Influence of Light Intensity on the Yield and Quality of *Houttuynia cordata*

Aimin Li¹,²,³, Shenghua Li¹,²,³, Xianjin Wu¹,²,³, Hongmei Lu⁴, Min Huang¹,²,³, Ronghui Gu¹,²,³, Lin Wei¹,²,³ and Anna He¹,²,³

¹Department of Life Sciences, Huaihua University, Huaihua 418008, China; ²Key Laboratory of Research and Utilization of Ethnomedicinal Plant Resources of Hunan Province, Huaihua University, Huaihua 418008, China; ³Key Laboratory of Xiangxi Medicinal Plant and Ethnobotany of Hunan Higher Education, Huaihua University, Huaihua 418008, China; ⁴Research Center for Modernization of Chinese Herbal Medicine, College of Chemistry and Chemical Engineering, Central South University, Changsha 410083, China

Abstract: The contents of major nutrient components, and the composition and contents of medicinal substances were examined in *Houttuynia cordata* cultivated under field conditions and treated with natural light at full intensity, 40% intensity, and 20% intensity from sprouting to harvesting. The results indicated that the yield of the aboveground portion per unit area was highest at a 40% intensity and lowest at 20% intensity. The yield of the underground portion per unit area was highest under full intensity and lowest at a 20% intensity. As light intensity was reduced, protein and water content increased, while the contents of soluble sugar and fat, the contents of volatile oils both the aboveground and underground portion decreased. The total flavonoid content in both the aboveground and underground portions decreased with diminishing light intensity, but the composition of these flavonoids was hardly affected. In summary, although proper shading can increase the yield and the contents of some nutrients in *H. cordata*, this treatment reduces the net contents of medicinal components such as volatile oils and flavonoids, as well as the contents of active components. Therefore, it is necessary to provide sufficient light when growing *H. cordata* for medicinal and functional food purposes, but the crop may be treated with appropriate shading or intercropped when grown as food.

Key words: *Houttuynia cordata*, Light intensity, Yield, Quality.

*Houttuynia cordata* is a perennial herbaceous plant of the genus Houttuynia in the family Saururaceae. This plant is mainly distributed in the Sino-Japanese regions of eastern Asia, ranging from Japan to the Himalayas through the Ryukyu Islands, Taiwan, and China, to Southeast Asia (Oginuma et al., 2007). It has been used for treatment of pneumonia, acute/chronic tracheitis, urinary tract infections, elimination of toxins, the removal of furuncles and sanies, the induction of diuresis to treat stranguria and as an antipyretic (China Pharmacopoeia Committee. 2010). It has been shown to have anti-inflammatory (Chen et al., 2014), bacteriocidal (Zhang et al., 2007; Li et al., 2012a), anti-viral (Lin et al., 2009), anti-oxidant (Tian et al., 2011), cancer preventing (Lai et al., 2010), and nonspecific immunity promotive effects (Lau et al., 2008; Lee et al., 2008). Therefore, the plant has bright prospects for use as a drug. In addition to its healthcare functions, *H. cordata* is a vegetable containing abundant nutrients (Wu, 2011). Wild resources of *H. cordata* can no longer fulfill market requirements. Therefore, *H. cordata* is artificially cultivated in extensive areas in many regions. The appropriate cultivation conditions to obtain the crude drug meeting the requirements of GAP (Good Agricultural Practice for Chinese Crude Drugs) need to be determined. The optimal sowing time, fertilization method, and irrigation measures for *H. cordata* have been studied thoroughly, and a standard operating procedure has been formulated (Wu, 2011). However, the detailed effects of light condition and the optimal protocol for light control in its cultivation have not been determined. Producers usually choose areas with a weak light intensity or grow plots under fruit trees or maize, which resemble the sciophilous habit of *H. cordata* (Su, 2010; Chen et al., 2012). Whether these conditions are optimal for *H. cordata* remains unclear.

Light intensity significantly influences the yield and components of medicinal plants. For example, light impacts the yield, total saponins, and amino acid content of *Panax quinquefolius* (Yu et al., 1994); root growth and salidroside content of *Rhodiola sachalinensis* (Yan et al., 2004); biomass and volatile oil content in the rhizomes of *Atractylodes lancea*. 

