Table S1: Overview of nodulation genes identified by forward and/or reverse genetics. Lj: *Lotus japonicus*, Mt: *Medicago truncatula*, Ms: *Medicago sativa*; Gm: *Glycine max*, Ps: *Pisum sativum*; Pv: *Phaseolus vulgaris*, As: *Astragalus sinicus,* Ag: *Alnus glutinosa*, Cg: *Casuarina glauca*, Dg: *Datisca glomerata* and Pan: *Parasponia andersonii.*

receptor complexes	gene name	description	symbiosis	references
LysM-RLK	LjEPR3	Exopolysaccharide receptor	-/Nod	(Kawaharada et al., 2015)
LysM-RLK	MtLYK3, LjNFR1	Rhizobium LCO receptor	AM/Nod	(Radutoiu et al., 2003; Limpens et al., 2003; Smit et al., 2007; Broghammer et al., 2012)
LysM-RLK	LjNFRe	Epidermis specific rhizobium LCO receptor	-/Nod	(Murakami et al., 2018)
LysM-RLK	MtLYK9, LjCERK6, PsLYK9	CO receptor	AM/-	(Bozsoki et al., 2017; Leppyanen et al., 2017; Gibelin-Viala et al., 2019)
LysM-RLK	MtNFP, LjNFR5, PanNFP1	Rhizobium LCO receptor	-/Nod	(Madsen et al., 2003; Arrighi et al., 2006; Op den Camp et al., 2011b; Broghammer et al., 2012)
LysM-RLK	MtLYR3	LCO receptor, induced in nodules	-/Nod	(Fliegmann et al., 2013; Fliegmann et al., 2016)
Flotilin	MtFLOT2, MtFLOT4	Scaffolder of LysM-type LCO receptors, required for nodule formation and infection	-/Nod	(Haney and Long, 2010; Haney et al., 2011)
Rho-like Small GTPase	LjROP6	Interacts with LjNFR5. Controls infection	-/Nod	(Ke et al., 2012)
NFR5-interacting cytoplasmic kinase	LjNiCK4	Promotes nodule organogenesis	-/Nod	(Wong et al., 2019)
E3-ligase	MtPUB1	Interacts with MtLYK3, negative regulator	-/Nod	(Mbengue et al., 2010)
E3-ligase	LjPUB13	Interacts with LjNFR5, positive regulator	-/Nod	(Tsikou et al., 2018)
Symbiotic receptor kinase	MtDMI2, LjSYMRK, MsNORK	LRR-RLK, essential for LCO signalling	AM/Nod	(Stracke et al., 2002; Endre et al., 2002)
SYMRK interacting protein HMGR	MtHMGR1	3-hydroxy-3-methylglutaryl coenzyme A reductase involved in mevalonate pathway	AM/Nod	(Kevei et al., 2007; Venkateshwaran et al., 2015)
SYMRK interacting protein SIP1	LjSIP1	ARID/BRIGHT DNA binding domain containing protein	-/Nod	(Zhu et al., 2008)
MAP kinase kinase	LjSIP2	Interacts with LjSYMRK.	-/Nod	(Zhu et al., 2008; Chen et al., 2012)

MAP kinase	LjMPK6	MAP kinase. Target of LjSIP2. Targets LjLHK1	-/Nod	(Yin et al., 2019)
E3-ligase	LjSINA4	Interacts with LjSYMRK, negative regulator of rhizobium infection.	-/Nod	(Den Herder et al., 2012)
E3-ligase	LjSIE3	Interacts with LjSYMRK, involved in nodule formation	-/Nod	(Yuan et al., 2012)
Lectin nucleotide phosphohydrolase	LjLNP	Essential for LCO signalling	AM/Nod	(Yuan et al., 2012; Roberts et al., 2013)
Nod factor hydroloase	MtNFH1	LCO hydrolase	-/AM	(Cai et al., 2018a)
Nuclear signalling				
Calcium-dependent protein kinase	MtCPK3	Controls nodulation efficiency	-/Nod	(Gargantini et al., 2006)
Calcium ATP-ase	MtMCA8	Essential for LCO induced perinuclear calcium oscillations	AM/Nod	(Capoen et al., 2011)
Cyclic nucleotide–gated Ca2+ channel	MtCNGC15a, MtCNGC15b, MtCNGC15c	Essential for LCO induced perinuclear calcium oscillations	-/Nod	(Charpentier et al., 2016)
Nucleoporin	LjNUP85	Essential for LCO induced perinuclear calcium oscillations	AM/Nod	(Saito et al., 2007)
