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COMPARISON OF FOUR RUCOLA FORMS GROWN IN CONTAINERS IN DIFFERENT LIGHT CONDITIONS

PORÓWNANIE CZTERECH FORM RUKOLI W UPRAWIE POJEMNIKOWEJ W ZRÓŻNICOWANYCH WARUNKACH ŚWIETLNYCH

Summary. Garden rocket (rucola) is well known for its pleasant bitter taste and also for its high content of health-promoting phytonutrients. Rucola is usually marketed as leaf bundles or fresh-cut individual leaves in modified atmosphere packages. An alternative form is the cultivation and sale of plants in containers. Two of the significant factors limiting the growth of rucola plants especially in winter are shortage of light and excessive density. The aim of the study was to determine usefulness of four forms of rucola for cultivation in containers in different lighting conditions. A two-factor experiment was performed in growth chamber. The first factor comprised four forms of rucola, the other – two day-lengths: 12 and 16 h. The three forms belong to species *Eruca sativa*, while the fourth to *Diplotaxis tenuifolia* species. The experimental plants were grown in pots of 280-cm^3 volume. The number of plants grown in pots was identical and amounted to 50. Plants cultivated in the 16-hour lighting system were characterised by a lower hypocotyl in comparison with the plants grown in the 12-hour lighting system. In comparison with the 12--hour daylight period, the foliage weight of plants cultivated in the 16-hour lighting system was significantly higher in the first three weeks. The highest mass of fresh foliage (day 28) and the highest plant surface was recorded in Ogrodnik plants and the lowest – in Selvatica de campo forms.

Key words: garden rocket, *Eruca sativa*, sand rocket, *Diplotaxis tenuifolia*, container, light, RGR, LAI

Introduction

Recently many raw leafy vegetables other than lettuce have been used in salads, either alone or as part of a salad mixture. Rucola has been used as food for a long time in several Mediterranean countries, but its popularity is now increasing remarkably, also in Poland (SIOMOS and KOUKOUNARAS 2007). Garden rocket is well known for its pleasant bitter taste and also for its high content of health-promoting phytonutrients (BARILLARI et AL. 2005, MELCHINI et AL. 2009). Leaves are a good source of vitamin C and iron. Rucola is usually marketed as leaf bundles or fresh-cut individual leaves in modified atmosphere packages. The product is generally stored refrigerated and has a shelf life of 1-2 weeks (NIELSEN et AL. 2008). An alternative form is the cultivation and sale of plants in containers. This form of sales minimizes negative physiological and microbiological processes that occur in the case of sales of fresh-cut individual leaves. Container grown spice plants ensure their longer home use.

Eruca is now one of the objects of the research carried out by the International Plant Genetic Resources Institute (IPGRI). In the cultivation two following species are used:

Eruca sativa Miller (**garden rocket**) – a diploid, annual species which flowers in spring. Seeds are ready for collecting in late spring. Although *E. sativa* prefers rather rich soils can be found mixed with ruderal flora in very marginal areas. A wild type, known as subspecies *vesicaria* (L.) Cav., is also rather well represented in the Mediterranean flora.

Diplotaxis tenuifolia (L.) DC. (**sand rocket**) – a diploid and perennial species, that the roots can survive winters and produce new sprouts in the next spring; it flowers from late spring to autumn and its seeds are generally ready for collecting in autumn. It adapts very well to harsh and poor soils. This species has succulent leaves and is much appreciated in cuisine. In some Italian areas *D. tenuifolia* is cultivated, but it is also collected from the wild and sold in small bunches at local markets (PIGNONE 1997).

One of the significant factors limiting the growth of rucola plants especially in winter is shortage of light. Insufficient light intensity can cause exuberant growth of plants which are also poorly leaved and dyed. Excessive density of seasoning plants grown in containers hinders light access to lower plant parts and causes them to overgrow (FRĄSZCZAK et AL. 2008). The main parameters in the cultivation of spice plants in containers include the height and surface of plants. These parameters are decisive for the termination of cultivation and the suitability of plants for sale. The objective of this study was to compare four forms of rucola with the aim to determine their usefulness for cultivation in containers in different light conditions.

