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A simple and efficient protocol for generating transgenic hairy roots using *Agrobacterium rhizogenes* V.2

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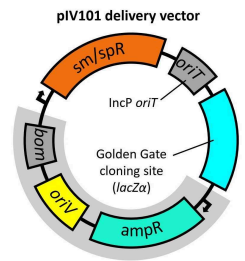
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We use this protocol and it's working

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Abstract

For decades, *Agrobacterium rhizogenes* (now *Rhizobium rhizogenes*), the causative agent of hairy root disease, has been harnessed as an interkingdom DNA delivery tool for generating transgenic hairy roots on a wide variety of plants. One of the strategies involves the construction of transconjugant *R. rhizogenes* by transferring gene(s) of interest into previously constructed *R. rhizogenes* pBR322 acceptor strains; little has been done, however, to improve upon this system since its implementation. We developed a simplified method utilising bi-parental mating in conjunction with effective counterselection for generating *R. rhizogenes* transconjugants. Central to this was the construction of a new Modular Cloning (MoClo) compatible pBR322-derived integration vector (pIV101). Although this protocol remains limited to pBR322 acceptor strains, pIV101 facilitated an efficient construction of recombinant vectors, effective screening of transconjugants, and RP4-based mobilisation compatibility that enabled simplified conjugal transfer. Transconjugants from this system were tested on *Lotus japonicus* and found to be efficient for the transformation of transgenic hairy roots and supported infection of nodules by a rhizobia symbiont. The expedited protocol detailed herein substantially decreased both the time and labour for creating transconjugant *R. rhizogenes* for the subsequent transgenic hairy root transformation of *Lotus*, and it could readily be applied for the transformation of other plants.



Guidelines

Whenever the protocol requires working with bacteria, whether picking a clone or streaking it fresh, always start from a single colony and ensure proper streaking technique on fresh media to obtain isolated single colonies.

Make sure your antibiotics and media containing antibiotics are fresh, otherwise selection may be insufficient resulting in false positive transconjugant colonies.

Ensure you wash the cells before and after biparental mating. This ensures adequate removal of both the antibiotics for plasmid selection, and the supplements required by the auxotrophic *E. coli*.

For this protocol we use *E. coli* strain ST18 for transformation of our cloned construct and subsequent biparental mating to transfer the construct to *R. rhizogenes*. Another *E. coli* strain could be substituted but it must contain the RP4 conjugative machinery for mobilisation of pIV101 and we would recommend that it also contains the *lacZ*ΔM15 mutation for blue white/screening as well as an auxotrophy for efficient counterselection (E.g. Δ*dapA*, or Δ*hemA*).

The Modular Cloning (MoClo) strategy implemented for pIV101 is based on the publication by Weber *et al.* 2011.

For standard molecular biology techniques (E.g. PCR, plasmid preparation etc.) please refer to Molecular Cloning: A Laboratory Manual, 4th edition.

Materials

Chemicals for Golden Gate reaction

- Vector backbone (pIV101)
- Additional assembly piece(s)
- 10X NEB BSA (If using BsaI-HF®v2)
- NEB BsaI-HF®v2
- NEB BbsI-HF®
- 10X NEB T4 Ligase Buffer
- NEB T4 Ligase, 2,000,000 cohesive end units/ml
- Nuclease-free water

Chemicals for *E. coli* chemical transformation

- Filter sterilised diaminopimelic acid (DAP) stock at 30 mM in water (For $\Delta dapA$ mutant *E. coli* strains).
- Previously prepared chemically competent aliquots of *E. coli* donor strain.
- KCM buffer (5X)
- 5-Bromo-4-chloro-3-indolyl β -D-galactopyranoside (X-gal) 1:1000

Media for bacteria

- LB medium

Material for seed germination and hairy root transformation

- Sand paper
- Hypochlorite (12% stock solution)
- Nuclease-free water
- Filter paper
- Gamborg B5 media including vitamins (Duchefa-biochemie)
- Scalpel for plant cutting
- Syringe needles (0.4 mm)
- Parafilm
- 3M Milipore tape

Antibiotics(Stock).

