitive to exogenous C_2H_4 (Cantwell 2001), no information is available regarding the effect of ethylene concentration on yellowing. According to our data (Koukounaras *et al.* 2006), exposure to 1 μl C_2H_4/l increases yellowing, induced by a great loss of total chlorophyll (**Table 3**).

Table 3 The effect of ethylene on yellowing score, hue angle decline/day and total chlorophyll loss (%) of rocket leaves stored at 10 °C for 10 days.

Ethylene (μl/l)	Yellowing score[1]	Hue angle decline/day[2]	Total chl loss (%)
0	3.40	0.34	21.8
1	4.47	1.37	71.0

[1] Yellowing was scored using a scale from 1 to 5. Leaves with a score of 3 or higher are considered unmarketable
[2] Hue angle was calculated from *a** and *b** values taken with a chromameter. Hue angle decline indicates a color change from green to yellow.
Source: Adopted from Koukounaras *et al.* 2006

Relative humidity

Relative humidity (RH) has a strong effect on the rate of water loss from rocket leaves. At a given temperature, the rate of water loss increases with the decrease of relative humidity (Ben-Yehoshua and Rodov 2003). The only tool to reduce shriveling of rocket leaves is the increase of RH in the storage environment.

Atmosphere modification

Packaging rocket leaves with a suitable film leads to a commodity-generated atmosphere equilibrium (a passive modification of the atmosphere) through the consumption of O_2 and the evolution of CO_2 due to the respiration process. An interesting practice involves the active atmosphere modification, which is generated by flashing the package with the appropriate gas mixture. However, only limited research results are available to determine the proper atmosphere composition. In this regard, besides the required investigation regarding the influence of O_2, CO_2 and C_2H_4 concentration on quality, research data are needed for the appropriate films to be used in packaging.

The use of an initial active atmosphere of 6 kPa O_2 and 8 kPa CO_2 inside a package of wild rocket leaves resulted in a decrease of O_2 to 1-3 kPa and an increase of CO_2 to 11-13 kPa after 5 days of storage at 4°C equilibrated thereafter throughout the 12 days of storage (Martínez-Sánchez *et al.* 2006a). The above atmosphere modification promoted the visual deterioration followed by a significant loss of nutritional quality of wild rocket, including a decrease of total GSL content by 60-100%.

A controlled atmosphere with 5 kPa O_2 and 10 kPa CO_2 was beneficial for maintaining the visual quality of wild rocket leaves for 14 days at 4°C, while an atmosphere with 5 kPa O_2 and 5 kPa CO_2 showed a moderate to severe browning as well as a decay (Martínez-Sánchez *et al.* 2006b).

Based on the above information, it is relevant to carry out specific research aimed at solving the problems related to the packaging of the rocket according to different market requirements. Special attention should be paid to determine the injurious levels of O_2 and CO_2 at the optimal or at the higher temperatures, usually expected to occur along the marketing chain. The limit of tolerance to low O_2 and high CO_2 would be higher as storage temperature increases since O_2 requirements for aerobic respiration of the tissue increase with higher temperatures. Depending on the commodity, damage associated with CO_2 may either increase or decrease with an increase in temperature. Production of CO_2 increases with temperature but its solubility decreases. Thus, the CO_2 concentration in the tissue can increase or decrease with an increase in temperature (Kader and Saltveit 2003).

Processing

The effect of processing Brassica vegetables on GSLs has received relatively strong attention. Minimal processing (cutting or chopping) of cabbage induces some physiological changes, due to wounding, which markedly affect the levels of total or individual GSLs (Mithen *et al.* 2000), thus largely influencing some quality factors such as flavor or the assumed pharmaceutical activity. Glucosinolates and myrosinase are located separately in intact plant tissues. Processes like cutting or chopping damage plant cells and this enzyme and its substrate (GSLs) are released, come into contact causing hydrolysis of the thioglucosidic bond. However, there are no systematic studies on the changes in GSL levels of minimally processed rocket.

HARVEST, POSTHARVEST HANDLING AND MARKET PREPARATION

In Mediterranean countries, rocket is available on the market year round. Harvest, postharvest handling and market preparation of rocket are dependent on the specific market requirements. Until now, rocket is usually marketed as leaf bunches or as fresh-cut individual leaves in modified atmosphere packages (MAP). However, lately there is a growing interest for marketing whole rocket plants either as baby or as a living plant with or without the attached roots. To meet these requirements, several systems are applied for rocket production in the soil or in a soilless culture. A description of the protocol for soilless culture or hydroponics, with the benefits associated with this, is given by Pimpini and Enzo (1997).

For marketing leaf bunches or fresh-cut individual leaves, harvesting is carried out usually by hand and the leaves are being cut at least 0.5 cm above the plant vegetative apex, allowing thus the plant to regrow and produce new leaves. Most attention is being focused on prospects of harvest mechanization. The harvesting of leaves can be started 20-60 days after plant emergence or after transplanting. After the first harvest, it is possible to continue with 2-5 more harvests at intervals of 20-60 days, depending on season, the production system and the market destination.

Rocket harvested for the fresh market is tied into bunches of 100-150 g each and packed into cartons immediately after harvesting, in the field; the rocket for the minimally processed market is shipped from the field in bulk containers to the packing house, where the leaves are thoroughly washed, chopped and a quantity of 100-150 g is packaged in polyethylene bags. Fresh-cut rocket may also be packaged as a mixture with other leafy greens. Rocket packaged in this way is destined exclusively for supermarket distribution.