Material and methods

Experiments were carried out in the experimental station "Marcelin" of the Poznań University of Life Sciences in 2007. Objects of the research were four forms of rucola, whose seeds came from the following companies: Polish PPHU **Ogrodnik**, Dutch **Pieter**pikzonen B.V., Italian L'Ortolano: forms **Colvitata** and **Selvatica de campo**.

The first three forms belong to species *Eruca sativa*, while form Selvatica de campo belongs to *Diplotaxis tenuifolia* species.

Plants were grown in growth chambers. A two-factor experiment was performed in eight repetitions, where one pot was treated as one repetition. The investigations were conducted in two series (cycles). The first factor comprised four forms of rucola mentioned above, the other – two lengths of day (light period): 12 and 16 h. Artificial light was provided using fluorescent lamps 36W/84 of Philips Company. Photosynthetic photon flux density (PPFD) amounted to 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The temperature in the growth chambers was 23°C during the day and night. The plants were grown in pots of 280-cm^3 volume, (pot area 7 × 7 cm – 49 cm^2) filled peat substrate for vegetable transplanting production. The number of plants grown in pots was identical and amounted to 50. The measurements of plants were made every 7 days during four weeks, first time – 7 days after emergence, and later on the 14^{th}, 21^{st} and 28^{th} (harvest time) day of cultivation. In every pot, 10 plants were measured. The harvesting involved hand cutting of plants close to the surface of the substrate. After the harvest, the weight of the fresh matter of plants from the pot and the yield of dry matter using of drier-balance WPS 210S were determined. In addition, measurements of plant heights, hypocotyls length and foliage area were made. A scanner and Skwer program were used to calculate the surface of the experimental foliage.

The significance of the impact of light and forms on the height, hypocotyl length, yields and area of rucola leaves was determined using the F test. Differences between means were estimated with the Newman-Keuls test at the level of significance of $\alpha = 0.05$. All statistical analyses were carried out using the Stat program.

The index of the relative growth rate (RGR) was calculated on the basis of the following formula:

$$\mathrm{RGR} = \frac{dW}{W \cdot dt}$$

where:

W – weight of fresh plant material at the moment of harvesting (g),
dW – fresh mass increment (g),
dt – time of cultivation (day).

The leaf area index (LAI) refers to the size of the leaf surface in relation to the pot area taken up by all plants. It was calculated on the basis of the following formula:

$$\mathrm{LAI} = \mathrm{A/P}$$

where:

A – plant assimilation area (dm^2),
P – pot area (dm^2).

Results

Plants cultivated in the 16-hour lighting system were characterised by a lower hypocotyl in comparison with the plants grown in the 12-hour lighting system (with the exception of the first week) (Table 1). In the harvest time (day 28), the hypocotyl was found the shortest in Selvatica de campo form and the longest – in the case of Pieterpikzonen plants. In addition the length of day was found to exert a significant impact on the fresh weight of the foliage. In comparison with the 12-hour daylight period, the foliage weight of plants cultivated in the 16-hour lighting system was significantly higher. Only on day 28 of cultivation, no significant differences were observed in the foliage mass in relation to the day length. The highest mass of fresh foliage (day 28) was recorded in Ogrodnik plants and the lowest – in Selvatica de campo form.

Table 1. Influence of light period on some morphological characteristics of four rucola forms
Tabela 1. Wpływ okresu świetlnego na niektóre cechy morfologiczne czterech form rukoli