Nucleoporin	LjNUP133	Essential for LCO induced perinuclear calcium oscillations	AM/Nod	(Kanamori et al., 2006)
Nucleoporin	LjNENA	Required for rhizobium and mycorrhizal infection	AM/Nod	(Groth et al., 2010)
Potassium channel	MtDMI1, LjPOLLUX	Essential for LCO signalling	AM/Nod	(Ané et al., 2004; Imaizumi-Anraku et al., 2005)
Potassium channel	LjCASTOR	Essential for LCO signalling	AM/Nod	(Imaizumi-Anraku et al., 2005)
Calcium Calmodulin dependent kinase	MtDMI3, LjCCAMK	Essential for LCO signalling	AM/Nod	(Mitra et al., 2004; Lévy et al., 2004; Tirichine et al., 2006)
Transcriptional regulators				
CYCLOPS transcription factor	MtIPD3, LjCYCLOPS, MtIPD3L	Essential for LCO signalling. Interacts with CCaMK	-/Nod	(Messinese et al., 2007; Yano et al., 2008; Singh et al., 2014; Jin et al., 2018)
NODULE INCEPTION transcription factor	MtNIN, LjNIN, PsSYM35, CgNIN	Nodule Inception transcription factor, essential for nodule formation	-/Nod	(Schauser et al., 1999; Borisov et al., 2003; Marsh et al., 2007; Clavijo et al., 2015)

NIN-LIKE PROTEIN	MtNLP1, LjNRSYM1	Represses NIN upon physical interaction	-/Nod	(Nishida et al., 2018; Lin et al., 2018)
Nuclear Factor YA transcription factor	MtNF-YA1, LjNF-YA1, PvNF-YA1, MtNF-YA2, LjCBFA22, LjCBFA01	Direct target of NIN, forms complex with NF-YB and NF-YC subunits. Essential for nodule development and infection	-/Nod	(Combier et al., 2006; Soyano et al., 2013; Rípodas et al., 2019)
Nuclear Factor YB transcription factor	MtNF-YB16, LjNF-YB1, PvNF-YB7	Direct target NIN, forms complex with NF-YA and NF-YC subunits.	-/Nod	(Soyano et al., 2013; Baudin et al., 2015; Rípodas et al., 2019)
Nuclear Factor YC transcription factor	MtNF-YC1, MtNF-YC2 / PvNF-YC1	Involved in rhizobium infection and nodule development. Forms complex with NF-YA and NF-YB subunits.	-/Nod	(Zanetti et al., 2010; Mazziotta et al., 2013; Baudin et al., 2015; Rípodas et al., 2019)
AP2-ERF transcription factor	MtERN1, MtERN2	Essential for nodule formation, and AM symbiosis	-/Nod	(Middleton et al., 2007; Cerri et al., 2016)
AP2-ERF transcription factor	LjERF1	iIvolved in nodule formation	-/Nod	(Asamizu et al., 2008)
AP2-ERF transcription factor	MtEFD	Essential for nodule development	-/Nod	(Vernié et al., 2008; Asamizu et al., 2008)
GRAS-type transcriptional regulator	MtNSP1, LjNSP1, PanNSP1	Essential for nodule formation	-/Nod	(Smit et al., 2005; Heckmann et al., 2006b; van Zeijl et al., 2018)
GRAS-type transcriptional regulator	MtNSP2, LjNSP2, PanNSP2	Essential for nodule formation	AM/Nod	(Kalo et al., 2005; Heckmann et al., 2006a; van Zeijl et al., 2018)
GRAS-type transcriptional regulator	MtSymSCL1	Role in nodule number regulation	-/Nod	(Kim and Nam, 2013)
bHLH transcription factor	GmbHLHm1 (GmSAT1)	Essential for nodule functioning	AM/Nod	(Chiasson et al., 2014)
bHLH transcription factor	MtbHLH1	Involved in nodule vasculature patterning	-/Nod	(Godiard et al., 2011)
bHLH transcription factor	MtbHLH476	Direct target of CRE1-dependent cytokinin signaling regulating nodulation	-/Nod	(Ariel et al., 2012)