Received 27 October 2014. Accepted 4 February 2015. Corresponding author: W. Xianjin (hhuxianjin@163.com, fax +86-745-2851305).
(Gu et al., 2008); yield, alkaloid content, and guanosine and protein accumulation in *Pinellia ternata* (Zhang et al., 2009); and growth and diosgenin content of *Dioscorea opposita* (Sun et al., 2011). However, the importance of light to the contents of volatile oils and flavonoids is hardly known. Light intensity has obvious impacts on the growth, dry matter accumulation, and nutrient composition of numerous edible plants, including purslane (Wu et al., 2008), cucumber (Ding et al., 2010), pepper (Ding et al., 2010), tomato (Ding et al., 2010), and eggplant (Ding et al., 2010). Decreasing light intensity to 20% has been reported to increase the soluble protein, vitamin C, and 2-undecanone contents of the *H. cordata* plant, as well as its yield (Peng, 2007). However, this experiment was conducted under shaded conditions with 1-year-old materials without intact aboveground portions, and the variations in the contents of specific medicinal components were not studied. Therefore, these results do not accurately reflect the influence of light intensity on the yield and quality of *H. cordata* under an actual cultivation environment. In the present study, we examined the yield, and the contents of major nutrient and medicinal components in the plants grown in the field under different light intensity treatments from sprouting to harvest to formulate a standardized operating procedure for *H. cordata* production.

**Material and Methods**

1. **Plant cultivation**  
*Houttuynia cordata* Thunb. cultivar ‘Xiangbai’, approved by the Crop Variety Registration Committee of Hunan Province, registration No.: XPD017-2009, was used in 2010 and 2011. Uniform ‘Xiangbai’ seedlings were propagated using rhizomes in September 2010.

The experiment was conducted in the biological park of Huaihua University in Hunan Province, China (27º34’ N and 110º01’ E). Each sample plot was 1 m × 1 m, and a total of nine sample plots were used. After the emergence of seedlings in March 2011, all the plants were watered once daily to field capacity.

2. **Effect of light intensity**

Three different light intensity treatments were applied, using three replicates, until harvest in late August: natural light at full intensity, 40% intensity (one layer of shading screen) and 20% intensity (two layers of shading screen). Shading was achieved by placing seedlings in 1-m tall shade-houses covered with water- and air-permeable acrylic shade nets. The light intensity under the one-layer and two-layer shade netting was confirmed to be 40% and 20% of that of full sunlight using an integrating photometer with a quantum sensor (LI-6400, Li-Cor Inc., Lincoln, NE).

3. **Determination of yield and nutrient contents**

The aboveground portion of *H. cordata* was harvested close to ground, and then the underground portion was excavated completely. The yields of these two portions were measured.

The water, vitamin C, protein, soluble sugar, and fat contents of *H. cordata* were detected according to previously described methods (Wu, 2011). Water content was calculated by subtracting the dry weight of the sample from the fresh weight. Vitamin C, protein, soluble sugar, and fat contents were determined in dry samples. The VC content was determined by the 2, 4-dinitrobenzene hydrazine method. The Kjeldahl nitrogen determination method was used to determine protein content. Sugar content was determined by anthrone colorimetry. Fat content was determined by the Soxhlet extraction method.

4. **Determination of flavonoids and volatile oils and their composition**

The composition and contents of flavonoids in *H. cordata* were detected using high-performance liquid chromatography (HPLC, Lu et al., 2010). The chromatographic conditions were as follows: chromatographic column: SHIMADZU VP-ODS column (250 mm × 4.6 mm, 5 μm); detection wavelength: 280 nm; column temperature: 20°C; filling 20 μL; mobile phase: methanol (A) and (B) 0.1% (v/v) sodium phosphate buffer; velocity: 1.0 mL/min.

The contents and composition of volatile oils were determined using gas chromatography-mass spectrometry (Lu et al., 2011). A GC - 2010 gas chromatograph and QP - 2010 mass spectrometer (Shimadzu) with a OV - 1 capillary column (30 m × 0. 25 mm i. d., 0. 25 mm) were employed. The measurement conditions were as follows: injection port temperature, 280°C; detector temperature, 230°C; carrier gas, helium; current mode, constant; velocity, 0.70 mL/min; split ratio, 10:1; The temperature was programmed as follows: 50°C for 6 min, then increased at 10°C /min to 230°C and maintained for 16 min. The sample quantity was 1.0 mL. EI ionization was employed at 70 eV, with a quality range of 20–450 U and a scanning interval of 0.2 s/time.