- Rifampicin (50 mg/ml DMSO)
- Streptomycin (50 mg/ml water)
- Spectinomycin (50 mg/ml water)
- Ampicillin (100 mg/ml water)

Buffers and stock solutions

KCM Buffer (5X):

- 0.5M KCl
- 0.15 M CaCl_2
- 0.25 M MgCl_2



- Filter sterilise through 0.2 μ M filter. Store at -20.

5-Bromo-4-chloro-3-indolyl β -D-galactopyranoside (X-gal):

- 20 mg/ml in dimethylformamide (2% w/v)

Auxotrophic *E. coli* supplement

5-aminolevulinic acid (ALA):

- 50 mg/ml dissolved in water and filter sterilised

Diaminopemelic acid (DAP):

- 30 mM dissolved in water and filter sterilised

General materials

- Thermocycler suitable for Golden Gate reactions
- Tabletop microcentrifuge
- Spectrophotometer
- 1.5 ml nuclease-free microcentrifuge tubes
- Round and square (11 cm²) petri dishes

Safety warnings

- ! Please refer to the manufacturers safety warnings for the individual reagents and chemicals used throughout.

Before start

Ensure you have an appropriate *E. coli* cloning/donor strain that contains the RP4 conjugative machinery to enable conjugal transfer of pIV101. Some commonly used strains for this include: *E. coli* S17/ST18, *E. coli* MFD*pir*, *E. coli* WM3064.

If using an auxotrophic *E. coli* strain such as ST18 or MFD*pir* make sure you have the required supplement (e.g. 5-aminolevulinic acid (ALA) for ST18 or diaminopimelic acid (DAP) for MFD*pir*).

pIV101 is available on Addgene and can be found here: <https://www.addgene.org/196671/>.

You must have a pBR322-derived *R. rhizogenes* acceptor strain e.g. *R. rhizogenes* AR1193.



Golden Gate cloning reaction with plasmid pIV101

1 Add the following components to a Golden Gate reaction:

15m

- Plasmid pIV101 DNA ( 100 ng) -  X μL
- Insert(s) DNA ( 100 ng) -  X μL
- Ligase buffer (10x) -  1 μL
- T4 DNA Ligase -  1 μL
- BpiI (BbsI) (or BsaI for level 1 constructs) -  1 μL
- MilliQ water - up to final volume of  10 μL

1.1

4h

Incubate reaction in thermocycler with the following steps:

	Temperature	Time	Cycles
	37C	00:05:00	30-60 X
	16C	00:05:00	
	80C	00:10:00	1

Note

If the Golden Gate reaction is failing to incorporate your desired insert, an additional step that may help:

Following completion of the reaction cycle from step 1.1 - add 1 μL of the restriction enzyme used in the reaction (step 1) to the mix again and incubate for a further 1 - 2hrs at 37C

Because the ligase has already been deactivated, additional active restriction enzyme can help to deplete any remaining plasmids that do not contain the desired insert fragments

Transformation of chemical competent *E. coli* ST18

2 Mix in a 1.5 ml tube:

5m

-  20 μL 5X KCM buffer
-  5 μL Golden Gate cloning mix (from step 1.1 following completion of the program)



-  75 μL ddH₂O
- 3 Incubate for  00:02:00 on ice 2m
 - 4 Thaw a  100 μL aliquot of chemically competent *E. coli* ST18 cells on ice
 - 5 Mix together the chemical competent *E. coli* cells and the reaction mixture from step 2 by pipetting 1m
 - 6 Incubate the mix for  00:20:00 on ice 20m
 - 7 Incubate for  00:10:00 at  Room temperature 10m
 - 8 Add  800 μL LB with 50 $\mu\text{g/ml}$ 5-aminolevulinic acid (ALA) and grow for  01:00:00 at  37 °C with shaking 1h
 - 9 Centrifuge to pellet the cells at  14000 rcf, 25°C, 00:02:00 2m
 - 10 Resuspend the pellet in  100 μL of LB containing 50 $\mu\text{g/ml}$ ALA 2m
 - 11 Plate out the  100 μL of resuspended pellet onto LB agar containing 100 $\mu\text{g/ml}$ ampicillin, 150 $\mu\text{g/ml}$ spectinomycin, and 50 $\mu\text{g/ml}$ ALA 5m
 - 11.1 ▪ If using blue/white selection then also add 2% (w/v) 5-Bromo-4-chloro-3-indolyl β -D-galactopyranoside (X-gal) to the media
 - 12 Grow at  37 °C  Overnight and check for colonies the following day 16h