BOP-type trancriptional regulator	MtNOOT1, MtNOOT2, LjNBCL1, PsCOCH	Regulator of nodule development	-/Nod	(Couzigou et al., 2012; Magne et al., 2018a; Magne et al., 2018b)
aminopetidase P1	LjAPP1	Interactor of LjNBCL1. Negative regulator of nodulation	-/Nod	(Liu et al., 2018)

C2H2 transcription factor	MsZPT2-1	Regulator of nodule development	-/Nod	(Frugier et al., 2000)
C2H2 transcription factor	MtRSD	Regulator of symbiosome development	-/Nod	(Sinharoy et al., 2013)
NAC transcription factor	MtNAC969	Antagonistically regulates root abiotic stress response and nodule senescence	-/Nod	(De Zélicourt et al., 2012)
MYB transcription factor	LjIPN2	Interacteracting protein of NSP2	-/Nod	(Kang et al., 2014)
MYB transcription factor	GmCND	Controls nodule Development	-/Nod	(Libault et al., 2009)
MADS box transcription factor	GmNMHC5	Postive regulator of nodulation. Sucrose-responsive	-/Nod	(Liu et al., 2015)
KNOX homeodomain transcription factor	MtKNOX3, MtKNOX4, MtKNOX5	Functions in nodule differentiation	-/Nod	(Azarakhsh et al., 2015; Di Giacomo et al., 2016)
WOX homeobox transcription factor	MtWOX5	auxin responsive marker for nodule meristem. Acts upstream of systemic regulator NODULATION3	-/Nod	(Osipova et al., 2012)
bZIP transcription factor	LjASTRAY	negative regulator of nodule formation	-/Nod	(Nishimura et al., 2002a)
AP2 transcriptional repressor	GmNNC1	negative regulator of nodule formation	-/Nod	(Wang et al., 2014; Wang et al., 2019a)
Infection related				
LRR-tye RLK	LjRINK1	Involved in infection thread formation	-/Nod	(Li et al., 2019)
Actin-related protein component	LjARPC1	ACTIN-RELATED PROTEIN COMPONENT1 essentail for rhizobium infection	-/Nod	(Hossain et al., 2012)
Annexin	MtANN1	Induced during symbiotic associations; marker for pre-infection	-/Nod	(de Carvalho Niebel et al., 1998; Niebel et al., 1998; De Carvalho-Niebel et al., 2002)
Cystathionine-β-Synthase	MtCBS1	Required for rhizobium infection	-/Nod	(Sinharoy et al., 2016)
Devil-type peptide	MtDVL	Controls nodulation	-/Nod	(Combier et al., 2008)
Deubiquitinating enzyme	LjAMSH1	Required for rhizobium infection and nodule organogenesis	-/Nod	(Małolepszy et al., 2015)
DNA topoisomerase VI subunit A	LjSUNERGOS1	Required for rhizobium infection	-/Nod	(Yoon et al., 2014)

DNA topoisomerase VI RHL1	LjVAG1	Required for the ploidy-dependent cell growth of rhizobial-infected cells	-/Nod	(Suzaki et al., 2014)
E3 ubiquitin ligase	MtLIN / LjCERBERUS	Essential for rhizobium infection	-/Nod	(Kiss et al., 2009; Yano et al., 2009)
Long coiled-coil protein	MtRPG	Essential for rhizobium infection	-/Nod	(Arrighi et al., 2008)
SCAR/WAVE protein	MtNAP1 / LjNAP1	Essential for rhizobium infection, involved in actin rearrangement or nucleation	-/Nod	(Yokota et al., 2009; Miyahara et al., 2010)
p53 inducible RNA	LjPIR1	Essential for rhizobium infection, involved in actin rearrangement or nucleation	-/Nod	(Yokota et al., 2009)
Pectate lyase	LjNPL	Essential for rhizobium infection	-/Nod	(Xie et al., 2012)
Peroxidase	MtRIP1	Rhizobium-induced peroxidase	-/Nod	(Cook et al., 1995; Ramu et al., 2002)
