Title page

PLANT REGENERATION FROM MATURE ZYGOTIC EMBRYO EXPLANTS OF *ACACIA CRASSICARPA* VIA ADVENTITOUS SHOOT ORGANOGENESIS

**Running Title: Plant regeneration of *Acacia crassicarpa***

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Abstract:

*Acacia crassicarpa*is a major species for fiber production in Southeast Asia. *In vitro* multiplication of this species could be valuable for expanding plantation.Toexplore new approachesto propagate*A. crassicarpa*, we developed an efficient system to regenerateplants from mature zygotic embryoexplants via shoot organogenesis. Embryos were cultured on Murashige and Skoog (MS) medium supplemented with various concentrations of 1-pheny l-3-(thiadiazol-5-yl) urea (thidiazuron) (TDZ) and indole-3-acetic acid (IAA).Combinations of TDZ at 1-2 mgl-1 and IAA at 0.1-1.0 mg l-1were optimum to induceshoot budformation.The medium containing 1 mg l-1TDZ and 0.5 mg l-1IAA yielded the highest rate of shoot buds(73.23%). The embryos with shoot buds were subcultured in fresh medium of the same composition above for shoot development and then grew into big green nodule-like callus. The callus were then transferred to the media containing Gibberellic acid (GA3) forshoot elongation induction.The elongated shoots would be rooted on 1/2 MS medium with 0.5 mg l-1 3-indol ebutyric acid (IBA) within 1month. Rooted plantlets were hardened and successfully established in soil with an 97.5 % survival rate. Thedata from this study provided a useful technique with using mature zygotic embryos for *A. crassicarpa in vitro* regeneration,which might facilitate the expanding plantation of *A. crassicarpa*with high-quality regenerated plantlets.The highest rate of shoot bud induction (73.23%) was on medium containing 1 mg l-1TDZ and 0.5 mg l-1IAA. Embryos with shoot buds were subcultured on fresh medium with the same composition as that described above for shoot development. Large, green nodule calli grew fromthese embryos. The calli were then transferred to medium containing gibberellic acid (GA3) to induce shoot elongation. The elongated shoots formed roots within 1 month when grown on 1/2 MS medium containing 0.5 mg l-13-indolebutyric acid (IBA). The rooted plantlets were hardenedand successfully established in soil with a survival rate of 97.5%. This system, in which mature zygotic embryos were used to regenerate *A. crassicarpa* plants *in vitro*, will be useful for producing high-quality regenerated plantlets that could be used to expand plantations of this species.

Key words:Acaciacrassicarpa,thidiazuron, indole-3-aceticacid

Introduction:

*Acacia* is a leguminous tree that is widely dispersed in tropical and sub-tropical regions. The planting area of *Acacia* species has increased, as they have been used for reforestation, reclamation of wasteland, and industrial material production around Southeast Asia, especially Indonesia, as well as in some southern provinces of China(Midgley 2000, Minquan et al. 1995, Zhigang and Yintian 1994).Many *Acacia* species are important for shelterbelts and soil improvement and as sources of fuel and timber(Palmberg et al. 1981) .*A. crassicarpa*has become increasingly important as a plantation species in various parts of Southeast Asia, where it is grown specifically for the production of pulp(Beilharz et al. 2004). It has been become a preferred fiber source for the paper and pulp industry because of its rapid growth, high pulp yield, high fiber quality, and its ability to thrive in degraded soils(Zhigang and Yintian 1994). To meet the increasing requirements for fiber products, and because of its environmental importance, it would be useful to increase its yield and/or planting area. However, classical breeding programs of *Acacia* are strongly limited by its recalcitrant regeneration, its long life cycle, and the long delay until mature traits can be evaluated. Therefore, establishing a highly efficient *in vitro* regeneration system for *A. crassicarpa* is essential to meet the practical requirements for forestry production.

In natural habitats, the regeneration rate of leguminous trees is quite low (Dewan et al. 1992). There are several reports of *in vitro* regeneration of some *Acacia* species, including *Acacia catechu* (Rout et al. 1995), *Acacia auriculiformis*(Ranga Rao and Prasad 1991), *Acacia mangium*(Ahmad 1991, Bhaskar and Subhash 1996, Galiana et al. 1991a, b, Xie and Hong 2001a, Xie and Hong 2001b), *Acacia sinuate*(Vengadesan et al. 2002, Vengadesan et al. 2000), *Acacia nilotica*(Garg et al. 1996) and *Acacia farnesiana*(Ortiz et al. 2000).

