*Medicinal and Aromatic Plant Science and Biotechnology* ***©2009 Global Science Books***

# Photosynthetic Responses of Two Angelica Cultivars to Organic Cultures and Supplemental Lighting in Greenhouse

**Hui-lian Xu[1] • Feifei Qin[1,2,3*] • Wudeneh Letchamo[4] • André Gosselin[5] • Shigenori Morita[3]**

[1] International Nature Farming Research Center, Hata, Nagano 390-1401, Japan
[2] Peanut Research Institute, Shandong Academy of Agricultural Sciences, Qingdao 266100, China
[3] Field Production Science Center, Graduate School of Agricultural and Life Sciences, the University of Tokyo, Nishitokyo, Tokyo 188-0002, Japan
[4] Department of Biochemistry and Microbiology, Rutgers, the State University of New Jersey, 76 Lipman Drive, New Brunswick, N.J. 08901, U.S.A.
[5] Horticulture Research Center, Laval University, Ste-Foy, Québec G1K 7P4, Canada

***Corresponding author*: * jialing_300@163.com**

## ABSTRACT

Angelica has a multitude of uses in alternative medicines and food processing. In recent years, organic herbs are more popular than ever. In the present study, two cultivars (‘Archadie’ and ‘Munchen’) of *Angelica archangelica* L., were cultivated in a greenhouse to investigate the responses of photosynthesis, photosynthetic related factors and dry matter production to organic substrate and supplemental lighting. Peat-based organic substrate was supplied with organic matter-based nutrient solution with sand substrate as control supplied with standard nutrient solution. Light regimes were natural light and 75 μmol $m^{-2}$ $s^{-1}$ supplemental in addition to natural light. A hyperbolic mathematical model, $P_N = K\,P_C\,i\,(1 + K\,i)^{-1} - R_D$, was used to fit the light photosynthesis curve. Photosynthetic capacity ($P_C$) and the maximum quantum yield ($Y_Q = K\,P_C$) and dark respiration rate ($R_D$) were analyzed from the model. Under natural lighting, both cultivars produced more total dry mass in organic culture than in sand culture, while under supplemental lighting, total dry mass production of ‘Munchen’ decreased in organic culture. Within all treatments and cultivars, both photosynthetic capacity ($P_C$) and the maximum quantum yield ($Y_Q$) were not positively proportional to the total dry mass. However, the total dry mass was significantly proportional to the shoot dry mass and the multiplication product of shoot dry mass and $Y_Q$, which showed the contribution from the canopy photosynthesis or the leaf area and photosynthetic rate under lower light intensity. With the exception of ‘Munchen’ in organic culture, total dry mass was increased by supplemental lighting in all other treatments. In conclusion, both organic culture and supplemental lighting are effective in improvement of dry mass production in angelica ‘Archadie’ but not ‘Munchen’.

**Keywords:** *Angelica archangelica* L., organic, photosynthesis, substrate, supplemental lighting

**Abbreviations:** $P_C$, photosynthetic capacity; $P_N$, photosynthetic rate; ***PPF***, photosynthetic photon flux; $R_D$, dark respiration rate; $Y_Q$, maximum quantum yield

## INTRODUCTION

*Angelica archangelica* L. is a biannual herbaceous plant of the *Apiaceae* family. Its cultivation is known in Eastern Europe, Germany and France (Hornok 1992; Sarker and Nahar 2004). The roots, stems and seeds are good sources of essential oils, cumannes, furanocumannes, resins and organic acids (Grieve http://www.botanical.com; Wei and Shibamoto 2007; Jin *et al.* 2008; Özek *et al.* 2008) in addition to medicinal uses. The extracts from angelica are used in beverage, food and tobacco processing industries. In alternative medicine, it is used as recipes against colds, coughs, pleurisy, rheumatism, stomach cancer, ulcers (Khayyal *et al.* 2001; Ye *et al.* 2003), digestive problems and diseases of the urinary organs (Kwon *et al*. 2003), and widely used in dental practices and as a stimulant (Tyler 1982; Sarker and Nahar 2004; Jackson and Bergeron http://www.altnature.com/gallery/angelica.htm). In recent years, there has been a growing interest in regional production, particularly organic-based industrial production of angelica in North America. Supplemental lighting is often adopted in angelica culture in greenhouses, where the light is usually weaker than natural light. However, there is no integrated data published relating to its horticultural requirements, yield parameters and photosynthetic activity under different growing conditions. Therefore, to elucidate the basic horticultural behavior, a comparative investigation was conducted with two angelica cultivars under organic and hydroponic systems with natural and supplemental light regimes in a greenhouse.