5. **Statistical analyses**

SPSS13.0 (SPSS) was used for the statistical analysis and normality testing of the data. Single-factor analysis of variance and the multiple comparison of least significant difference (LSD) method were employed.

**Results**

1. **Influence of light intensity on yield and nutrient components**

As shown in Table 1, the aboveground and underground yields of *H. cordata* per unit area were obviously influenced by light intensity. The fresh and dry weights of the aboveground portion were both highest at 40% intensity and lowest at 20% intensity. The fresh and dry weights of
the underground portion per unit area were highest at full intensity and lowest at 20% intensity.

As shown in Fig. 1, the protein and water contents in both the aboveground and underground portions of \textit{H. cordata} increased as light intensity decreased; the contents of soluble sugar and fat in the underground portion decreased with the reduction of light intensity. The influence of light intensity on vitamin C content was complex: in the aboveground portion, vitamin C content was highest at 40% intensity and lowest at 20% intensity, while in the underground portion, the content of this vitamin gradually decreased with the reduction of light intensity. The degrees of influence of light intensity on the nutrient contents of the aboveground portion may be ranked in descending order as follows: vitamin C > fat > protein > soluble sugar > water. The degrees of influence of light intensity on the nutrient contents of the underground portion may be ranked as follows: soluble sugar > vitamin C > fat > protein > water.

2. Influence of light intensity on the contents and composition of flavonoids

The contents of total flavonoids decreased greatly in both the aboveground and underground portions of the plants with reduced light transmission. The magnitude of the decrease in the aboveground portion was slightly larger

| Treatment                | Aboveground part | Underground part |
|--------------------------|------------------|------------------|
|                          | Fresh weight     | Dry weight       | Fresh weight | Dry weight       |
| Natural sunlight         | 2.25 ± 0.23 a    | 0.46 ± 0.05 a    | 3.07 ± 0.53 a| 0.64 ± 0.11 a    |
| 40% Natural sunlight     | 2.48 ± 0.43 a    | 0.48 ± 0.08 a    | 2.44 ± 0.42 a| 0.48 ± 0.08 a    |
| 20% Natural sunlight     | 1.82 ± 0.32 b    | 0.33 ± 0.06 b    | 1.36 ± 0.33 b| 0.26 ± 0.06 b    |

Each value is the mean and standard error of the mean for 3 replicates, different lower case letters represent statistical significance between the means for each light condition, values with the same letter are not significantly different at $P < 0.05$. 

Fig. 1. Changes in the total flavonoid contents and main nutritional components of \textit{Houttuynia cordata} under different light intensities.
than that in the underground portion (Fig. 1). The flavonoid contents of *H. cordata* include many components. In the HPLC profile of the flavonoids in the aboveground portion there were no major changes in the number or position of major peaks after the different light intensity treatments, but the relative area of each peak was significantly changed. For example, the relative peak areas of rutin, quercitrin, and quercetin decreased to different degrees with the reduction of light intensity (Fig. 2). Rutin decreased to the greatest degree, by nearly 50%, at 40% intensity. The decreases of quercetin and quercitrin at 40% intensity were relatively small, but these reductions exceeded 40% at 20% intensity. Light intensity therefore exerted less influence on the composition of flavonoids in *H. cordata* than on the relative contents of each component. This effect decreased the total flavonoid contents.