Day of measurement Dzień pomiaru	Ogrodnik		Pieterpikzonen		Colvitata		Selvatica de campo		Mean for light period Średnia dla okresu naświetlania	
	12 h	16 h	12 h	16 h	12 h	16 h	12 h	16 h	12 h	16 h
	Hypocotyl length (cm) – Długość hipokotylu (cm)									
7	2.2 b*	2.3 b	2.4 ab	2.4 a	2.4 ab	2.3 a	2.5 a	1.6 c	2.4 a	2.2 a
14	2.5 bc	2.4 c	3.1 a	2.5 bc	2.7 b	2.5 bc	2.6 b	1.8 d	2.7 a	2.3 b
21	2.6 c	2.6 c	3.2 a	2.8 bc	3.0 ab	2.5 c	2.7 c	2.1 d	2.9 a	2.5 b
28	3.2 b	2.7 c	3.5 a	3.2 b	3.2 b	2.6 c	3.1 b	2.1 d	3.2 a	2.6 b
	Weight of fresh mass in pot (g) – Waga świeżej masy w doniczce (g)									
7	1.3 d	3.3 a	2.0 c	3.0 ab	1.7 c	2.8 b	0.3 e	0.3 e	1.4 b	2.3 a
14	3.1 c	4.6 a	3.1 c	3.9 b	2.8 c	3.9 b	0.6 d	1.36 d	2.4 b	3.5 a
21	5.5 b	7.1 a	5.2 bc	4.9 bcd	4.3 d	4.6 cd	1.5 f	2.3 e	4.1 b	4.7 a
28	6.8 ab	7.4 a	5.7 cd	6.3 bc	5.6 cd	4.9 d	2.8 e	2.9 e	5.2 a	5.4 a
	Leaf area in pot (dm^2) – Powierzchnia liści w doniczce (dm^2)									
7	0.23 b	0.37 ab	0.23 b	0.39 a	0.22 b	0.32 ab	0.13 b	0.07 c	0.23 a	0.29 a
14	0.55 c	0.79 a	0.58 c	0.69 b	0.50 c	0.69 b	0.23 d	0.17 d	0.44 b	0.59 a
21	1.29 a	1.24 ab	1.08 c	1.16 bc	0.98 d	0.95 d	0.39 f	0.65 e	0.93 b	1.00 a
28	3.15 a	3.27 a	2.47 b	2.60 b	1.57 c	1.47 cd	1.16 d	1.18 d	2.10 a	2.13 a

*Values followed by the same letters for individual dates do not differ significantly at $\alpha = 0.05$.
*Wartości oznaczone tą samą literą dla poszczególnych terminów nie różnią się istotnie przy $\alpha = 0,05$.

Day-length differentiated foliage surface only to 21st day of cultivation (Table 1). Both, in the first and last week of cultivation, no significant differences were observed in the leaves surface depending on the length of day. On the day of harvest, the greatest leaves surface was determined in Ogrodnik, while the smallest – in Selvatica de campo form.

Plants cultivated in the 16-hour daylight regime were characterised by a slightly higher percentage of dry matter content in herbage in comparison with the plants exposed to the 12-hour daylight (Fig. 1). The smallest dry matter content was recorded in Selvatica de campo form and the highest in Ogrodnik and Pieterpikzonen plants.

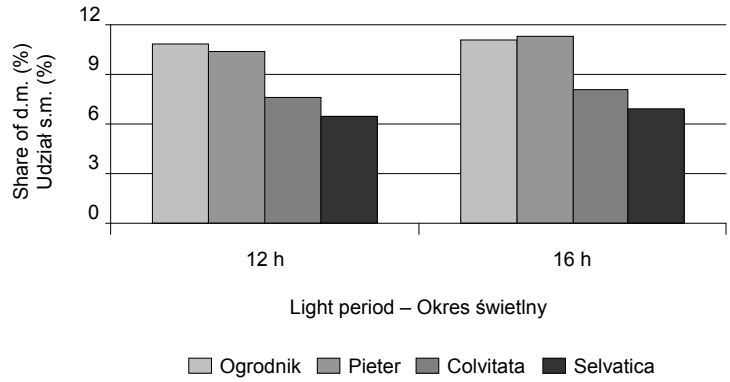

Fig. 1. Share of dry matter in four rucola forms' herbage after harvest (28 days after emergence) in dependence of rucola form and light conditions
Rys. 1. Udział suchej masy w zielu czterech form rukoli po zbiorze (28 dni po wschodach) w zależności od formy rukoli i warunków świetlnych