## MATERIALS AND METHODS

### Plant materials and growing conditions

This experiment was carried out at Laval University, Québec, Canada (47° N 77° E, 55 m above sea level). The seeds of the two angelica cultivars for this experiment were obtained from Germany and were identified as ‘Archadie’ and ‘Munchen’. The 30-days-old seedlings were transplanted into two substrates and grown under natural (0-800 μmol $m^{-2}$ $s^{-1}$ during day and night) and supplemental (75 μmol $m^{-2}$ $s^{-1}$) light regimes. Plants in sand substrate were supplied with standard nutrient solution as shown in **Table 1**; plants in peat-based organic substrate were supplied with organic matter-based nutrient solution (70% sphagnum peat and 30% perlite, v/v, Premier Peat Moss, Riviere du Lou, Québec, Canada) fertilized with organic post (oil mill sludge and fish meal mixed with soil). The nutrient solution for peat-based organic culture was compost tea extracted from the abovementioned compost. The nitrogen concentration in the compost tea was adjusted close to the sand culture hydroponic nutrient solution. The sand or organic substrate was filled into a 6.25-L plastic pot and seedlings were transplanted at one plant per pot. Dry and fresh masses of the shoot and root were determined 75 d after transplant. Photosynthetic photon flux (*PPF*) inside the canopy was higher for ‘Archadie’ than for ‘Munchen’ (data not shown).

**Received: 8 December, 2008. Accepted: 28 February, 2009.**

**Original Research Paper**

**Table 1** Composition of nutrient solution with an EC of 2.3 dS $m^{-1}$.

| Element | Fertilizer source | Nutrient concentration (mmol $L^{-1}$) |
|---|---|---|
| N | $KNO_3$, $Ca(NO_3)_2$ | 10.1 |
| P | $KH_2PO_4$ | 1.7 |
| K | KCl, $KNO_3$, $KH_2PO_4$ | 7.2 |
| Ca | $Ca(NO_3)_2$ | 3.5 |
| Mg | $MgSO_4$ | 1.8 |
| Fe | EDTA-Fe | 0.0726 |
| Mn | Mn-Chelate | 0.0180 |
| Zn | Zn-Chelate | 0.0076 |
| Cu | Cu-Chelate | 0.0016 |
| B | Borax | 0.0282 |
| Mo | $(NH_4)_2MoO_4$ | 0.0006 |

## Photosynthetic measurement and modeling

Photosynthetic rate ($P_N$) was measured using an infrared $CO_2$ analyzer (ADC-225-MK3, Analytical Development Co., Ltd., Hoddesdon, England) in a 2-chamber open circuit gas exchange system with an automatic data handling system (Yue *et al.* 1992; Xu *et al.* 1994). The following hyperbolic mathematical model was used to fit the photosynthetic light response curve:

$$P_N = K\, P_C\, i\, (1 + K\, i)^{-1} - R_D.$$

Here, $P_N$ (μmol $m^{-2}$ $s^{-1}$) is the net photosynthetic rate; $P_C$ (μmol $m^{-2}$ $s^{-1}$) is the theoretical saturation photosynthetic capacity, which shows the potential photosynthetic activity and is related to all activities in the whole photosynthetic process (Togari 1973; Jones 1983; Xu *et al.* 1987; Xu *et al.* 1994); $K$ ($m^2$ s $\mu mol^{-1}$) is a parameter of the light photosynthesis curve and is related to quantum yield; the value of $KP_C$ shows the initial slope of the curve and is defined as the maximum quantum yield ($Y_Q$, mol $CO_2$ $mol^{-1}$ *PPF*); $i$ (μmol $m^{-2}$ $s^{-1}$) is the photosynthetic photon flux; and $R_D$ (μmol $m^{-2}$ $s^{-1}$) is the dark respiration rate.