### 3. Influence of light intensity on the contents and composition of volatile oils

As light intensity decreased, the contents of volatile oils decreased in both the aboveground and underground portions of the plants. This decrease was greater in the aboveground portion than in the underground portion (Table 2). Light intensity also changed the contents of each component volatile oil. Among the 23 components accounting for 98% – 99% of the total volatile oils, ten components significantly decreased with reduced light intensity. Except for γ-terpineol, the decrease of these components at 20% intensity was greater than that at 40% intensity. The decrease of myrcene exceeded 50% at 40% intensity, while those of camphene, sabinene, β-pinene, and myrcene exceeded 50% at 20% intensity. Conversely, shading treatment increased the contents of nine components. Among these components, undecanoic acid, pentyl vinyl ketone, myristicin aldehyde, and 2, 6, 10, 14-tetramethylpentadecane increased to a greater degree at 20% intensity, while geranyl acetate and 2-decanone increased to a greater degree at 40% intensity. Moreover, the contents of camphene, α-terpineol, and palmitic acid increased at 40% intensity but decreased at 20% intensity; capraldehyde content showed the opposite trend (Table 3).

#### Discussion

Appropriate light intensity is important for photosynthesis, as well as for attaining a large biomass and the yield of valuable organs (Sun et al., 2011; Gu et al., 2008; Zhang et al., 2009). The optimal light intensity for growth and development varies with the plant ecotype: full exposure to the sun is favorable for the biomass of sun plants (Wu et al., 2008; Ding et al., 2010), while a certain degree of shading can increase the biomass of shade plants (Yu et al., 1994; Zhang et al., 2009). In this study, the yield of the aboveground portion of *H. cordata* was greatest at 40% intensity, while the yield of the underground portion was greatest at full intensity. These results were inconsistent with those of a previous short-term experiment using regrown *H. cordata* (Peng, 2007). In the present study, measurements were made from sprouting to harvesting, to determine the light intensity requirement of this species more accurately. When light intensity is low, sun plants can increase their chlorophyll contents to lower their light compensation and light saturation points, thereby improving light adsorption and photosynthetic rate. However, long periods of low light intensity will reduce the accumulation of the net photosynthetic products and compounds necessary for normal growth, leading to reduced biomass (Guo et al., 2010; Qin et al., 2013). Therefore, the biomass of sun plants can only be increased under full light conditions.

The root/shoot ratio reflects the allocation of photosynthetic products to the aboveground and underground portions.

| Treatment          | Aboveground part | Underground part |
|--------------------|------------------|------------------|
|                    | Volatile oil content (mL kg⁻¹) | Decline (%) | Volatile oil content (mL kg⁻¹) | Decline (%) |
| Natural sunlight   | 0.38 ± 0.06 a    | 0               | 0.89 ± 0.08 a    | 0               |
| 40% Natural sunlight| 0.32 ± 0.07 a   | 15.79           | 0.83 ± 0.06 a    | 6.74           |
| 20% Natural sunlight| 0.30 ± 0.04 b  | 21.05           | 0.80 ± 0.07 a    | 10.11          |

Each value is the mean and standard error of the mean for 3 replicates, different lower case letters represent statistical significance between the means for each light condition, values with the same letter are not significantly different at \( P < 0.05 \).
of the plant (ratio of biomass) (Li et al., 2012b; Yang et al., 2013). A decrease in root-shoot ratio ensures that the assimilating organs, in which optical energy is captured for photosynthesis, are better developed and is consistent with the adaptation strategy of other sun plants to shaded conditions (Moacyr, 2002; Xu et al., 2003; Grechi et al., 2007; An and Shangguan, 2009). Regarding the influence of light intensity on its yield and root-shoot ratio, H. cordata differs from typical shade plants and is closer to sun plants. This result is in agreement with the effects of the growth environment in wild H. cordata (Peng, 2007).

Light intensity can influence both the primary and secondary metabolism of plants (Peng, 2007; Zhang et al., 2009), thus changing the contents of nutrients and medicinal components. In the present study, light intensity impacted the contents of the examined components in both the aboveground and underground portions of H. cordata. Significant differences were observed in the vitamin C contents of the aboveground portion among the three treatment groups and in the soluble sugar content of the underground portion in the 20% intensity treatment.

Protein content generally increases under shaded conditions, which promote the contents of enzymes with assimilating functions to improve assimilation at a low light intensity. In our experiment, the protein content of *H. cordata* increased with the decrease of light intensity. This result agrees with those obtained in previous research on *H. cordata* (Peng, 2007), *Moringa oleifera* (Lv, 2009), and maize (Jananadan and Jiro, 2006) but disagrees with that obtained for *Pinellia ternata* (Zhang et al., 2009). Our results indicated that the soluble sugar content of *H. cordata* decreased with decreased light intensity, as has been observed in *Catharanthus roseus*. *H. cordata* grown for food can be cultured under shaded conditions or intercropped in orchards and maize fields with only small differences in nutrient composition compared to cultivation under full light (Su, 2010). This practice promotes land-use efficiency, thereby increasing the farmer income.