Rapid alkalinization factor (RALF) peptide	MtRALF1	Controls nodulation	-/Nod	(Combier et al., 2008)
Vapyrin	MtVPY	Essential for rhizobium infection and arbuscule formation	AM/Nod	(Pumplin et al., 2010; Murray et al., 2011)
Nodule & symbiosome development				
Symbiosome localized esterase	MtENOD8	Localized to symbiosome membrane.	-/Nod	(Coque et al., 2008)
Early nodulin	GmaENOD93, Dg93	Nodule-induced.	-/Nod	(Kouchi and Hata, 1993; Okubara et al., 2000)
Ankyrin-repeat membrane protein	LjIGN1	Membrane protein, required for persistence of nitrogen-fixation in nodules.	-/Nod	(Kumagai et al., 2007)
Methionine-rich membrane protein	LjSEN1, GmNOD21	Legume-specific, exclusively expressed in infected nodule cells, essential for symbiosome differentiation.	-/Nod	(Delauney et al., 1990; Hakoyama et al., 2012a)
Small membrane localised protein	MtNAD1	Required to repress defense responses in nodules.	-/Nod	(Wang et al., 2016)
Stress up-regulated Nod 19	MtN19	Nodule-induced, possible target of miR398b.	-/Nod	(Gamas et al., 1996)
Small peptide	LjALOG	Controls nodulation efficiency.	-/Nod	(Lei et al., 2018)

Remorin	MtSYMREM1, LjSYMREM1	Symbiotic remorin, interact with SYMRK and LCO LysM-RK receptors.	AM/Nod	(Lefebvre et al., 2010; Tóth et al., 2012)
Signal peptidase	MtDNF1	Required for symbiosome formation.	-/Nod	(Wang et al., 2010)
Phosphatidylinositol phospholipase C-like	MtDNF2	Required for bacteroid persistence.	-/Nod	(Bourcy et al., 2013)
t-SNARE syntaxin	MtSYP132	Gene encoding two splice variants, of which one is essential for symbiosome and arbuscule formation.	-/Nod	(Catalano et al., 2007; Huisman et al., 2016; Pan et al., 2016)
v-SNARE syntaxin	LjSYP71	Ambiguous expressed. Commits essential function in nodules	-/Nod	(Hakoyama et al., 2012b)
v-SNARE syntaxin	MtVAMP721d, MtVAMP721e	Essential for symbiosome and arbuscule formation	AM/Nod	(Ivanov et al., 2012)
Systemic signaling				
CLV1-type LRR-receptor kinase	MtSUNN, LjHAR1, GmNARK	Systemic control of nodulation.	AM/Nod	(Krussel et al., 2002; Nishimura et al., 2002b; Searle et al., 2003; Schnabel et al., 2005; Müller et al., 2019)
CLI1-type LRR-receptor kinase	LjKLV	Systemic control of nodulation	-/Nod	(Miyazawa et al., 2010)
CLV2-type LRR-receptor	LjCLV2 / PsSYM28	Systemic control of nodulation	-/Nod	(Krusell et al., 2011)
CLE peptide	MtCLE12, MtClE13	Responsive to cytokinin, controls nodule development	AM/Nod	(Mortier et al., 2010; Mortier et al., 2012; Müller et al., 2019)
CLE peptide	LjCLE-RS1, LjCLE-RS2	Systemic control of nodulation, binds to LjHAR1	-/Nod	(Okamoto et al., 2009; Okamoto et al., 2013)
CLE peptide	GmRIC	Systemic control of nodulation	-/Nod	(Ferguson et al., 2014)
CEP peptide receptor	MtCRA2	Controls lateral root and nodule development	-/Nod	(Mohd-Radzman et al., 2016)
CEP peptide	MtCEP1	Systemic control of nodulation	-Nod	(Djordjevic et al., 2015; Mohd-Radzman et al., 2016)
Kelch repeat-containing F-box protein	LjTML	Systemic control of nodulation, acts downstream of CLE-RS signalling	-/Nod	(Takahara et al., 2013)
Arabinosyl transferase	MtRDN1, LjPLENTY, PsNOD3	Systemic control of nodulation	-/Nod	(Yoshida et al., 2010; Schnabel et al., 2011)