## RESULTS

## Dry mass production

### *Responses of dry mass production to organic culture and supplemental lighting*

Under the natural lighting regime, both cultivars produced more total dry mass in organic culture than in sand culture, while under the supplemental lighting regime, the total dry mass production of 'Munchen' decreased in organic culture. Except for 'Munchen' in organic culture, total dry mass increased under supplemental lighting in all other treatments. In conclusion, both organic culture and supplemental lighting are effective in improvement of dry mass production in angelica 'Archadie' but not 'Munchen'. Within all the treatments and in both cultivars, the total dry mass was positively proportional to the shoot dry mass but not to root dry mass. This was logical because the biomass was contributed by the photosynthate from shoot and shoot biomass was also the main part of the total biomass.

### *Cultivar differences in dry mass production*

Under the supplemental lighting regime, total dry mass of 'Munchen' was higher in sand culture but lower in organic culture when compared with that of 'Archadie'. There were no differences between both cultivars in the natural lighting regime (**Table 2**). In some cases, lighting with high intensity or long period can cause water stress and directly or indirectly depress the growth of the aboveground part of a plant, especially in soil-based culture. Further experiments are necessary to confirm the reasons why the dry mass of 'Munchen' decreased under supplemental lighting in organic culture.

## Photosynthetic activities

### *Responses to organic culture and supplemental lighting*

Under both natural and supplemental lighting regimes, 'Munchen' showed higher $P_C$ in organic culture than in hydroponic culture while 'Archadie' showed lower $P_C$ in organic culture than in hydroponic culture (**Table 3**). However, the trend of $Y_Q$ was not consistent with that of $P_C$ (**Table 3**). For example, under both natural and supplemental lighting regimes, $P_C$ in 'Archadie' was lower in organic culture than in sand culture but the $Y_Q$ showed opposite trends, higher in organic than in sand culture. This trend was also visually shown by **Fig. 1**. With the exception of 'Archadie' in sand culture, $P_C$ was lower under supplemental than under natural lighting regime (**Table 3**). However, for all the treatments and cultivars, $Y_Q$ was higher under supplemental than under natural lighting regime (**Table 3**). The inconsistency was also shown by **Fig. 1** in which the curve showing lower photosynthetic rate under higher light intensity might indicate a higher photosynthetic rate under lower light intensity. $Y_Q$ is positively proportional to the photosynthetic rate under lower light intensity and usually promoted by strong light (Togari 1973).

### *Cultivar differences in photosynthetic responses*

Both cultivars showed opposite responses to organic culture. For example, 'Munchen' showed a higher $P_C$ but a lower $Y_Q$ in organic culture than in sand culture while 'Archadie' showed a lower $P_C$ but a higher $Y_Q$ in organic culture than in sand culture (**Table 3**). There was no much cultivar difference in photosynthetic response to the supplemental lighting. In almost all cases, $P_C$ was lower in organic culture than in sand culture. This might be attributed to the differences in response to the environmental stresses caused by the supplemental lighting.

### *Consistency between photosynthesis and dry mass production*

Within all treatments and in both cultivars, both $P_C$ and $Y_Q$ were not positively proportional to the total dry mass. However, the total dry mass was significantly proportional to the shoot dry mass and $Y_Q$. $Y_Q$ is usually positively proportional to the contribution from the canopy photosynthesis or the

**Table 2** Dry and fresh mass (g $plant^{-1}$) of two angelica cultivars grown under sand or organic substrates with or without supplemental lighting.