Selvatica de campo form was characterised by slowest height increase, as it was not until the last week of cultivation that these forms of rucola plants began to grow intensively (Fig. 2). The biggest increase in plant height during the entire cultivation period was observed in Ogrodnik and Colvitata forms. It should also be emphasised that the examined individual forms of rucola cultivated in the 16-hour daylight regime were characterised by lower height in comparison with the forms exposed to the 12-hour daylight period. The highest dynamics of fresh weight increment was observed in Selvatica de campo form exposed to 12-hour daylight (Fig. 3).

After 28 days of cultivation, the value of the leaf area index (LAI) ranged from 2.52 to 6.96 (Fig. 4). This wide range of values indicates differences in leaf surface of individual forms of rucola plants. The highest values of the LAI index were recorded in Ogrodnik and the lowest in Selvatica de campo form. It was found that plants growing in the 16-hour lighting regime were characterised by a slightly higher LAI value in comparison with those kept under 12-hour exposure, with the exception of Selvatica de campo form.

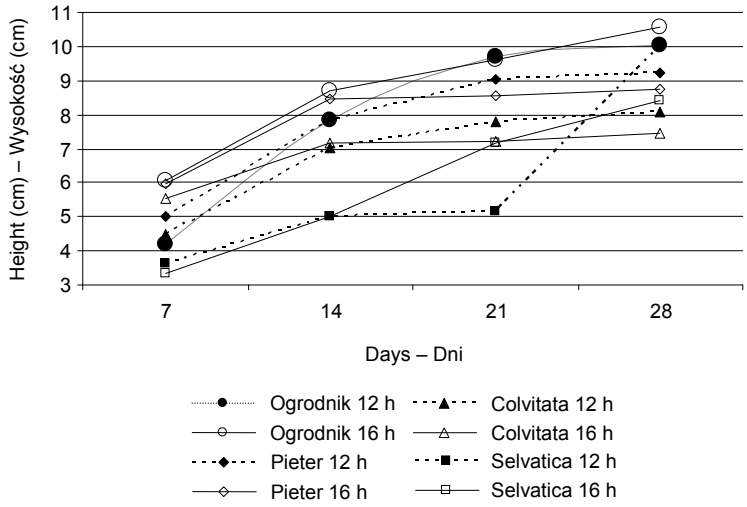

Fig. 2. Increase in plant height of four rucola forms in the growing season at two periods of light
Rys. 2. Dynamika wzrostu wysokości czterech form rukoli w okresie wegetacji dla dwóch okresów naświetlania

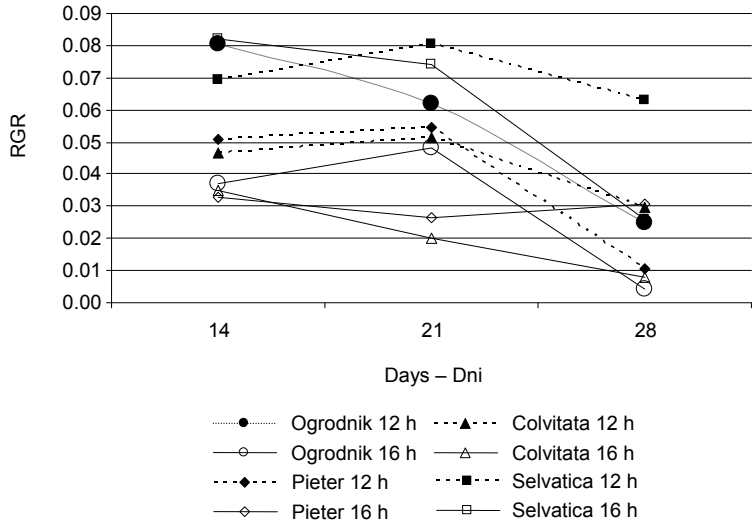

Fig. 3. Relative growth rate (RGR) of the individual rucola forms in the growing season at two periods of light
Rys. 3. Względny wskaźnik wzrostu (RGR) poszczególnych form rukoli w okresie wegetacji dla dwóch okresów naświetlania

