SOMATIC EMBRYOGENESIS FOR AGROBACTERIUM MEDIATED TRANSFORMATION OF TOMATO SOLANUM Lycopersicum L.

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Abstract Agrobacterium mediated transformation through somatic embryogenesis was achieved using cotyledon explants of tomato cv. Shalimar (Solanum lycopersicum L.). Somatic embryos were induced directly from the cotyledon explants on MS medium supplemented with 2, 4-D (5mg/l) for the first time, and also through the callus produced from cotyledon explants on MS liquid medium supplemented with 2, 4-D (2mg/l). The maturation of somatic embryo globular to torpedo was presumed by using sorbitol (0.4 M) and ABA (0.25mg/l). The competency of induced somatic embryos for agrobacterium mediated transformation was confirmed by using GUS reporter gene in pBI121 vector and the npt II with PCR. The transformant was selected using kanamycin (100mg/l). Seventy percentage of transformation efficiency was obtained from the transformed somatic embryo.

Keywords: pB1121, Shoot regeneration, transformation, 2, 4-D

Introduction Tomato is an important worldwide commercial crop. World tomato trade is growing rapidly [25]. Several transgenic traits encoding genes were introduced in to tomato to improve their nutritional quality a path started by Calgene Inc.[14], all these studies were carried out by adopting different regeneration methodology standardised henceforth. Micro propagation through somatic embryogenesis provides an efficient mean of producing large numbers of elite or transgenic plants. The potential use of somatic embryogenesis in developmental studies, crop improvement and genetic transformation has been widely recognized and the number of species displaying the potential for somatic embryogenesis is constantly increasing [9]. Somatic embryogenesis can probably be achieved for all plant species provided that the appropriate explant, culture media and environmental conditions are employed [2]. Somatic embryogenesis in tomato is still at infancy, and substantial research is still required to be undertaken to obtain high quality somatic embryos, this technique will be usefull for crop improvement using in vitro culture and transformation [3]. Agrobacterium mediated transformation have been used as an effective tool for transfer of gene into plant system, while use of somatic embryos as explant in transformation of plants is a recent approach. Somatic embryos consist of embryogenic cells when successfully transferred can produce large number of transgenic plant from a single explant. Hence, Agrobacterium mediated transformation of somatic embryos hold an important role in transgenic plant production. Only few works have been reported for Agrobacterium mediated transformation using somatic embryos, in plants like walnut [17], cork oak (Quercus suber L.) [22], alfalfa (Medicago falcata L.) [23] and Vitis rotundifolia [5] so standardising succesful regeneration protocol for agrobacterium mediated transformation using somatic embryo in tomato would help improve the efficiency of obtaining the stable transformatant as the gene has been transformed to the embryonic tissue. The present study was aimed to develop plant regeneration system for tomato via somatic embryogenesis and optimizing several key factors to utilize tomato somatic embryos for Agrobacterium-mediated genetic transformation using cotyledon explants which not reported earlier.

Experimental Procedure Collection and germination of seeds Tomato seeds var. Shalimar was obtained from the Defence Institute of High Altitude Research, Leh, India. Seeds were washed with distilled water for 5 times, followed by treatment with 0.1% HgCl2 for 3 min and rinsed with sterile water 6 times to remove the sterilant. Seeds were germinated in test tubes containing moist, sterile cotton (Fig.1a). Seedlings were grown under white
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fluorescent light (40 μmol m⁻² s⁻¹) at a 16 h-day photoperiod and 25 ± 2°C.

**Somatic embryo Induction, development**

For the induction of somatic embryo cotyledons were excised from two-week old seedlings and the whole cotyledons were inoculated onto MS medium. They were aseptically placed with the abaxial surface touching the MS medium + B5 vitamins supplemented with different concentrations of 2, 4-D (0.5-25mg/l), NAA (2-10mg/l) and TDZ (2-8mg/l) separately and in combination.

**Maturation of Somatic embryo and plant development**

After 2-3 weeks of culture in various described media, the explants along with somatic embryos of heart shaped stage were transferred to maturation medium for 10 min followed by washing twice with liquid LB. Finally, the reaction mixtures were allowed to complete an additional extension of 10 min at 72°C before rapid cooling to 4°C. The PCR mixture (25 μl) contained 1.5 U Taq DNA polymerase, 10 mM Tris-HCl (pH=9.0 at room temperature), 50 mM KCI, 1.5 mM MgCl₂, 200 μM of each dNTP, 1 μl of each forward and reverse primer at 5°C. The PCR was carried out using a Cyber Cycler P series (Peltier model P96+) with the fastest PCR analysis of nptII