Essential for ethylene mediated signalling	MtSKL1, LjEIN2-1, LjEIN2-2, PanEIN2	Negative regulator of symbiotic and pathogenic microbial associations	-/Nod	(Penmetsa et al., 2008; Miyata et al., 2013; van Zeijl et al., 2018)
Hormones				
Histidine kinase Cytokinin receptor	MtCRE1 / LjHK1	Essential for nodule formation.	-/Nod	(Gonzalez-Rizzo et al., 2006; Murray et al., 2007)
C3HC4-type RING finger protein	LjCZF1	Interacts with LjLHK1, controls nodulation efficiency.	-/Nod	(Cai et al., 2018b)
Isopentenyltransferase	LjIPT3	Adenylate isopentenyltransferase IPT3.	AM/Nod	(Chen et al., 2014)
Cytokinin oxidase / dehydrogenase	MtCKX1	Direct target of CRE1-dependent cytokinin signaling, regulating nodulation.	-/Nod	(Ariel et al., 2012)
Cytokinin oxidase / dehydrogenase	LjCKX3	Direct target of CRE1-dependent cytokinin signaling, regulating nodulation	-/Nod	(Reid et al., 2016)
Cytokinin type-A Response Regulator	MtRR4, MtRR9, MtR11	Responsive to cytokinin, control nodule development.	-/Nod	(Op den Camp et al., 2011a; Ariel et al., 2012)
Tryptophan Amino-transferase Related protein	LjTAR1	LCO responsive. Involved in auxin biosynthesis.	-/Nod	(Nadzieja et al., 2018)
Carotene Hydroxylase	GmBCH1, GmBCH2, GmBCH3	involved in nodule development	-/Nod	(Kim et al., 2013)
Carotene isomerase	MtDWARF27	essential for strigolactone biosynthesis, LCO responsive	-/Nod	(Liu et al., 2011; Van Zeijl et al., 2015)
Carotenoid cleavage dioxygenase	MtCCD7, LjCCD7	essential for strigolactone biosynthesis, involved in nodulation and mycorrhization	AM/Nod	(Liu et al., 2013; Van Zeijl et al., 2015)
Carotenoid cleavage dioxygenase	MtCCD8, PsRMS1	essential for strigolactone biosynthesis, involved in nodulation and mycorrhization	AM/Nod	(Gomez-Roldan et al., 2008; Foo and Davies, 2011; Foo et al., 2013; Breakspear et al., 2014)
Jasmonate-Zim-domain	AsJAZ1	Interacts with LB	-/Nod	(Li et al., 2015)
Ammonium transporter	LjAMT1;1	Ammonium transporter 1, involved in nodule functioning	-/Nod	(Rogato et al., 2008; Straub et al., 2014)
Ammonium transporter	MtAMT1;3	Ammonium transporter 1; involved in nodule functioning	-/Nod	(Straub et al., 2014)

Anion transporter	LjN70 / GmN70	Localizes at symbiosome membrane of nodules and has transport preference for nitrate	-/Nod	(Vincill et al., 2005)
Aquaporin	MtAQP1, GmNOD26	Expressed in infected nodule cells	AM/Nod	(Miao and Verma, 1993)
Divalent metal transporter	GmDMT1	Nodule specific expression	-/Nod	(Kaiser et al., 2003)
Class 1 hemoglobin	PanHB1	Class I hemoglobin, commits symbiotic function in *Parasponia*	-/Nod	(Appleby et al., 1983; Sturms et al., 2010; van Velzen et al., 2018)
Class 2 hemoglobin	LjLB1, LjLB2, LjLB3	Class II symbiotic hemoglobins, essential for nodule functioning	-/Nod	(Ott et al., 2005; Wang et al., 2019b)
Transporters				
Iron-activated citrate transporter	MtMATE67,LjMATE1, GmFRD3a, GmFRD3b	Required for nitrogen-fixation	-/Nod	(Takanashi et al., 2013; Kryvoruchko et al., 2018)
Nitrate transporter	MtNIP/LATD	Controls rhizobium infection and lateral root organ formation	-/Nod	(Bagchi et al., 2012)