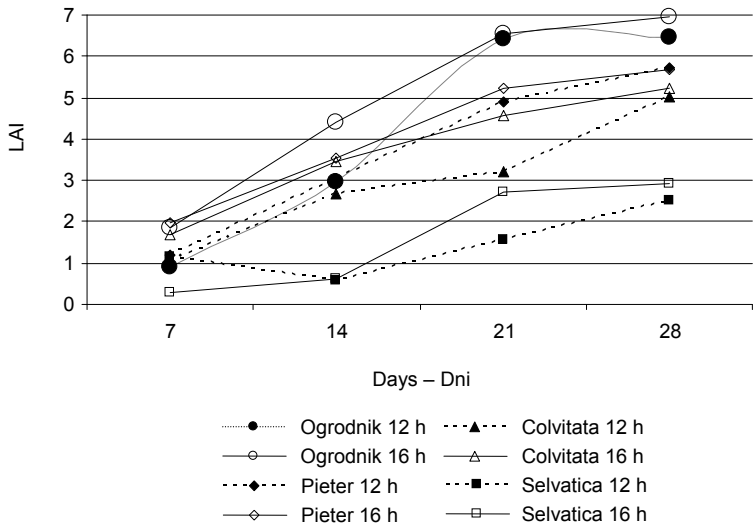

Fig. 4. Leaf area index (LAI) of the individual rucola forms in the growing season at two periods of light
Rys. 4. Indeks powierzchni liści (LAI) poszczególnych form rukoli w okresie wegetacji dla dwóch okresów naświetlania

Discussion

The plant growth rate process depends on environmental conditions and one of the major ones is light. Without sufficient light quantities plants tend to grow excessively and produce smaller leaves. ERWIN and HEINS (1995) as well as HIGASHIDE et AL. (2002) maintain that, in comparison with plants grown in natural conditions, those that are cultivated in growth chambers and which receive insufficient amounts of light tend to grow excessively elongated hypocotyls and leaf stalks. In the present experiment, the length of hypocotyl in the case of plants exposed to 12 hours of light was significantly longer in comparison with the plants kept in the 16-hour lighting regime. Experiments carried out by many researchers on various herb species confirm that both excessive plant density and light shortage stimulate plant height (PUTIEVSKY et AL. 1983, AL--RAMAMNEH 2009, NURZYŃSKA-WIERDAK and DZIDA 2009). According to RAO (2002), insufficient space around plants exerts a significant influence on plant height which is connected with plant competition for light. In studies carried out by FRĄSZCZAK et AL. (2008), higher garden rocket plants were obtained in cultivations with worse lighting conditions. However, those findings were not confirmed by current investigations as there were no significant differences in the height of plants at harvest between plants derived from 12- and 16-hour lighting regimes. In experiments carried out by FRĄSZCZAK and KNAFLEWSKI (2004), garden rocket plants cultivated in growth chambers in the initial period of vegetation were characterised by a higher growth dy-

namics in comparison with plants cultivated in the glasshouse in summer. Nevertheless, at harvest higher plants were obtained from the glasshouse cultivation.

Investigations on correlations between plant biomass and light have been conducted for many years. MONTEITH and MOSS (1977) demonstrated a linear relationship between biomass production and the amount of light at optimal levels of the remaining factors. This dependence is known and has been described in many papers (WARREN-WILSON 1981, JAMIESON et AL. 1995, TEI et AL. 1996). In the present experiments, during the first three weeks of vegetation, plants growing in the 16-hour lighting regime were characterised by a higher fresh mass weight in comparison with the plants exposed to 12-hour daylight, irrespective of the form. At harvest, there were no significant differences in foliage yields depending on the length of daylight. This can be explained by plant adaptation capabilities to worse lighting conditions, especially in the case of such sciophilous plants as garden rocket. Investigations carried out by FRĄSZCZAK and KNAFLEWSKI (2009) revealed that the fresh mass yield of garden rocket was affected more by total amount of light than by the day length. The lowest fresh mass yield was recorded for the longest daylight. GRAZIA et AL. (2001) also reported that the level of light intensity was the most influenced factors on the lettuce plants yield. The obtained differences in foliage weight between the examined forms were associated with differences in the plant habit and area. The largest area was recorded for the Ogrodnik form, while the smallest – for the Selvatica de campo form.