DNA was isolated from putative transformed and untransformed somatic embryos of torpedo stage. The forward and reverse primer sequences (F \( \Rightarrow \) 5’- GAG CTC ATT TCG GCT ATG ACT G 3’ and, R \( \Rightarrow \) 5’-ATC GGG AGA GGC GAT ACC GTA - 3’ respectively) (Sigma Aldrich, India) used for PCR amplification of the nptII gene. The primers were so designed as to give amplification products of the internal sequence of the nptII of 1200 bp. The PCR mixture (25 μl) contained 1.5 U Taq DNA polymerase, 10 mM Tris-HCl (pH=9.0 at room temperature), 50 mM KCl, 1.5 mM MgCl₂, 200 μM of each dNTP, 1 μl of each forward and reverse primer at a final concentration of 10 pmol and 50 ng template DNA. 50 pg of pBI121 plasmid DNA was used as a positive control. Samples for enzymatic amplification were subjected to an initial programme of one cycle of 95°C for 150 s, 60°C for 30 s, 73°C for 45 s. Plant material was treated at 65°C with 70% ethanol twice at 1-h intervals to remove traces of chlorophyll. The possibility of endogenous GUS expression was tested by subjecting uninfected somatic embryos and tissues to the histochemical GUS assay. GUS expression was visually observed and photographed under a light stereo-zoom microscope (Nikon HF II).

**Analysis of putative transformatants**

**Assay of GUS activity**

The histochemical assay of GUS activity was carried out as described by Jefferson et al. (1987). Somatic embryos of torpedo stage were soaked in GUS assay buffer in 2 ml microcentrifuge tubes and incubated overnight at 37°C. Plant material was treated at 65°C with 70% ethanol twice at 1-h intervals to remove traces of chlorophyll. The possibility of endogenous GUS expression was tested by subjecting uninfected somatic embryos and tissues to the histochemical GUS assay. GUS expression was visually observed and photographed under a light stereo-zoom microscope (Nikon HF II).
Results

Indirect Somatic embryogenesis

Embryogenic calli formation (Fig.1c) was observed after two weeks of culture when the cotyledonary explants from 10 day old in vitro germinated tomato plants were cultured in MS media supplemented with 2, 4-D (0.5-2 mg/l)(Fig.1b). The embryogenic calli when further subcultured for 2 weeks in MS basal liquid medium produced somatic embryos of global stage (Fig.1g). MS media supplemented with 2, 4-D (1.5mg/l) showed maximum percentage of somatic embryogenesis (Tab 1). Whereas the cotyledon explants cultured in MS media supplemented with different concentrations (2-10 mg/l) of NAA resulted in only callus formation and no embryo formation was obtained in any of the concentration of NAA.

Direct Somatic embryogenesis

Similarly Tomato cotyledon explants cultured on MS media supplemented with 2, 4-D (5 mg/l) showed maximum somatic embryo formation followed by 2, 4-D (10mg/l, and 15mg/l) respectively. Direct somatic embryos at globular stage either singly or fused (Fig.1c) heart shaped (Fig.1c) were visible on the surface of swollen cotyledon explants in all the higher concentrations of (5, 10, 15 and 25mg/l) 2, 4-D. After 4 weeks, all the cotyledon explants showed direct somatic embryo formation (Table 1). Somatic embryo formation was not observed after 4 weeks of cotyledon culture on MS basal media, further sub culturing of cotyledon explants on to the same media composition did not show any precipitation of somatic embryos instead green meristematic nodule formation was observed. The cotyledon explants cultured individually in MS media consisting of TDZ, NAA, and the 2, 4-D (0.5 mg/l to 2.5 mg/l) were callused after 3 weeks, and had no visible signs of somatic embryos even after the 4th week. In addition, more than 80% of explants cultured in MS media supplemented with NAA formed roots primarily at the proximal end. Whereas cotyledons cultured on MS media fortified with BAP (2mg/l to 15mg/l) concentrations, were swelled and slightly callused on the cut surfaces after 3 weeks of culture. Sorbitol showed a significant role in the further development of tomato somatic embryos. Somatic embryos were developed in to shoots (Fig.1d and Fig.1e) when maintained in MS + Sorbitol (0.2 to 0.6 M) and the highest rate of germination was in media supplemented with sorbitol (0.4M) (Table 3).