## Previously, we reported a stable *in vitro* regeneration system through organogenesis based on the production of shoots and roots from phyllode (leaf) explants, rather than explants from cotyledons or hypocotyls(Yang et al. 2006).In the present study, we established a system for *in vitro* regeneration of *A. crassicarpa* from mature zygotic embryo explants viaadventitious shoot organogenesis. The advantages of using embryos as the explant source include the ease of handling and ready availability of seeds, the high degree of physiological uniformity, and the ability to transport seeds and embryos long distances.

Materials and methods：

Plant material and surface sterilization：

## Mature seeds of *A. crassicarpa*were collected from the 10-year-old trees in anatural grove . The trees were 20–30 m in height and were located at a seed orchard in Guangzhou, China. The seeds were treated with water (100°C) for 1 min and then soaked in distilled water for 36 h. To sterilize the seed surface, the seeds were soaked in 70% ethanol for 1 min, and then in 4% sodium hypochlorite for 5 min. The sterilized seeds were rinsed five times with sterile distilled water. The episperm of each seed was cut manually with a sterile surgical blade. The seeds were dehulled and embryos were excised aseptically and prepared for primary shoot bud induction.

Culture medium and conditions:

## The culture medium was MS basal medium(Murashige and Skoog 1962) supplemented with 5% (v/v) coconut water (CW) and 3% (w/v) sucrose, and solidified with 0.6% (w/v) agar. All media were adjusted to pH 5.8 with 1N NaOH.The plant growth regulators TDZ and IBA were added to various concentrations before autoclaving media at 121°C for 15 min. IAA and GA3 were filter-sterilized through a 0.2-μm membrane filter, and added to autoclaved media. Unless otherwise mentioned, all cultures were maintained at 28°C under cool-white fluorescent lights at an irradiance of 26 *μ*mol s-1m-1 (PAR) under a 16-h light/8-h dark photoperiod.

Shoot buds induction and elongation:

Embryo explants were placed onto shoot bud induction media containing different combinations of TDZ (0.5, 1.0, 2.0, 4.0 mg l-1) and IAA (0.1, 0.5, 1.0 mg l-1). Each Petri dish (90 × 15 mm) contained 10 embryo explants. The experiment was duplicated with 100 explants per treatment and was repeated three times.The percentage of embryos that produced shoot buds was calculated after 2 months of culture. After 2 months, calli with shoot buds were transferred to MS media supplemented different combinations of GA3 (0, 0.5mg l-1) and TDZ (0, 0.5, 1mg l-1) for shoot elongation. The experiment was duplicated with 50 explants per treatment and was repeated three times.The length of shoots was measured after 1 month of culture on shoot elongation media.Rooting from regenerated shoots and plantlet survival

## Elongated shoots (≥2 cm) were removed from the callus base and transferred to rooting medium (1/2 MS supplemented with0.1,0.5,1.0,2.0mg l-1IBA). After formation of lateral roots, plantlets were transferred into pots.The experiment was duplicated with 50 explants per treatment and was repeated three times.The survival ratio was determined 1 month after acclimatization. Subculturing onto fresh medium of the same composition was conducted every 20 days.

Histological staining

## For histological analysis, shoot bud tissues were fixed in FAA fixative (5% (v/v) formaldehyde, 5% (v/v) acetic acid, and 90% (v/v) alcohol) for 24 h. After dehydration through an alcohol­–xylene series, the tissues were transferred to liquid paraffin at 60°C, and then embedded in paraffin blocks. Sections (5-*μ*m thick) were cut using aLEICA RM 2135 rotary microtome(Germany). The sections were mounted on microslides, and then dewaxed and hydrated with xylene and decreasing concentrations of alcohol. The sections were stained with 1% safranin and 0.1% fast green and dehydrated in xylene and increasing concentrations of alcohol. The slides were observed at 10× and 20× magnifications and photographed under a LEICA DM 2500 microscope(Germany).

Results

Induction of adventitiousshootbuds and nodule-like callus from mature zygotic embryos

## The zygotic embryo explants (Fig. 1a) excised from mature seeds started to swell (Fig. 1b) after 2 days in culture. After 2 weeks in culture, one end of the swelling embryos enlarged faster than the other (Fig. 1c). Shoot buds formed from the surface of the enlarged end after approximately 3 weeks in culture on medium containing TDZ and IAA (Fig. 1d) and then turned green when exposed to light (Fig. 1f). One month later, the parts of buds contacting medium gradually formed green nodule-like calli with potential regeneration capacity (Fig. 1g). As shown in Table 1, the addition a moderately low concentration of TDZ to the medium resulted in shoot bud formation. The highest rate of shoot bud induction (73.23%) was on medium supplemented with 1 mg l-1 TDZ and 0.5mg l-1 IAA. At higher concentrations of IAA or TDZ, fewer calli formed, and those that did form showed a poor regeneration capacity and a withered appearance.