The highest increment of the LAI coefficient took place, in the majority of forms, in the first week of cultivation. PIETKIEWICZ (1985) claims that the LAI value during the vegetation period undergoes changes; initially it increases but later on declines. In the described experiments, due to a short vegetation period, no drop in the LAI coefficient values was observed. The Ogrodnik plants was characterised by a considerably higher value of this coefficient in comparison with the remaining forms.

Relative growth rate (RGR) is a useful indicator of the extent to which a species is using its photosynthates for growth (GROENEVELD 1998). The Selvatica de campo form was characterised by the highest dynamics of the fresh mass increment and it was associated with its initial very slow growth. It is evident that the greatest fresh mass increment took place during the first three weeks of cultivation. BLACKMAN (1919) and BRIGGS et AL. (1920) were the first to notice that relative growth intensity is usually the greatest at the beginning and exhibits a declining tendency during ontogenesis.

Conclusions

1. Hypocotyl was found to be shorter in the case of the 16-hour lighting regime compared with 12-hour light exposure.
2. After four weeks of cultivation there were no significant differences in plant height, as well as in the fresh foliage weight between 16-hour and 12-hour light period.
3. The Ogrodnik form was characterised by the greatest leaf-growth dynamics, while Selvatica de campo form – by the smallest.
4. The Ogrodnik form appeared to be most suitable for the cultivation in containers.

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PORÓWNANIE CZTERECH FORM RUKOLI W UPRAWIE POJEMNIKOWEJ W ZRÓŻNICOWANYCH WARUNKACH ŚWIETLNYCH

Streszczenie. Rukola jest znana ze swojego przyjemnego, lekko gorzkiego smaku, ale także ze względu na dużą zawartość składników odżywczych mających właściwości zdrowotne. Jest ona zazwyczaj sprzedawana jako pęczek liści lub jako świeże liście pocięte i zapakowane w zmodyfikowanej atmosferze. Alternatywną formą jest produkcja i sprzedaż roślin w pojemnikach. Dwa istotne czynniki ograniczają wzrost roślin rukoli, zwłaszcza w okresie zimowym. Są to: niedobór światła i nadmierne zagęszczenie roślin w doniczce. Celem badań było określenie przydatności czterech form rukoli do uprawy w pojemnikach, w różnych warunkach świetlnych. Doświadczenie dwuczynnikowe przeprowadzono w kamerach wegetacyjnych. Pierwszym czynnikiem były cztery formy rukoli, drugim – dwie długości dnia – 12 i 16 h. Trzy formy należały do gatunku *Eruca sativa* jedna forma – do gatunku *Diplotaxis tenuifolia.* Rośliny uprawiano w pojemnikach o objętości 280 cm^3. W każdej doniczce rosło 50 roślin. Rośliny uprawiane przy 16-godzinnym dniu charakteryzowały się niższym hipokotylem w porównaniu z uprawianymi przy 12-godzinnym dniu. Długość dnia miała również istotny wpływ na świeżą masę ziela. Istotnie większą masę ziela uzyskano w uprawie przy 16-godzinnym dniu w porównaniu z dniem 12-godzinnym. Tylko w 28. dniu uprawy nie było istotnych różnic w masie ziela w zależności od długości dnia. W momencie zbioru największą powierzchnią roślin charakteryzowała się forma Ogrodnik, a najmniejszą – Selvatica de campo.

Słowa kluczowe: rokietta siewna, *Eruca sativa*, dwurząd wąskolistny, *Diplotaxis tenuifolia*, pojemnik, światło, RGR, LAI

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