The contents of total volatile oils and major medicinal components and their composition were changed by the underground portion in the 20% intensity treatment. Protein content generally increases under shaded conditions, which promote the contents of enzymes with assimilating functions to improve assimilation at a low light intensity. In our experiment, the protein content of *H. cordata* increased with the decrease of light intensity. This result agrees with those obtained in previous research on *H. cordata* (Peng, 2007), *Moringa oleifera* (Lv, 2009), and maize (Jananadan and Jiro, 2006) but disagrees with that obtained for *Pinellia ternata* (Zhang et al., 2009). Our results indicated that the soluble sugar content of *H. cordata* decreased with decreased light intensity, as has been observed in *Catharanthus roseus*. *H. cordata* grown for food can be cultured under shaded conditions or intercropped in orchards and maize fields with only small differences in nutrient composition compared to cultivation under full light (Su, 2010). This practice promotes land-use efficiency, thereby increasing the farmer income.

The contents of total volatile oils and major medicinal components and their composition were changed by

| No. | Compounds | Retention time (min) | Natural sunlight | 40% Natural sunlight | 20% Natural sunlight |
|-----|-----------|---------------------|------------------|----------------------|----------------------|
|     |           |                     |                  | Relative amount      | Variation (%)         | Relative amount      | Variation (%)         |
| 1   | α-Thuene  | 12.348              | 1.66 ± 0.98      | 1.43 ± 0.41          | −13.25               | 0.89 ± 0.27          | −46.39                |
| 2   | Camphene  | 12.690              | 0.32 ± 0.21      | 0.52 ± 0.09          | 62.50                | 0.12 ± 0.09          | −62.50                |
| 3   | Sabinene  | 13.217              | 1.36 ± 0.72      | 1.19 ± 0.43          | −12.50               | 0.65 ± 0.56          | −52.21                |
| 4   | β-Pinene  | 13.346              | 1.80 ± 0.21      | 1.59 ± 0.46          | −22.78               | 0.89 ± 0.29          | −50.56                |
| 5   | Myrcene   | 13.571              | 16.21 ± 3.58     | 7.45 ± 2.26          | −54.04               | 7.17 ± 1.04          | −55.77                |
| 6   | D-Limonene| 14.483              | 0.29 ± 0.11      | 0.22 ± 0.11          | −24.14               | 0.15 ± 0.04          | −48.28                |
| 7   | trans-β Ocimene | 14.537 | 0.99 ± 0.43 | 0.76 ± 0.18 | −23.23 | 0.57 ± 0.23 | −42.42 |
| 8   | γ-Terpineol| 15.072              | 0.42 ± 0.06      | 0.23 ± 0.07          | −45.23               | 0.24 ± 0.15          | −42.86                |
| 9   | 2, 6-Dimethyl-3, 5, 7-sympleetic triene-2 alcohol | 15.695 | 2.38 ± 0.61 | 2.76 ± 0.53 | 15.97 | 2.71 ± 1.30 | 13.87 |
| 10  | 4-Terpineol| 17.334              | 1.41 ± 0.68      | 2.21 ± 0.61          | 56.74                | 2.18 ± 1.09          | 54.61                |
| 11  | α-Terpineol| 17.544              | 0.25 ± 0.07      | 0.93 ± 0.43          | 272.00               | 0.39 ± 0.08          | −24.00                |
| 12  | Decanal   | 17.605              | 0.96 ± 0.21      | 0.79 ± 0.11          | −17.71               | 4.73 ± 1.17          | 392.71                |
| 13  | trans-Pinocarvyl acetate | 18.583 | 3.04 ± 0.46 | 2.75 ± 0.26 | −9.54 | 2.53 ± 1.01 | −16.78 |
| 14  | 2-Undecanone| 19.091              | 46.67 ± 4.71     | 50.39 ± 2.93         | 7.97                 | 44.11 ± 4.41         | 5.80                  |
| 15  | Undecanoic acid | 20.251 | 4.37 ± 1.08 | 7.46 ± 0.59 | 70.71 | 11.45 ± 2.41 | 102.01 |
| 16  | Geranyl acetate | 20.388 | 1.43 ± 0.41 | 2.22 ± 0.22 | 55.24 | 1.46 ± 0.26 | 2.09 |
| 17  | Pentyl vinyl ketone | 20.465 | 0.17 ± 0.11 | 0.24 ± 0.03 | 41.18 | 0.27 ± 0.04 | 58.82 |
| 18  | 2-Decanone| 20.657              | 0.77 ± 0.31      | 0.92 ± 0.03          | 19.48                | 0.84 ± 0.35          | 9.09                  |
| 19  | Myristicin aldehyde | 20.884 | 0.35 ± 0.20 | 0.38 ± 0.28 | 8.57 | 1.21 ± 0.13 | 245.71 |
| 20  | Caryophyllene | 21.547 | 0.49 ± 0.09 | 0.47 ± 0.07 | −4.08 | 0.45 ± 0.26 | −8.89 |
| 21  | 2-Tridecanone| 22.121              | 6.85 ± 1.04      | 6.04 ± 0.43          | −11.82               | 5.30 ± 1.28          | −22.63                |
| 22  | Palmitic acid | 23.003              | 0.61 ± 0.25      | 0.53 ± 0.26          | 52.46                | 0.45 ± 0.18          | −26.23                |
| 23  | 2, 6, 10, 14-Tetramethyl pentadecane acid | 23.598 | 6.04 ± 4.57 | 7.83 ± 2.37 | 29.64 | 10.21 ± 2.38 | 69.04 |