| Cv | Treatment | | Dry mass | | | Fresh mass | | |
|---|---|---|---|---|---|---|---|---|
| | Substrate | Light | Shoot | Root | Total | Shoot | Root | Total |
| Archadie | Sand | Natural | 58 ± 10 | 32 ± 7 | 90 | 303 ± 50 | 216 ± 29 | 519 |
| Munchen | Sand | Natural | 63 ± 7 | 27 ± 7 | 90 | 334 ± 39 | 193 ± 44 | 527 |
| Archadie | Organic | Natural | 70 ± 13 | 25 ± 6 | 95 | 339 ± 75 | 171 ± 42 | 510 |
| Munchen | Organic | Natural | 69 ± 11 | 26 ± 7 | 95 | 339 ± 75 | 171 ± 42 | 642 |
| Archadie | Sand | Supplemental | 69 ± 14 | 26 ± 7 | 95 | 426 ± 45 | 216 ± 47 | 642 |
| Munchen | Sand | Supplemental | 74 ± 11 | 39 ± 9 | 113 | 388 ± 73 | 311 ± 70 | 699 |
| Archadie | Organic | Supplemental | 77 ± 15 | 32 ± 12 | 109 | 343 ± 35 | 233 ± 61 | 576 |
| Munchen | Organic | Supplemental | 56 ± 11 | 28 ± 15 | 84 | 272 ± 66 | 219 ± 52 | 491 |

The experiment was designed as a split-plot with random 2 × 2 × 2 factors with lighting regimes as the main plots and both substrate and cultivar as the sub-plots, and the pots were replicated 5 times. There were totally 40 pots for samples. The data were presented as mean ± SD without multiple factor analysis.

**Table 3** Parameters obtained from the modeling photosynthetic light response curves for two angelica cultivars grown under sand or organic substrates with or without supplemental lighting.

| **Cv** | **Treatment** | | $P_{1000}$ | $P_C$ | $R_D$ | $K$ | $Y_Q$ |
|---|---|---|---|---|---|---|---|
| | **Substrate** | **Light** | | **(μmol m$^{-2}$ s$^{-1}$)** | | **(m$^2$ s mmol$^{-1}$)** | **(mmol mol$^{-1}$)** |
| Archadie | Sand | Natural | 15.4 ± 0.6 | 20.0 | 0.74 ± 0.04 | 4.2 | 8.3 |
| Munchen | Sand | Natural | 12.8 ± 0.5 | 15.6 | 0.67 ± 0.03 | 7.9 | 12.3 |
| Archadie | Organic | Natural | 13.3 ± 0.5 | 16.6 | 0.76 ± 0.04 | 5.9 | 9.8 |
| Munchen | Organic | Natural | 14.2 ± 0.6 | 19.2 | 0.76 ± 0.05 | 3.4 | 6.5 |
| Archadie | Sand | Supplemental | 16.1 ± 0.4 | 21.8 | 0.76 ± 0.04 | 3.6 | 7.9 |
| Munchen | Sand | Supplemental | 10.2 ± 0.6 | 12.6 | 0.89 ± 0.05 | 7.6 | 9.6 |
| Archadie | Organic | Supplemental | 12.8 ± 0.6 | 15.3 | 0.58 ± 0.03 | 6.9 | 10.6 |
| Munchen | Organic | Supplemental | 13.0 ± 0.4 | 16.6 | 0.89 ± 0.05 | 5.2 | 8.6 |

The experiment was designed as a split-plot with random 2 × 2 × 2 factors with lighting regimes as the main plots and both substrate and cultivar as the sub-plots. The pots were replicated 5 times. There were totally 40 pots for samples. The data were presented as mean ± SD without multiple factor analysis.