**Note**

If you are having difficulties obtaining *E. coli* transformants then we suggest trying electrocompetent *E. coli* cells which have a higher transformation efficiency. For transformation by electroporation we recommend first performing a clean up of the Golden Gate reaction mixture DNA to prevent arcing

12.1 If using X-gal for selection avoid blue colonies as pLV101 contains the *lacZα* fragment in the GGA cloning site

12.2 In parallel with the next step (step 13), select colonies from the transformation (step 12) and confirm the construct from the Golden Gate assembly. This can be carried out by several standard approaches:

- Perform colony PCR to amplify the region of the plasmid that contains the GGA cloning site to ensure that the cloning site contains the expected insert size
- This product can be sent for further confirmation by Sanger sequencing
- Additionally, perform a plasmid preparation (miniprep) from the *E. coli* clone which can then be used as template for PCR amplification or for whole plasmid sequencing

1d

Note

If your insert is large then we recommended sending the construct for whole plasmid sequencing as an alternative to confirmation by standard Sanger sequencing

R. rhizogenes transformation

13

10m

Note

This section and the next section can be carried out in parallel to save time

Start liquid culture of the wild-type *Agrobacterium rhizogenes* (now *Rhizobium rhizogenes*) from a single colony in LB media with 100 µg/ml rifampicin (a 5 ml broth is sufficient)

14 Incubate for  48:00:00 at  28 °C with shaking

2d



- 15 Inoculate an LB broth containing 100 µg/ml ampicillin, 150 µg/ml spectinomycin, and 50 µg/ml ALA with a single colony for an ST18 clone carrying the construct of interest (from the previous section) 5m
- 16 Incubate the LB broth from step 15 Overnight at 37 °C with shaking. 1d
- 17 Centrifuge ~100 µl of the overnight broth for the *E. coli* ST18 culture carrying the construct of interest at 14000 rcf, 00:02:00 2m
- 18 Resuspend the *E. coli* pellet in 1 mL sterile dH₂O and repeat the previous step. This is to wash away the broth culture containing antibiotics 3m
- 19 Resuspend the *E. coli* pellet in 50 µL sterile dH₂O 2m
- 20 Centrifuge 0.3 - 1 ml of the broth culture of *R. rhizogenes* from step 13-14 at 8000 rcf, 00:02:00 2m
- 21 Resuspend the *R. rhizogenes* pellet in 1 mL sterile dH₂O and repeat the previous step. This is to wash away the broth culture containing antibiotics 3m
- 22 Resuspend the *R. rhizogenes* pellet in 50 µL sterile dH₂O 2m
- 23 Perform a biparental mating by mixing the resuspended *E. coli* ST18 (step 19) and *R. rhizogenes* (step 22) in 100 µL total volume and spot onto plates of LB media supplemented with 50 µg/ml ALA (but no antibiotics) and then wait until the spot is dry 30m

Note

Adjust the volume of *R. rhizogenes* that you spin down so that the pellet is similar in size to *E. coli*

Note

Can be better to aliquot the 100 µL across multiple spots (at least 2 x 50 µl spots)



- 24 Grow the biparental mating spot plates Overnight at 28 °C 16h
- 25 Scrape the biparental mating spot of the *E. coli* ST18 clone + *R. rhizogenes* and resuspend in 1 mL sterile dH₂O 5m
- Note