Plant growth regulators promoted shoot differentiation and elongation

## The explants were transferred to differentiation medium after 2 months in culture. The nodule-like calli with shoot buds developed into clustered shoots. Clustered shoots elongated to 1–2 cm and developed a stem in 3 months (Fig. 1h). Efficient shoot elongation was achieved on medium containing 1 mg l-1 GA3 (Table 2).

Rooting and plantlet survival

## When shoots reached 2 cm, they were removed from the base of the calli and transferred to rooting medium (Fig. 1i). The highest rooting rate (98.87%) was obtained on medium containing 0.5 mg l-1 IBA (Fig. 1j; Table 3). When the plantlets reached 4–5 cm in height 1 month later (Fig. 1k), they were transplanted into pots. The transplanted plantlets showed a 97.5% survival rate, vigorous growth, and normal phenotypes (Fig. 1l).

Histological analyses

## Analysis of histological sections of 40-day-old shoot buds showed that the growing tip and young leaves had already formed (Fig. 2). The [vascular](app:ds:vascular)[bundle](app:ds:bundle)s of the bud and maternal tissues were linked together and were not independently differentiated. The meristematic regions had sieve tubes and ringed vessels (Fig. 2a, and amplified in Fig. 2b) and were connected to the maternal tissues. These data and observations indicated that the *A. crassicarpa*plantlets had regenerated via shoot organogenesis.

Discussion

In this study, we tested a new protocol for plant regeneration of*A. crassicarpa* via adventitious shootorganogenesis. The success of tissue culture largely relies on the selection of a suitable explant for use as the starting material(Sahin-Demirbag et al. 2010).Recently, there has been increasing use of zygotic embryos as the experimental explant material to study regeneration in various plant species(Hosseini Tafreshi et al. 2011, Muñoz-Concha et al. 2012, Zhang et al. 2010).The use of mature zygotic embryos for *A. crassicarpa*regeneration eliminates the need for immature explant materials.In this study, we obtained a high rate shoot bud production in vitro by culturing embryo explants on MS medium containing TDZ and IAA. After shoot elongation and rooting treatments, the regenerated plantlets with healthy roots were hardened and successfully established in soil, with a 97.5% survival rate. The entire regeneration process took less than 5 months.

Plant growth regulators that are known to play a key role in organogenesis can regulate the dedifferentiation and redifferentiation of plant cells. Many previous reports showed that low concentrations of auxins and cytokinins play a critical role in plant regeneration(Carra et al. 2012, Yang et al. 2012)**.**TDZ has been used widely to promote shoot regeneration in many plant species, and generally gives better results than other cytokinins(Xie and Hong 2001b,Abu-Qaoud 2012).Xie reported that the combination of TDZ and IAA promoted the differentiation of green-yellowish and friable embryogenic callus and its development into plantlets via somatic embryogenesis in *A. mangium*(Xie and Hong 2001b). TDZ atmoderately low concentrations was useful for micropropagation of woody species(Lu 1993).Our results showed that TDZ effectively induced adventitious bud formation in *A. crassicarpa.* It was reported that the phytohormone GA3 promoted plant growth by stimulating cellular expansion(Sauret‐Güeto et al. 2012)and induced shoot elongation in species that were normally recalcitrant to elongation *in vitro*(Phinney 1984).We tested the effects of GA3 on shoot elongation, and found that it had a promoting effect (Table 2). This finding demonstrated that GA3 may have a significant role in the shoot elongation of *A. crassicarpa.*

## Shoots formed roots on 1/2 MS medium supplemented with IBA, which has been reported to be the optimum PGR to induce the root-forming response of shoots(Wakhlu and Barna 1989). IBA has been used to induce rooting in the regeneration process for many species (Rafique et al. 2012, Sahin-Demirbag et al. 2010, Zhang et al. 2010). In our study, plantlets showed strong root growth after 15 days on medium containing 0.5 mg l-1 IBA; the rooting frequency was greater than 98% (Table 3). The survival rate of rooted plantlets transferred to soil and grown in the greenhouse was 97.5% and the rooted plants grew normally after acclimatization.