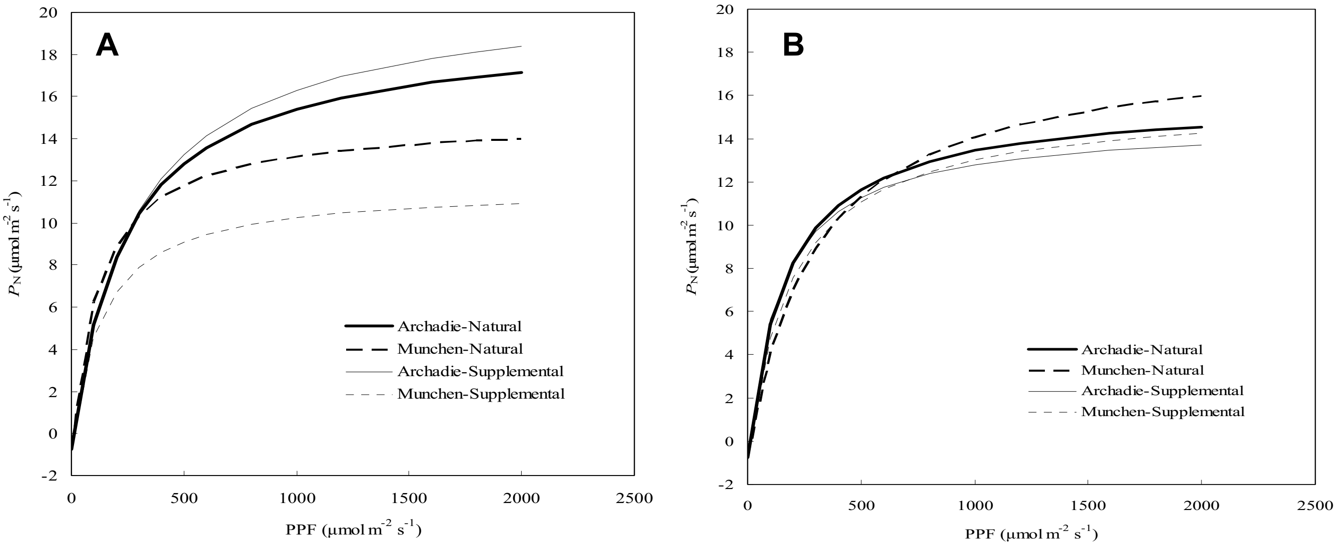

**Fig. 1 Light response curves of leaf photosynthesis of angelica grown in sand (A) or organic (B) substrate.**

multiplication product of the leaf area and photosynthetic rate under lower light intensity.

### *Other variables related with photosynthetic activities*

In the analysis of light response curve of photosynthesis, there are two other factors, the half time constant ($K$) and the dark respiration rate ($R_D$) in addition to $P_C$ and $Y_Q$. $K$ is also called Michaelis-Menten constant and equals the reciprocal of the light intensity (*PPF*) at which the photosynthetic rate reaches half value of $P_C$ (Xu *et al.* 1994). Usually the larger the value of $K$, the faster the photosynthetic light response curve gets roughly saturated. At a given $P_C$, a larger $K$ means higher photosynthetic rates under lower light intensities. In the present study, there was no meaningful difference found between substrate or lighting treatments or between cultivars. Respiration rate was small for angelica in the present study. There was also no meaningful trend in differences between substrate or lighting treatments or between cultivars.

## DISCUSSION

Angelica root has been cultivated and used as Chinese medicine for thousands of years in the Orient. *Angelica archangelica* also grows wild in North Europe, Finland, Sweden, Norway, Denmark, Greenland, the Faeroe Islands and Iceland. *A. archangelica* roots are now produced in large quantities in China and exported to various countries over the world (http://detail.en.china.cn/provide/detail,1077066290.html). However, consumers are keen to use locally grown, in-season, chemical-free, non-genetically manipulated produce; high quality is needed for angelica products that are used for health care and food additives (Wei and Shibamoto 2007; Jin *et al.* 2008; Özek *et al.* 2008). Not only the root, but also the stems, leaves and seeds are used as alternative medicines, food additives, tonics and cosmetics. In recent years, there has been a growing interest in greenhouse production of angelica in North America. In the present study, organic hydroponic substrate and supplemental lighting were adopted in greenhouse angelica culture. The results confirmed that both organic substrate and supplemental lighting were effective in promotion of angelica production in greenhouse. As reported elsewhere (Letchamo *et al.* 1995), supplemental lighting increased the essential oil content in the angelica plants. However, photosynthetic capacity was not consistent with dry mass production. Especially, supplemental lighting decreased the photosynthetic capacity. This meant that environmental stresses, such as leaf water deficit, might be caused by supplemental lighting treatment, especially in peat-based organic substrate, where the substrate volume was limited. Further studies are needed to examine the plant-water relations of angelica in the organic substrate system with supplemental lighting. According to the results of dry mass production 'Munchen' was not adapted to organic culture when compared with 'Archadie', especially under supplemental lighting conditions.