Transformation of somatic embryos

Selection of transformed Somatic embryos

Transient GUS activity was detected by characteristic blue spots which appeared on the somatic embryos 48 h following co-cultivation (Fig.2c). Eventually this blue coloration became uniformly distributed over the entire embryo surface (Fig.2d). No endogenous GUS expression was detectable in non transformed somatic embryos. Putative transformed somatic embryos were selected, based on their growth on media with kanamycin 50µg/ml. The GUS-positive reaction of kanamycin-resistant somatic embryos was unambiguously due to the expression of the transgene gus in the tissue and not due to the persisting Agrobacterium, used in the transformation experiments. DNA obtained from several independent kanamycin-resistant, GUS-positive lines revealed the specific predicted amplification product of 1.2 kb with nptII-gene-specific primers, (Fig.2f). No amplification product was detected in DNA from non transformed shoots.

Transformation efficiency

Somatic embryos of tomato showed 100% transformation efficiency, as all transformed somatic embryos showing GUS activity (Fig.2d), and amplification of npt II marker gene (Fig.2f). Torpedo shape intact somatic embryos on the cotyledon that were directly infected with Agrobacterium without pre-culture showed a higher transformation competence than the ones detached from cotyledon and pre cultured prior to bacterial treatment. Transformation efficiency based on GUS expression was 100% without pre-culture, while it varied from 30% to 40% for a 48 hour pre-culture (Tab 4). Elimination of the pre-culture condition was also helpful in producing transformants in kiwifruit and apple [13]. The maximum number of transformation events (approx. 100%) was scored using intact (unwounded) somatic embryos. When somatic embryos were injured manually, a lower number of transformation events (10%) coupled with a high rate of tissue browning were noticed (Tab 4). Thus, wounding was not only unnecessary for inducing transformation but also deleterious to tomato somatic embryos. This was also found to be the case for walnut [17], and tea [18]. The transformed embryos germinated in to plantlet in the kanamycin supplemented selection media with proper rotting and morphological character (Fig.2e).

Discussion

The studies on tissue culture of Tomato have been restricted to plant regeneration via organogenesis via leaf and cotyledon explants. Less emphasis has been placed on somatic embryogenesis except from protoplast cultures [4], hypocotyls [20] and from intact seedlings growing on a medium containing high concentrations of cytokinin [8] and [14]. Being a model plant in molecular developmental studies, and important traits has been introduced in tomato somatic embryogenesis in tomato also has considerable importance. It was observed that transformation efficiency of somatic embryos are higher than that of cotyledons or leaf disc thus, may be due to the fact that the whole surface of somatic embryos are exposed to the Agrobacterium for infection compared to the exposure of only cut edges in case of former. As the transgenic plant develops from whole transformed somatic embryo, the confirmation of transgene integration at this stage is very relevant and also reduces the time by avoiding occurrence of any false positive transformants. The method utilises a time interval of 4
Somatic embryogenesis

From our observation, it is evident that the somatic embryogenesis and further regeneration of the embryos can be achieved in two ways, either direct embryogenesis or indirect embryogenesis. In the former the embryos are induced directly from the surface of the cotyledon explant, where as in the latter, an intermediary callus stage precedes the somatic embryo formation. Breaking the dormancy of the torpedo shaped somatic embryos form the threshold in case of many plant species, especially in case of tomato. Also, the fact that regeneration protocols are genotype specific in tomato makes the present study a relevant and significant one, for the researchers who are interested in the genetic modification of tomato. In this study, 2, 4-D (2mg/l) alone did not induce any direct somatic embryogenesis, even though it facilitated somatic embryogenesis after a callus stage. However 2,4-D seems to show negative effect on the further regeneration of shoots from torpedo shaped somatic embryos in tomato, this agrees with the results obtained in carrot [4] and [7] they believed that once the embryogenic potential is induced, the expression of an embryogenic program no longer requires 2,4-D. Other workers have induced direct somatic embryogenesis on Carica [17] and carrot [25]. A recent study of somatic embryogenesis and genetic transformation in Opium [11] showed that in recalcitrant plant varieties, somatic embryogenesis is useful method of transformation. It was showed that sorbitol can be used as a stress agent and carbon source for somatic embryogenesis in Arabidopsis thaliana [12].

Microscopic analysis of Somatic embryos

Somatic embryos of globular (Fig. 2a), heart (Fig.2b) and torpedo shape were stained with safranin stain and were clearly visible when observed under microscope 400X magnification.

Conclusion

In conclusion, we have developed culture conditions for somatic embryogenesis from cotyledon in tomato and is found suitable for Agrobacterium mediated transformation and showed enhanced percentage of transformation frequency which can be adopted for further transformation studies.