Be sure to avoid collecting any agar (better off to leave some of the mating colony behind) as the agar contains ALA which we need to avoid
- 26 Centrifuge at 14000 rcf, 00:02:00 to pellet, and resuspend in 1 mL sterile dH₂O. This step should wash away any residual supplement from the mating plates that enables *E. coli* growth 2m
- 27 Centrifuge again at 14000 rcf, 00:02:00 to pellet, and resuspend in 1 mL sterile dH₂O (The total volume will be more due to the pellet) 2m
- 28 Transfer the resuspended mating mix from the previous step onto LB media plates supplemented with 100 µg/ml ampicillin, 100 µg/ml spectinomycin, and 100 µg/ml rifampicin. (No ALA). Perform spread plating to obtain single colonies, see step 28.1 2m

R. rhizogenes transformation

- 28.1 Plate different volumes of the resuspended mating mix onto separate plates to ensure single colonies (avoid getting a lawn of bacteria). We suggest three plates, each with the following volume:
- Plate 1 - 50 µl
 - Plate 2 - 100 µl
 - Plate 3 - Pellet the remaining volume and then resuspend in 100 µl of dH₂O to spread

Note

It is best to choose single colonies from the plate with the fewest colonies present.



R. rhizogenes transformation

29 Incubate the plate(s) for 48:00:00 at 28 °C

2d

Note

Attention: Colonies should be present within 1 - 2 days, colonies arising after this time may be false positives so regularly check your plates during incubation for first colonies that appear.

30 Re-streak (at least once) the *R. rhizogenes* strains carrying the construct of interest on fresh LB agar containing 100 µg/ml ampicillin, 100 µg/ml spectinomycin, and 100 µg/ml rifampicin (ensure single colonies)

5m



Note

Re-streaking the single colonies onto fresh media to obtain new single colonies is critical.

The *E. coli* should not grow on the initial spread plates (Steps 28 and 29), however it is important to purify your transconjugant *R. rhizogenes* clones to remove any remaining *E. coli* cells.

Plasmid from dead *E. coli* cells may still produce false positive results during PCR confirmations for *R. rhizogenes* transconjugant clones, so pure single colonies is crucial.

31 Incubate the plate(s) for 48:00:00 at 28 °C

2d

Preparation of seeds for hairy root transformation (for *Lotus japonicus*)

32 To scarify the seeds, transfer the required number of seeds to a mortar and rub them with sand paper until they become white on the ends

2m

33 Transfer the seeds to a sterile tube (at least 15 ml capacity) and sterilise the seeds by immersing them in a 1% hypochlorite solution, and incubate in this solution for 15 min at

15m

Room temperature

34 Remove the hypochlorite solution and discard appropriately. Add sterile water and invert the tube several times. Repeat this 5 times to wash the seeds and remove any residual hypochlorite

5m



- 35 Fill the tube with sterile water and incubate for at least 02:00:00 at Room temperature with shaking (alternatively incubate Overnight at 4 °C) 2h
- 36 Using sterile forceps, transfer seeds to square petri dishes containing sterile filter paper soaked in sterile dH₂O (approximately 15 min per plate) 15m
- 37 Incubate the square plates containing the surface sterilised seeds sitting on damp filter paper from the previous step for 72:00:00 at 21 °C 3d
- 38 Transfer germinated seeds to a square petri dish that contains solid Gamborg B5 media including vitamins 15m
- 39 Grow seedlings for 72:00:00 at 21 °C with 16H/8H light/dark cycle, until the root has attached itself to the media 3d

Preparation of *R. rhizogenes* for hairy root transformation

- 40 Resuspend the *R. rhizogenes* strain from the agar plate (step 30-31) into sterile dH₂O as a thick suspension (OD₆₀₀ >2). Approximately 100 µL is needed per plant, so make sure the volume of water for the suspension is sufficient for the number of plants that will be transformed 10m

Note

The actual concentration is not important, there just needs to be an excess of the *R. rhizogenes*

Hairy root transformation of *Lotus* seedlings with *R. rhizogenes*

- 41 Wound seedlings with syringe needle (0.4mm) at the hypocotyl 1m
- 42 Add one large drop (~ 100 µL) of the thick suspension of *R. rhizogenes* (from step 40) on top of the wound 1m