## ACKNOWLEDGEMENTS

The authors express their thanks to Bioplant Inc. and Natural Science and Engineering Research Council of Canada for their financial support and to Rachel Daigle and Fabien Labbé for their technical assistance in this research.

## REFERENCES

**Grieve M** A modern herbal – Angelica. Available online: http://www.botanical.com

**Hornok L** (1992) *Cultivation and Processing of Medicinal Plants*, Akadémiai Kiadó, Budapest, 337 pp

**Jackson D, Bergeron K** Angelica. Available online:

http://www.altnature.com/gallery/angelica.htm

**Jin RC, Li GW, Ma SL** (2008) Separation and purification technology of ferulic acid in Angelica sinensis by macroporous adsorption resin. *Chinese Traditional and Herbal Drugs* **39 (9)**, 1324-1327

**Jones HG** (1983) *Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology* (1st Edn), Cambridge University Press, Cambridge, UK, 452 pp

**Khayyal MT, El-Ghazaly MA, Kenawy SA, Seif-El-Nasr M, Mahran LG, Kafafi YAH, Okpanyi SN** (2001) Antiulcerohenic effect of some gastrointestinally acting plant extracts and their combination. *Arzneimittel-Forschung/Drug Research* **51 (7)**, 545-553

**Kwon OS, Song YS, Shin KH, Ryu JC** (2003) Identification of new urinary metabolites of byakangelicin, a component of *Angelica dahuricae* Radix, in rats. *Archives of Pharmacal Research* **26 (8)**, 606-611

**Letchamo W, Gosselin A, Holzl J** (1995) Growth and essential oil content of *Angelica archangelica* as influenced by light intensity and growing media. *Journal of Essential Oil Research* **7**, 497-504

**Özek T, Özek G, Baçer KHC, Duran A, Sagiroglu M** (2008) Composition of the essential oils of *Angelica sylvestris* L. var. *sylvestris* isolated from the fruits by different isolation techniques. *Journal of Essential Oil Research* **20 (5)**, 408-411

**Sarker SD, Nahar L** (2004) Natural medicine: The genus *Angelica*. *Current Medicinal Chemistry* **11 (11)**, 1479-1500

**Tyler VE** (1982) *The Honest Herbalist*, George F. Stickley Company, Philadelphia, PA. USA. 253 pp

**Togari Y** (1973) *Photosynthesis and Matter Production*, Yokendo, Tokyo, Japan, 268 pp

**Wei A, Shibamoto T** (2007) Antioxidant activities and volatile constituents of various essential oils. *Journal of Agricultural and Food Chemistry* **55 (5)**, 1737-1742

**Xu HL, Gauthier L, Gosselin A** (1994) Photosynthetic responses of greenhouse tomato plants to high nutrient solution electric conductivity and low soil water content. *The Journal of Horticultural Science* **69**, 821-832

**Xu HL, Yamagishi T, Kumura A** (1987) Effects of soil water deficit on photosynthesis in wheat plants. II Physiological basis for the different sensitivity of photosynthesis to water stress among plant parts. *Japanese Journal of Crop Science* **56**, 461-466

**Ye YN, So HL, Liu ESL, Shin VY, Cho CH** (2003) Effect of polysaccharides from *Angelica sinensis* on gastric ulcer healing. *Life Sciences* **72 (8)**, 925-932

**Yue D, Desjardins Y, Lammare M, Gosselin A** (1992) Photosynthesis and transpiration of *in vitro* cultured asparagus plantlets. *Scientia Horticulturae* **49**, 9-16