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Original Research Paper

Seasonal Changes in Soluble Sugar Contents in Different Parts of *Alternanthera philoxeroides* from Aquatic and Terrestrial Habitats

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ABSTRACT

Exotic invasion is considered as the second factor influencing biodiversity after habitat lose. Alligator weed (*Alternanthera philoxeroides* Griseb.), a perennial herb native to the South America, has established itself on almost all the surface of the earth except Africa. In China, alligator weed has invaded most temperate regions where the environmental conditions, particularly temperature, are obviously different from its origin. How can alligator weed survive through cold winters is a critical issue for its establishment in these areas. In this research, we investigated the seasonal change of soluble sugars content (SSC), which presented important physiological reaction to cold acclimation, in different parts including buds, nodes, and internodes of alligator weed from aquatic and terrestrial habitats. Results showed that accumulation of soluble sugars was regularly correlated to temperature change in environment, i.e., the highest SSC in the coldest season, and the lowest in summer. Among different parts such as nodes, buds and internodes in individuals from terrestrial and aquatic habitats, accumulation of SSC presented similar results. The accumulation of SSC and its seasonal dynamics may be a physiological acclimation to low temperature so that alligator weed could establish in these regions and survive through cold winters ecologically.

INTRODUCTION

Exotic invasive species could not only change the functions, structures, flora and fauna composition of native ecosystems, but also influence the socio-economic development (Cronk & Fuller 1995, Mack & D'Antonio 1998, Gill & Burke 1999, Mack et al. 2000, Josefsson & Andersson2001, Keane et al. 2002, Battaglia et al. 2007). It is often very difficult to control exotic species after they spread invasively into a new habitat for their high competition, strong propagation abilities, and fast spreading features (Zalba et al. 2000). The control of exotic invasion is expensive, for example, there are about 700,000 ha being invaded by exotic weeds every year in USA, and only the controls of exotic aquatic weeds will invest 100 million dollar (Pimentel et al. 2000). The globalization of world economies and tourism is creating more and more opportunities for exotic species invading new environments (Westbrooks et al. 2001, Xie et al. 2001). The invasive species usually has a strong reproductive ability, in particular, vegetative propagation ability, which allows invasive species to occupy territory and establish colonies rapidly (Piquot et al. 1998, Katovich et al. 1999, Hollingsworth et al. 2000, De Waal 2001, Doyle & Smart 2001). Study on the invading mechanisms and their adaptation strategies of exotic invasive species in new environments is the precondition for controlling them effectively (Shadel & Molofsky 2002).

Alligator weed (*Alternanthera philoxeroides* Griseb.) is a perennial herb native to the South America (Buckingham 1996), but it has been established almost on all the surface of the earth except the Africa due to its strong invasion ability (Cronk & Fuller 1995). In particular, introduced into Australia, Japan and the North America, alligator weed displayed strong invasion ability to new habitats (Cronk & Fuller 1995). In China, alligator weed not only displayed considerable invasion ability, but also could reproduce rapidly both in aquatic and terrestrial habitats with great phenotypic plasticity under different habitats (Huai et al. 2003, Geng et al. 2006). As it can rapidly propagate by vegetative reproduction both in territorial and aquatic habitats, alligator weed often become easily a dominant species and limit significantly the growth of native species in both territorial and aquatic communities (Huai et al. 2003, Stohlgren et al. 2002). Alligator weed originally came from a tropical and arid environment with a mean annual temperature above 24°C and precipitation less than 1000 mm in South America (Cronk & Fuller 1995). Alligator weed, however, has successfully invaded and established in temperate areas in China with a mean annual temperature of 12-16°C, in particular, there is a cold winter every year in these temperate areas (Li et al. 2001, Liu 2002). How alligator weed can survive through the cold winter in these temperate areas is an interesting issue in understanding of the invasive mechanisms and its ecological strategy for cold acclimation of the weed in these areas.

Generally, plants may avoid damages from cold stress through different strategies, morphologically or physiologically (Prasad 1997, Warren 1998, Beck et al. 2004, Ma et al. 2009). In particular, the change of soluble sugar content (SSC) is physiologically an important reaction to cold acclimation. Studies have shown that accumulation of soluble sugar physiologically plays an important role in protecting plants from low temperature stress by increasing intracellular osmotic potential (Skai 1960, Koster & Lynch 1992, Marquat et al. 1999, Ma et al. 2009), providing energy supply under low temperature stress (Hansen & Grauslund 1973), and protecting proteins and membranes (Steponkus et al. 1977). Soluble sugar content is also a primary messenger in signal transductions and may have certain functions of regulating gene expression under cold condition (Ma et al. 2009). In current research, we investigated the seasonal changes of soluble sugar content in different parts of alligator weed including buds, nodes and internodes from aquatic and terrestrial habitats in order to understand its reaction to low temperature stress physiologically. This investigation could contribute to understand invasive mechanisms of alligator weed and its ecological strategy for cold acclimation in temperate areas.

