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, and 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 existing 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, isothiocyanates; MAP, modified atmosphere packaging; RH, relative humidity

INTRODUCTION

The rocket plant [also known as arugula (English), roquette (French), ricola or rughetta (Italian) and πόξα (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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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, cleanliness, 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 mg, 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, 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 antioxidative 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 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 (Bennet et al. 2002, 2006; Martinez-Sanchez 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 mg/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 (Martinez-Sanchez 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 higher 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 preparations, nutritional status, 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. tenuefolia is more sensitive than E. vesicaria regarding the influence of seasonal factors (di Venere et al. 2000). The content does not seem to be a major contributor to the total antioxidant capacity of the wild rocket leaves (Martinez-Sanchez 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 major compounds are quercetin glycosides acylated with sinapic acid in D. tenuefolia (di Venere et al. 2000; Martinez-Sanchez 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. tenuefolia, the total content of quercetin glycosides was approximately 105 mg/100 g fw (Martinez-Sanchez 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 (Ar- rabi 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). 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 nornic 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-methylthiopentanitrile), 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 NO3-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 NO3-) 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 NO3-, 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 vege-
tables 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 mg CO₂/kg·h after 24 h at 4°C and it increased throughout storage to reach 53.8 mg CO₂/kg·h at day 14 (Martínez-Sánchez et al. 2006b).

The respiration rate of wild rocket was 11.6 mg CO₂/kg·h after 24 h at 4°C and it increased throughout storage to reach 53.8 mg CO₂/kg·h at day 14 (Martínez-Sánchez et al. 2006b).

The respiratory quotient (Q₁₀) 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, Q₁₀ 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).

**Ethylene production**

At harvest, the young leaves had the highest C₂H₄ 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, C₂H₄ 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 C₂H₄ production than the fully expanded and mature ones during the entire storage period (Koukounaras et al. 2007). The higher C₂H₄ 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 C₂H₄ in the yellowing process, caused by chlorophyll degradation.

As an average of the entire storage period, C₂H₄ 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 C₂H₄ production rate at 20°C (Kader and Saltveit 2003) rocket should be classified as a commodity with a moderate C₂H₄ production rate. In contrast to our data, rocket has been classified by Cantwell (2001) as a commodity with a very low C₂H₄ production rate (<0.1 μL/kg·h).

Our data (Koukounaras et al. 2006, 2007) suggest a minimal role of endogenous C₂H₄ in the yellowing process of rocket, caused by chlorophyll degradation; on the other hand exogenous C₂H₄ at a concentration of 1 μL/l found to be involved in the yellowing of rocket leaves. A prestorage treatment with the C₂H₄ 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 C₂H₄-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; Martinez-Sanchez 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.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Temperature</th>
<th>0°C</th>
<th>5°C</th>
<th>10°C</th>
<th>20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peiris et al. 1997</td>
<td>21.1 ± 5.3</td>
<td>58.1 ± 12.3</td>
<td>106.6 ± 12.4</td>
<td>198.1 ± 11.7</td>
<td></td>
</tr>
<tr>
<td>Koukounaras et al. 2007</td>
<td>80.3 ± 5.6</td>
<td>134.5 ± 4.8</td>
<td>192.1 ± 20.5</td>
<td>nd</td>
<td></td>
</tr>
<tr>
<td>Wright 2004</td>
<td>42.0</td>
<td>113.0</td>
<td>nd</td>
<td>nd</td>
<td></td>
</tr>
</tbody>
</table>

*nd* = not determined
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 14 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.

**Ethylene**

Although it has been reported that rocket is highly sensitive to exogenous C2H4 (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 C2H4/l increases yellowing, induced by a great loss of total chlorophyll (Table 3).

**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 decreases 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 O2 and the evolution of CO2 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 O2, CO2 and C2H4 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 O2 and 8 kPa CO2 inside a package of wild rocket leaves resulted in a decrease of O2 to 1-3 kPa and an increase of CO2 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 O2 and 10 kPa CO2 was beneficial for maintaining the visual quality of wild rocket leaves for 14 days at 4°C, while an atmosphere with 5 kPa O2 and 5 kPa CO2 showed a moderate to severe browning as well as a decay (Martínez-Sánchez et al. 2006a).

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 O2 and CO2 at the optimal or at the higher temperatures, usually expected to occur along the marketing chain. The limit of tolerance to low O2 and high CO2 would be higher as storage temperature increases since O2 requirements for aerobic respiration of the tissue increase with higher temperatures. Depending on the commodity, damage associated with CO2 may either increase or decrease with an increase in temperature. Production of CO2 increases with temperature but its solubility decreases. Thus, the CO2 concentration in the tissue can increase or decrease with an increase in temperature (Kader and Salt-veit 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

<table>
<thead>
<tr>
<th>Storage temperature (°C)</th>
<th>Yelling score1</th>
<th>Hue angle decline/day2</th>
<th>Total chl loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.69</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.14</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4.92</td>
<td>1.25</td>
<td></td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>Ethylene (μl/l)</th>
<th>Yelling score1</th>
<th>Hue angle decline/day2</th>
<th>Total chl loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.40</td>
<td>0.34</td>
<td>21.8</td>
</tr>
<tr>
<td>1</td>
<td>4.47</td>
<td>1.37</td>
<td>71.0</td>
</tr>
</tbody>
</table>

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.

**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.

Source: Adopted from Koukounaras et al. 2007
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 thioglicoside bond. However, there are no systematic studies on the changes in GSL levels of minimally processed rocket.

**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 chloride (250 mg/l by mixing 0.4 mg/l NaClO2 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-Methylocyclopropane (1-MCP)**

A treatment of rocket leaves with the C3-H2 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 C3H2 (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 typi-
cally are stored well 7 to 10 days (Cantwell 2001).

Controlled and modified atmosphere

CA of 5 kPa O2 and 10 kPa CO2 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 psychrotrophic 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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