Oligopeptide transporter	GmYSL1	Involved in remobilization of iron from the nodule	-/Nod	(Brear et al., 2013)
Potassium transporter	LjKUP1	Nodule specific expression	-/Nod	(Desbrosses et al., 2004)
Phosphate transporter	GmPT7	Required for nodule formation	-/Nod	(Chen et al., 2019)
Sucrose transporter	MtSUT1-1	Induced upon mycorrhization	AM/Nod	(Doidy et al., 2012)
Sucrose transporter	MtSUT4-1, LjSUT4	Induced upon mycorrhization	AM/Nod	(Reinders et al., 2008; Doidy et al., 2012)
Sucrose transporter	MtSWEET11, MtSWEET12, LjSWEET3	Nodule specific expression	-/Nod	(Kryvoruchko et al., 2016; Sugiyama et al., 2016)
Sulfate transporter	LjSST1	Essential for nodule functioning	-/Nod	(Krusell et al., 2005)
Zinc transporter	GmZIP1	Nodule specific expression	-/Nod	(Moreau et al., 2002; Krusell et al., 2005)
Enzymes				
Carbonic anhydrase	MsCA1, LjCA1, GmCA1	Nodule enhanced expression, catalyzes interconversion of CO_2 and water to bicarbonate and protons	-/Nod	(Kavroulakis et al., 2000; Flemetakis et al., 2003; Aivalakis et al., 2004)

Cysteine protease	LjCYP1, LjCYP2, LjCYP4, PsCYP15A	Involved in nodule and arbuscule senescence	AM/Nod	(Goetting-Minesky and Mullin, 1994; Vincent and Brewin, 2000; Deguchi et al., 2007)
Glutamate synthase	MtNADH-GOGAT, MsNADH-GOGAT	NADH-dependent glutamine oxoglutarate aminotransferase essential enzyme in nitrogen metabolism in nodules	-/Nod	(Vance et al., 1995; Glevarec et al., 2004)
Glutamine synthetase	MtGS2	Plastid localized enzyme essential enzyme in nitrogen metabolism in nodules	-/Nod	(Melo et al., 2003)
Glutamine synthetase	GmGS1-2	Cytolsolic enzyme essential enzyme in nitrogen metabolism in nodules	-/Nod	(Guan et al., 1996; Morey et al., 2002)
Glycinamide ribonucleotide synthetase	GmPURD	nodule enhanced expression, enzyme acts in nitrogen metabolism	-/Nod	(Schnorr et al., 1996)
Glycinamide ribonucleotide transformylase	GmPURN	Nodule enhanced expression, enzyme acts in nitrogen metabolism	-/Nod	(Schnorr et al., 1996)
Homocitrate synthase	LjFEN1	Can compensate homocitrate deficient rhizobia in nodules	-/Nod	(Hakoyama et al., 2009b)
NADH-malate dehydrogenase	MsMDH, GmMDH	Involved in metabolism of malate	-/Nod	(Miller et al., 1998; Imsande et al., 2001)
NADPH oxidase	MtRBOHA, PvRBOHB	Expressed in rhizobium containing nodule cells and arbusculated cells	AM/Nod	(Marino et al., 2011; Montiel et al., 2012; Arthikala et al., 2014; Belmondo et al., 2016)
Nicotianamine synthase	LjNAS2	Nodule specific expression	-/Nod	(Hakoyama et al., 2009a)
Phosphoenolpyruvate carboxylase	GmPEPC7	Involved in metabolism of C4 dicarboxylic acids	-/Nod	(Nakagawa et al., 2003)
Subtilisin-like protease	AgAG12, CgCG12	Nodule enhanced expression	AM/Nod	(Ribeiro et al., 1995)
Subtilisin-like protease	LjSBTS	Expression strongly enhanced in nodules and mycorrhizaed roots	AM/Nod	(Kistner et al., 2005)
Sucrose synthase	MtSUCS1, AglSUS1	GT1 Sucrose synthase	-/Nod	(van Ghelue et al., 1996; Hohnjec et al., 1999)
Uricase	GmNOD35	Essential enzyme in nitrogen metabolism in nodules	-/Nod	(Nguyen et al., 1985)

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