[In conclusion](app:ds:in%20conclusion), we have established a stable and effective regeneration system to produce *A. crassicarpa* plantlets. In this system, mature zygotic embryos were used as explant materials, and were cultured on MS basal medium containing various PGRs. Previously, we reported regeneration from phyllode explants of *A. crassicarpa,* with a shoot bud induction rate of 56% (Yang et al. 2006). The system reported here represents a more efficient (73.23% bud induction rate) and convenient method of regeneration via shoot organogenesis. Using mature seeds as the explant source has several advantages, including the ease of handling and the year-around availability of seeds. Using this method, the entire process from mature seeds to regenerated plantlets took less than 5 months. Our protocol can offer an alternative strategy for *A. crassicarpa*propagation, which will be useful for expanding plantations of this species.The describedmethod for shoot proliferation andregeneration of *A. crassicarpa*is not only suitable for rapid micropropagationbut also for furthermolecular biology researchof*A. crassicarpa.*

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Figure legends:

**Fig. 1** Shoot buds induction and plant regenation from mature zygotic embryos of *Acacia crassicarpa*

a.Zygotic embryos excised from the mature seeds. b.Swelling of zygotic embryos after 2 days of culture on MS medium. c. Differentiation of zygotic embryos after 2 weeks of culture on MS medium containing TDZ and IAA. Note that one end of embryo is enlarged. d. Shoot buds formed after 3 weeks of culture on MS medium containing TDZ and IAA. e. Magnification of buds under stereomicroscope (red arrows).f. Greening of shoot buds after exposure to light. g. Callus with shoot buds. h. Elongated shoots.i. Shoots on rooting medium. j. Roots formed from shoots. k. Regenerated plant. l. Hardened plant.

**Fig.2** Histological sections of 40-day-old shoot buds of *Acacia crassicarpa*

a.Transverse section of emerging bud. Note that [vascular](app:ds:vascular)[bundle](app:ds:bundle)s of bud and maternal tissue are linked together (arrows) (10×). b. Magnification of fig. 2a. ,arrow shows ringed vessel of [vascular](app:ds:vascular)[bundle](app:ds:bundle) (20×).

**Table 1** Effect of TDZ and IAA on shoot buds regeneration from mature zygotic embryos explant of *A. crassicarpa*

|  |  |  |  |
| --- | --- | --- | --- |
| **Plant growth regegulators(mg/l)** | | **Explants with shoot buds(%)** | **Mean number of shoots per explant** |
| **TDZ** | **IAA** |
| 0.5 | 0.1 | 65.53±1.11d | 24.50±0.87de |
| 0.5 | 0.5 | 64.50±0.79d | 26.33±0.65d |
| 0.5 | 1 | 64.60±0.90d | 23.50±0.66e |
| 1 | 0.1 | 73.23±1.10b | 46.47±3.89b |
| 1 | 0.5 | 76.87±1.50a | 56.53±0.96a |
| 1 | 1 | 69.60±1.42c | 46.27±0.83b |
| 2 | 0.1 | 53.00±1.00g | 33.83±0.74c |
| 2 | 0.5 | 59.43±1.37e | 34.37±0.72c |
| 2 | 1 | 55.27±0.87f | 33.07±0.15c |
| 4 | 0.1 | 48.87±0.74h | 25.90±0.80de |
| 4 | 0.5 | 47.63±0.47h | 24.20±0.91de |
| 4 | 1 | 41.93±1.36j | 19.50±0.53f |

Data were recorded after 2 months in culture when shoots were clearly visible. The experiment was duplicated with 100 explants per treatment. Means followed by same letters within a column are not significantly different at *P* = 0.05 (Duncan’s multiple range test).

**Table 2**Effects of GA3 and TDZ on shoot elongation in MS medium

|  |  |  |
| --- | --- | --- |
| **Plant growth regegulators(mg/l)** | | **Mean length per shoot(cm)** |
| **TDZ** | **GA3** |
| 0 | 0 | 0.87±0.19c |
| 0 | 0.5 | 1.76±0.27b |
| 0 | 1 | 2.32±0.34a |
| 0.5 | 0 | 0.92±0.32c |
| 0.5 | 0.5 | 1.14±0.19c |
| 0.5 | 1 | 1.21±0.16c |

Data were recorded after 1 month of culture on elongation medium. The experiment was duplicated with 50 explants per treatment. Means followed by the same letters within a column are not significantly different at at P = 0.05 (Duncan’s multiple range test).

**Table 3** *In vitro* rooting of shoots on 1/2 MS mediumsupplemented with different concentrations of IBA.

|  |  |  |
| --- | --- | --- |
| **Plant growth regegulators(mg/l)** | **Rooted shoots(%)** | **Mean roots per shoot** |
| **IBA** |
| 0.1 | 97.17±1.98a | 19.7±1.61bc |
| 0.5 | 98.87±1.06a | 27.67±2.99a |
| 1 | 98.37±0.71a | 22.5±3.01b |
| 2 | 96.67±1.53a | 17.27±1.70c |

Data were recorded after 1 month in culture, when root initiation and development could be clearly visualized. The experiment was conducted in duplicate with 50 explants per treatment. Means followed by the same letters within a column are not significantly different at P = 0.05 (Duncan’s multiple range test).