MATERIALS AND METHODS

Study site and sample collection: Study was conducted in the Yangtze valley downstream near Yangzhou city, Jiangsu Province. This area is one of main paddy rice production areas in China, with a mean annual temperature of 14-16°C and a mean annual precipitation of 1058.7 mm. It is hot in summer and cold in winter. Usually, the hottest month is July or August with a monthly mean temperature of 27-30°C, and the coldest month is January or February with a monthly mean temperature of 3-6°C (Yuan & Yang 2007). Alligator weed has invaded most parts in this area, such as rivers, pools, lawns, farmlands and roadsides. Alligator weed displays considerable vegetative propagation ability with great phenotypic plasticity in both aquatic and terrestrial habitats, and removing alligator weed from farmlands for crop growth is arduous work every year in this area (Huai et al. 2003). Because the leaves and most of the above-ground parts of the weed die, and only rhizomes and buds underground remain in winter. Rhizomes and buds survived, revive and start vegetative propagation with seasonal change. To investigate its physiological reaction to seasonal temperature change, we monthly sampled buds, nodes and internodes in rhizomes from individuals from terrestrial and aquatic habitats during November 2006 to October of 2007. We collected samples around 10:00 a.m. in the morning on the 10th day of every month. Every sample was collected from 20 individuals from terrestrial and aquatic habitats. After cleaning with water, buds, nodes and internodes were cut for further treatment.

Table 1: Comparison of SSCc through a year in buds, nodes and internodes.

Habitat	SSCs (Mean ± SD) FW%		
	buds	nodes	internodes
Terrestrial habitats	3.51 ± 1.91	6.35 ± 1.41	5.91 ± 1.44
Aquatic habitats	4.34 ± 2.70	5.58 ± 2.26	5.33 ± 2.07

Measurement of soluble sugar components: Anthrone colorimetry method was used to measure the total soluble sugar contents as described by Gao (2000). The samples were treated at 105°C for 15 min, dried to attain stable weights under 85°C, and finely ground. 0.6g ground material of each sample was divided equally into 6 groups, i.e. 0.1g of each group. The extraction of soluble sugars was done by mixing the dried sample with 10mL distilled water, and then heating it at 80°C in an electric-heated thermostatic water bath for 40min. After centrifugation at 6000 rpm for 8 min, supernatant was collected and the settling was re-extracted in 5 mL distilled water for 15 min. 1 mL of the extracting liquid was mixed with 4mL prepared anthrone reagent and heated at 100°C for 10 min. The OD values were determined at A620nm by a spectrophotometer (UV-2450, SHIMADZU) using glucose as a standard. SSCs were calculated according to the following formula:

$$w = \frac{C \times V}{m} \times 100\%$$

Where, w is SSCs (FW%);C is the sugar content (mg/mL) corresponding to the glucose standard curve;V is the diluent volume of sample (mL); and m is the weight of sample (g).

Each measurement was repeated six times. The SSCs values were expressed as mean±SD. All data were analysed by SPSS 11. Paired-Samples Test and One-Way ANOVA have been used to determine the differences among SSCs in different parts or different times. The differences were statistically significant when $p < 0.05$.

RESULTS

The SSCs from terrestrial habitats: The seasonal change of SSCs in node and internode from terrestrial individuals was similar ($t = 0.760$, $P > 0.05$), but they differed from that in buds ($t = 4.148$, $P < 0.05$; $t = 3.477$, $P < 0.05$) (Fig. 1). The SSCs were negatively correlated with temperature change. The accumulation of SSCs in three different parts from October to May was significantly higher than that in other periods (from November to April) (df = 1, 35, F = 12.235,

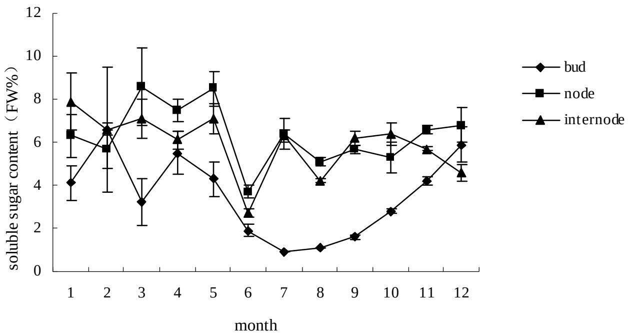

Fig. 1: Monthly variation of SSCs in buds, nodes and internodes from terrestrial habitats.