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Table 1- Effect of various types, concentrations and combinations of plant growth regulators on callus induction from cotyledonary segments of tomato on Murashige and Skoog (1962) medium with additives

| Hormone level (mg L⁻¹) | Number of Days for callus initiation | Response (%) | Somatic embryo formation | Days to formation | Number of Somatic embryos/explants |
|------------------------|-------------------------------------|--------------|--------------------------|------------------|-----------------------------------|
| 2,4-D (0.5)            | 7                                   | 65           | 15                       | 20⁶              |
| 2,4-D (1.0)            | 7                                   | 65           | 15                       | 22⁶              |
| 2,4-D (1.5)            | 7                                   | 80           | 15                       | 30⁵              |
| 2,4-D (2.0)            | 7                                   | 95           | 15                       | 15⁶              |
| NAA (2.0)              | 10                                  | 65           | 0                        | 0                |
| NAA (5.0)              | 10                                  | 65           | 0                        | 0                |
| NAA (10.0)             | 10                                  | 65           | 0                        | 0                |

Each value is the mean of 3 replications with 20 explants each. Values within a column followed by different letters are significantly different at the 0.05 probability level using DMRT.

Table 2- Effect of various levels of 2, 4-D on the direct somatic embryo formation from the cotyledonary explants of tomato (Solanum lycopersicum L.) cv Shalimar

| Concentration of 2,4-D (mg/L) | Number of somatic embryos (Mean ± std dev*) | Response In % |
|-------------------------------|---------------------------------------------|---------------|
| 5                             | 20.11±10.11a                                | 100           |
| 10                            | 16.11 ± 3.756a                              | 90            |
| 15                            | 17.12 ± 3.834a                              | 85            |
| 20                            | 8.00 ± 3.033b                               | 65            |
| 25                            | 5.66 ± 2.422b                               | 65            |

Each value is the mean of 3 replications with 20 explants each. Values within a column followed by different letters are significantly different at the 0.05 probability level using DMRT.

Table 3- Effect of various Concentration (Molar) of Sorbitol in germination of somatic embryos of tomato (Solanum lycopersicum L.) cv Shalimar

| Concentration (M) of Sorbitol in germination medium | Percentage of somatic embryos germinated |
|---------------------------------------------------|----------------------------------------|
| 0.2                                               | 65±5⁶                                  |
| 0.4                                               | 75±5⁶                                  |
| 0.6                                               | 65±5⁶                                  |
| 0.8                                               | 65±5⁶                                  |

Each value is the mean of 3 replications with 25 Somatic embryos each. Values within a column followed by same letters are not significantly different at the 0.05 probability level using DMRT.

Table 4- Effect of transformation conditions on the tomato somatic embryo transformation

| Method                            | Transformation efficiency | Number of shoot regenerant/SE | Number of transformed shoots per explants |
|-----------------------------------|---------------------------|-------------------------------|------------------------------------------|
| With pre culture                  | 30 - 40%                  | 1                             | 5⁶                                       |
| Without pre culture               | 80 - 100%                 | 1                             | 25⁶                                     |
| Somatic embryo intact with explant| 80-100%                   | 1                             | 25⁶                                     |
| Somatic embryo detached from explants | 50 – 60%              | 0                             | 0                                        |
| Un wounded SE                     | 80-100%                   | 1                             | 25⁶                                     |
| Wounded SE                        | 30-40%                    | 0                             | 0                                        |

Each value is the mean of 3 replications with 20 explants each. Values within a column followed by different letters are significantly different at the 0.05 probability level using DMRT.
Fig. 1

- **Fig (1a)**: Tomato cultivar ‘Shalimar’ seeds germinated in vitro. Swollen tomato cotyledons after three days of inoculation in embryogenic media.
- **Fig (1c)**: Cotyledon surface showing globular and heart shaped direct somatic embryos (indicated with arrow mark).
- **Fig (1d)**: Cotyledon surface showing torpedo shaped direct somatic embryos.
- **Fig (1e)** & **(1f)**: Somatic embryos at cotyledonary stage in the Fig (1g), (1h) and (1i).
- **Fig (1g)**, **(1h)** and **(1i)**: Somatic embryos as observed under microscope with 40x magnification. Scale = 1mm.
Fig (2a) & (2b) - globular and heart shaped somatic embryos stained with safranin and observed under microscope. Fig (2c) Partially GUS stained transformed somatic embryos on the surface of cotyledon explant after torpedo stage. Fig (2d) Completely GUS expressing transformed somatic embryos. Fig (2e) Transformed tomato plantlet maintained in selection media. Fig (2f) Electrophoretogram of PCR amplification (nptII gene) from transformed plantlet leaf DNA: lane one DNA ladder 1kb, Lane 2 positive control, lane 3 npt II 1.2kb amplicon from Leaf DNA sample as template.
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Fig. 3

Fig (3)- Map showing the T-DNA portion of pBI121 plant binary vector