Each value is the mean and standard error of the mean for 3 replicates.
lowering light intensity in *H. cordata*. In a previous study (Gu et al., 2008), the content of volatile oils in the rhizome of *Atractylodes lancea* was highest at 72.90% intensity; in the study by Peng (2007), the content of 2-undecanone of *H. cordata* increased even at 20% intensity. The composition of volatile oils is important for the medicinal effects of the plant. Terpenoids are the major active ingredients of volatile oils (Chen et al., 2014). According to the quality standard of the Pharmacopoeia of the People’s Republic of China, the quality of the medicinal materials is considered high when the content of 2-undecanone is high. The content of 2-undecanone was 46.67, 50.39 and 44.11%, at full intensity, 40% intensity; and 20% intensity. The content of 2-undecanone increased at first and then decreased with the decrease of light intensity. Therefore, as light intensity decreased, the proportion of volatile oil components with pharmacological activity also decreased while that of inactive components increased.

Flavonoids represent another important class of medicinal components in *H. cordata* (Lu et al., 2010). The contents of flavonoids decreased with reduced light intensity, as was observed in soybean (Sun et al., 1998) and gingko (Leng et al., 2002). This result is also in agreement with those obtained using cultured cells of *Eucommia ulmoides* (Li et al., 2004) and *Scutellaria baicalensis* (Chen et al., 2010). However, the total flavonoid content of *Portulaca oleracea* L. (Wu et al., 2008) was higher at a low light intensity, and the saponin content of *Dioscorea zingiberensis* (Sun et al., 2011) was highest at 40% intensity. Shading not only reduces the total flavonoid content in *H. cordata* but also particularly decreases the contents of rutin, quercitrin, and quercetin, which have pharmacological activities.