After the first harvest, the subsequently grown rocket leaves may change in shape, color and taste; therefore crop is suggested to be harvested only three times (Pimpini and Enzo 1997). However, some markets prefer rocket leaves of the subsequent cuts instead of the first one, as those leaves are more consistent in size, their aroma is more intense and the products stored better. In addition, it appears that leaves obtained from the regrowth of plant tend to have improved organoleptic characteristics. Contrary to the above, in other markets, leaves of the first cut are preferred, since they are slightly fibrous, more tender and crisp with light aroma (Pimpini and Enzo 1997). Total leaf GSL content, including some individual GSLs, increased significantly as the harvest period progressed. In *D. tenuifolia* the amounts of gloucoraphanin increased from 8.2 mg/100 g fw in the first cut to almost three-fold in the second one and up to eight-fold in the third cut. *E. sativa* contained 30.7 mg/100 g fw already in the first harvest which increased to 53.5 in the second harvest (Nitz and Schnitzler 2002).

More recently, whole rocket plants are packaged in a clamshell container with the roots resting in a peat ball, which extends the postharvest life (Wright 2004). In that case, the produce is not rinsed with water prior to packaging and because it is live it can resist to *E. coli* infection. In the case of lettuce, the above technique results in maintaining a shelf life of the product up to 18 days (Gordon 2006). It is obvious that for the application of the above method marketing the rocket plants should be produced in a hydroponic system.

RECOMMENDED CONDITIONS

The following recommendations are based mainly to the available empirical knowledge for similar vegetable species, particularly the salad greens, rather than to research results. Generally, information on the postharvest handling of rocket is relatively scarce.

Harvesting

Plant and leaf functional attributes are known to change diurnally and consequently this fact could have an impact on the processibility traits of the rocket leaves. Therefore, the time of day the leaves are harvested could have a significant impact on their postharvest quality. Current farming practice is to harvest the leaves at the time of first light allowing the crop to be shipped, processed or packed the same day. However, it has been reported (Clarkson *et al.* 2005) that the baby salad leaves of rocket had an increased postharvest shelf life of 2 to 6 days when harvested at the end of the day compared to the leaves harvested at the start of the day.

Rapid postharvest cooling

Rocket leaves should be cooled to 0°C rapidly after harvest. Vacuum cooling is an effective technique for removing field heat (Wright 2004).

Sanitizing

Sanitizers studied for their effectiveness in disinfecting fruits and vegetables from pathogens include chlorinated water and organic acids. Chlorine is still the most widely used as a sanitizer in the production chain of fresh-cut rocket products in a concentration of 100 mg/l (Martínez-Sánchez *et al.* 2006a) in order to reduce normal microflora, which may include food-born pathogens. *Salmonella*, *Escherichia coli* and *Listeria monocytogenes* are of most concern in fresh-cut fruits and vegetables. Recent data (Martínez-Sánchez *et al.* 2006a) indicate that acidified sodium chlorite (250 mg/l by mixing 0.4 mg/l $NaClO_2$) and peroxyacetic acid (300 ml/l) washing solutions could be alternative sanitizers to chlorine for rocket leaves due to satisfactory retention of the sensory quality without a detrimental effect on the antioxidant constituents. The samples were submerged in the washing solution for 1 min, before packaging under active modified atmosphere conditions with a 35 μm polypropylene film. Moreover, natural products such as fresh lemon juice and vinegar used in a mixture (1:1) for 15 min could be considered as a potential antimicrobial agent in preventing food-borne disease outbreaks related to fresh rocket leaves at the household level (Sengum and Karapinar 2005).

1-Methylcyclopropene (1-MCP)

A treatment of rocket leaves with the C_2H_4 action inhibitor 1-MCP at a concentration of 0.5 μl/l for 4 h at 10°C before storage for 10 days minimized the yellowing of leaves and consequently the shortening of shelf life, which is induced by C_2H_4 (Koukounaras *et al.* 2006).

Storage temperature and relative humidity

While several diverse methods have been used to extend the shelf life of fresh vegetables, temperature management remains the most effective method. Rocket is not sensitive to chilling and should be stored close, but above to 0°C with a 95 to 100% relative humidity (Wright 2004), in order to achieve a maximum storage life of 16 days (Koukounaras *et al.* 2007). At 5°C, a slight quality deterioration is observed and the shelf life is reduced by 3 days (Koukounaras *et al.* 2007). However, under the commonly applied postharvest handling procedures, the rocket leaves typically are stored well 7 to 10 days (Cantwell 2001).

Controlled and modified atmosphere

CA of 5 kpa O_2 and 10 kPa CO_2 had a beneficial effect on wild rocket storage, maintaining the visual and the sensory quality as well as the high content of health-promoting phytonutrients; moreover, it controlled effectively the aerobic mesophilic and psychotropic microorganisms as well as the coliforms. Thus, considering the above quality parameters, the self-life of wild rocket terminated after 7 to 10 days at 4°C (Martínez-Sánchez *et al*. 2006b). Although MAP is currently applied in a commercial scale, limited research data are available regarding atmosphere composition inside the package as well as the optimum film specifications for packaging.

Postharvest pathology

Rocket leaves are typically susceptible to the same bacterial soft rot and fungal decay as lettuce. Low temperatures should be maintained throughout the cold chain from harvest to consumer to minimize pathological disorders and prolong the shelf life (Wright 2004).

CONCLUDING REMARKS

Quality deterioration of fresh rocket after harvest is still a problem; however that problem could be partially solved by using some of the limited available information. To ensure freshness and a high quality produce, rocket needs a gentle handling and a rapid marketing procedure. It is important for all individuals involved in the production and marketing of the produce to maintain at all times rocket temperature at 0-2°C. Dehydration must be prevented either by maintaining in storage and transit the RH at ≥95% or by MAP. To avoid leaf yellowing, a special caution must be exercised during storage or transport, so that rocket will not be exposed to ethylene.

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