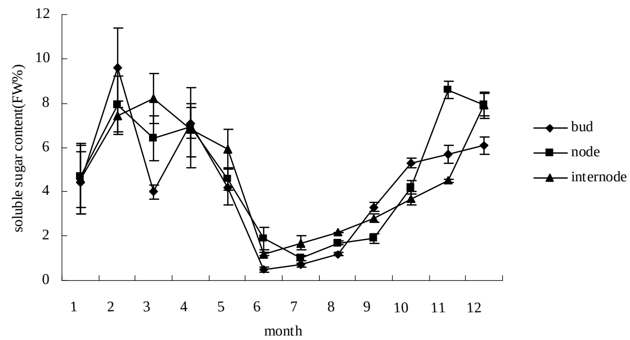

Fig. 2: Monthly variations of SSCs in buds, nodes and internodes from aquatic habitats.

p = 0.001). In particular, the accumulation of SSCs in buds was lowest during summers (with a mean temperature of 29.2°C between July-August in 2007), while SSCs were higher during winter (with a mean temperature of 5.8°C in 2006). Compared with nodes and internodes, buds accumulated lower SSCs during a year (df = 1, 23, F = 17.209, $p < 0.001$; df = 1, 23, F = 12.088, p = 0.002, respectively). These results suggested that accumulation of soluble sugar in alligator weed from terrestrial habitats is related to environmental temperature.

The SSCs from aquatic habitats: Monthly change of SSCs from aquatic habitats showed a similar trend to that from terrestrial habitats. Soluble sugar accumulation was negatively correlated with temperature change (Fig. 2). The SSCs were higher from November to April than that from May to October (df = 1, 35, F = 72.048, p = 0.000). The SSCs were at the lowest level from June to August corresponding to the highest temperature a year. There was no difference in SSCs among buds, nodes and internodes with seasonal change (df = 2, 23, F = 0.110, p = 0.896). Unlike terrestrial individuals displayed, the monthly variation of SSCs in buds has no difference from that in nodes (df = 1, 7, F = 0.087, p = 0.778) and that in internodes (df = 1, 7, F = 0.571, p = 0.478) from June to September.

Comparing SSCs through a year in buds, nodes and internodes, there were no significant difference between terrestrial and aquatic habitats (df = 1, 23; F = 0.762, 3.025, 1.984; p = 0.392, 0.096, 0.173, respectively) (Table 1). It suggested that the physiological accumulation of SSCs in alligator weed is relatively stable in different habitats, though it varied with seasonal change.

DISCUSSION

Soluble sugars, including glucose, fructose, maltose and sucrose etc., are the direct or indirect products of photosynthesis and one of main substrates for metabolism (Mcpherson et al. 1997, Zhao et al. 2000). To meet the rapid growth and fast propagation and spreading from April to October in a year, alligator weed exhibited high efficient photosynthesis ability during this period (Huai et al. 2003). Correspondingly, the SSCs are at the lower level than other periods of a year. This may be explained as the abundant soluble sugars produced during photosynthesis are exhausted for its rapid growth and propagation. The leaves of alligator weed withered away in the winter, and growth and photosynthesis nearly stopped, however, the SSCs maintained at the highest level. It is most likely as a result of physiological response to environmental stress.

Studies have shown that soluble sugars are closely correlated with the abilities to resist coldness in plants (Hansen & Grauslund 1973, Steponkus et al. 1977, Marquat et al. 1999). The accumulation of SSCs was usually considered as a physiological reaction to cold acclimation (Koster & Lynch 1992, Marquat et al. 1999, Ma et al. 2009). The monthly variation of SSCs in buds, nodes and internodes from both aquatic and terrestrial habitats displayed a close consistency with environmental temperature. What is more, SSC accumulated were at a significantly higher level in winter than that in other seasons (Figs. 1 and 2). These results strongly suggested that the variation of SSCs with environmental temperature be a physiological reaction of alligator weed to cold acclimation. The accumulation of the highest SSCs in February was likely as a result of acclimating low temperature stress. It seems that alligator weed has ecologically developed a strategy for acclimating low temperature stress in this area so that it can survive through the cold winter by accumulating the high SSCs. However, whether alligator weed presents a similar dynamics through a year and physiologically accumulated the highest SSCs in winter in other areas including its original home South America is unknown yet.

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