Low light intensity reduced both the net contents and quality of volatile oils and flavonoids. Therefore, sufficient light is essential for producing high-quality *H. cordata* as a crude drug. The mechanism underlying this result may be as follows. Flavonoids are synthesized along the general phenylpropanoid pathway (Petrussa et al., 2013). Glucose serves as the precursor for the formation of flavonoids and volatile oils. Volatile oils are composed of acetyl-CoA, by the mevalonic acid (MVA) and meyererylthritol phosphate (MEP) pathway. Acetyl-CoA could form malonyl-CoA by acetyl-CoA carboxylase, and malonyl-CoA is the precursor for the formation of flavonoids (Dudareva et al., 2013). The basic skeleton of all flavonoids consists of three molecules of malonyl-CoA and one of 4-coumaroyl-CoA. They form chalcone by chalcone synthase (CHS), Chalcone is then synthesized and processed into various flavonoids (Petrussa et al., 2013). Whether it is a volatile oil or flavonoids, their precursors are acetyl-CoA. Acetyl-CoA is a product of fatty acid beta-oxidation and oxidation and decarboxylation of pyruvate, which come from glycolysis. Light intensity decreased, the contents of carbohydrate and fat were decreased leading to reduced synthesis of acetyl-CoA. Acetyl-CoA is the precursor which synthesizes volatile oils and total flavonoids. Precursors were reduced, resulting in the reduction of the content of volatile oils and total flavonoids. This hypothesis is supported by the decrease of soluble sugar due to increased shading and the associated decrease in flavonoids and volatile oils content.

**Acknowledgements**

This work was supported by the construct program of the key discipline in the Education Department of Human Province (2011-42), Innovation platform open fund in Higher Educational Institutions of Human Province (14K074), National Natural Science Foundation of China (No. 30870250), Hunan Provincial Scientific Research Project Funding (No. 2013FJ0900).

**References**

An, H. and Shangguan, Z.P. 2009. Effects of light intensity and nitrogen application on the growth and photosynthetic characteristics of *Trifolium repens* L. *Acta Ecol. Sin.* 29: 6017–6024*.

Chen, H.L., Li, A.H., Yang, Y.L., Zhang, X.Y. and Chen, Z.B. 2012. Discussion on undergrowth pattern of *Citrus reticulata* in Hubei. *Hubei For. Sci. Technol.* (5): 38-42*.

Chen, J., Fang, J.G., Wu, F.J., Shi, C.Y., Xiong, M.M. and Wang, W.Q. 2014. Research progress on anti-inflammatory mechanism of *Houttuynia cordata*. *Chin. Tradit. Herb. Drugs*, 45: 284-289*.

Chen, S.Q., Yuan, Y., Liao, Y.J., Huang, L.Q., Chen, P. and Li, X.M. 2010. Effects of light on flavonoids accumulation and related gene expression in suspension cultures of *Scutellaria baicalensis*. *Chin. J. Chin. Mater. Med.* 35:682-685*.

China Pharmacopoeia Committee 2010 Pharmacopoeia of the People’s Republic of China (Part I). Beijing: China Medical Science Press, 208-209*.

Ding, X.T., Jin, H.J., Zhang, H.M. and Yu, J.Z. 2010. Effect of shading on growth and diurnal photosynthetic changes of four vegetables in glasshouse. *Acta Agric. Zhejiang* 22: 51-56*.

Dudareva, N., Klemptien, A., Muhlemann, J.K. and Kaplan, I. 2013. Biosynthesis, function and metabolic engineering of plant volatile organic compounds. *New Phytol.* 198: 16-32.

Grechi, I., Vivin, P., Hilbert, G., Milin, S., Robert, T. and Gaudillere, J.P. 2007. Effect of light and nitrogen supply on internal C:N balance and control of root-to-shoot biomass allocation in *grapevine*. *Environ. Exp. Bot.* 59: 139-149.

Gu, Y.H., Feng, X. and Xia, B. 2008. Effects of light intensity on biomass of rhizoma and essential oil contents of *Atractylodes lancea*. *Jiangsu Agric. Sci.* 35:682-685*.

Guo, J.X., Xia, Y.T., He, J. and Zhu, G.F. 2010. Physiological responses to lighting and shading in two ornamental plants. *Guangdong Agric. Sci.* 43: 67-70,74*.

Janaeaban, K., and Jiro, T. 2006. Alteration in intra-plant distribution of δ15 N in response to shading in legumes. *Plant Prod. Sci.* 9: 219-227.

Lai, K.C., Chiu, Y.J., Tang, Y.J., Lin, K.L., Chiang, J.H., Jiang, Y.L., Jen, H.F., Kuo, Y.H., Agamaya, S., Chung, J.G. and Yang, J.S. 2010. *Houttuynia cordata* Thumb extract inhibits cell growth and induces apoptosis in human primary colorectal cancer cells. *Anticancer Res.*