- 43 Incubate the seedling for  01:00:00 horizontally to let the *R. rhizogenes* infect the hypocotyl 1h
- 44 Seal the plates containing the now infected seedlings with parafilm on the sides and bottom (prevents dehydration). Seal top with micropore tape on the top edge (Keeps the plates sealed but allows gas exchange) 1m
- 45 Grow the infected seedlings for  72:00:00 at  21 °C in the dark to enhance infection 3d
- 46 Grow the infected seedlings for 3 weeks at  21 °C with 16H/8H light/dark cycle until transformed roots emerge 3w

Selecting hairy roots

- 47 Hairy roots will emerge and develop from the infected wound sites
- 48 Place the plates containing the transformed plants on a transilluminator. Remove the non-fluorescently labelled roots (untransformed roots) using a scalpel 1h

Note

The Golden Gate assembly constructs should be designed to include a fluorescent marker to distinguish hairy roots from non-transformed roots. Alternative markers like RUBY can also be used

- 49 Transfer plants with transformed roots to new pots or plates and grow plants at  21 °C with 16H/8H light/dark cycle for one week 1w

For rhizobium inoculation of hairy roots (optional)

- 50 Resuspend the rhizobium strain (or your bacteria of interest) from a freshly streaked agar plate into sterile dH₂O 10m
- 51 Adjust the OD₆₀₀ of the suspension to between 0.01 - 0.05 in a volume that is sufficient to provide  100 µL per plant to be inoculated 15m



- 51.1 If plants are on square agar plates: lay the square plate flat. Inoculate the roots of the plants by carefully applying  100 μL of the suspension from the previous step using a pipette. Ensure that you apply the inoculum evenly to as much of the root as possible 5m
- 51.2 Leave inoculated plant plate(s) flat for a short period so that the bacterial suspension can spread evenly across the plate and ensure contact with the roots 5m
- 51.3 If the plants are in pots: determine the volume that is equal to  100 μL X the number of plants present, and distribute this evenly to the plant pot substrate using a pipette 5m
- 52 Grow the inoculated plants for 3 weeks post inoculation at  21 $^{\circ}\text{C}$ with 16H/8H light/dark cycle until nodules are formed 3w

Protocol references

Golden Gate cloning:

Engler C, Kandzia R, Marillonnet S. A one pot, one step, precision cloning method with high throughput capability. PloS One. 2008;3(11):e3647. doi: <https://doi.org/10.1371/journal.pone.0003647>.

Modular Cloning (MoClo):

Weber E, Engler C, Gruetzner R, Werner S, Marillonnet S. A modular cloning system for standardized assembly of multigene constructs. PloS One. 2011;6(2):e16765. doi: <https://doi.org/10.1371/journal.pone.0016765>.

E. coli strains:

Ferrieres L, Hémerly G, Nham T, Guérout A-M, Mazel D, Beloin C, et al. Silent mischief: bacteriophage Mu insertions contaminate products of *Escherichia coli* random mutagenesis performed using suicidal transposon delivery plasmids mobilized by broad-host-range RP4 conjugative machinery. Journal of Bacteriology. 2010;192(24):6418-27. doi: <https://doi.org/10.1128/JB.00621-10>.

Thoma S, Schobert M. An improved *Escherichia coli* donor strain for diparental mating. FEMS Microbiology Letters. 2009;294(2):127-32. doi: <https://doi.org/10.1111/j.1574-6968.2009.01556.x>.

R. rhizogenes pBR322-acceptor strains:

Stougaard J, Abildsten D, Marcker KA. The *Agrobacterium rhizogenes* pRi TL-DNA segment as a gene vector system for transformation of plants. Molecular and General Genetics MGG. 1987;207(2):251-5. doi: <https://doi.org/10.1007/BF00331586>.

Radutoiu S, Madsen LH, Madsen EB, Nielsen AM, Stougaard J. *Agrobacterium rhizogenes* pRi TL-DNA integration system: a gene vector for *Lotus japonicus* transformation. Lotus japonicus Handbook: Springer; 2005. p. 285-7.

Green, M. R., & Sambrook, J. (2012). Molecular cloning. *A Laboratory Manual* 4th.