STM JOURNALS

Research & Reviews: A Journal of
Pharmacognosy

https://journals.stmjournals.com/rrjopc

ISSN: 2394-7276
Volume 11, Issue 2, 2024
May-August
DOI (Journal): 10.37591/RRJoPC

Review RRJoPC

The Induction, Formation, and Establishment of Giant Cell in Plant-Parasitic (Meloidogyne Spp.)-Host Interactions: A Molecular and Cellular Basis

Abdulaziz Abdujabar Issa[1], Awais Ali[2], Uzma manzoor[3], Gurja Belay[1,*]

Abstract

Root-knot nematodes, (RKN) are obligatory endoparasites of over 3000 plant species, causing $70 billion in annual economic losses globally. The second stage juveniles hatch from the eggs invade the root apex and inject pathogen effectors that induce specialized feeding cell called Giants cell that are large multinucleated cell formed, due to repeated cycles of mitosis without cytokinesis and served sole source of feeding site for rootknot nematode. The ability RNN induce and maintain giant cell is an example of elaborated mechanism of parasitism (or survival adaptation) of RKN-host interaction. Therefore, understanding cellular & molecular mechanism used by RKN to establish feeding cell (giant) might provide idea of how to develop new and safe disease control strategies. In this review, therefore, we have summarized recent advance in molecular and cellular basis of giant cell induction, development and maintenance.The reviewers have summarized many genes involved in host fundamental process such as cell wall remodeling, cell cycle control, cytoskeleton organization as candidates for giant cell induction, development and maintenance. For example, transcriptional activation of the cell cycle markers cdc2a observed in Arabidopsis roots and in tomato expansin, the gene LeEXPA5 has been shown to be expressed in gall cells adjacent to the giant cells. The endo-b-D-glucanasesare also implicated in feeding cell formation. The actin cytoskeleton has a unique arrangement during the formation of giant cell expansion. A significant amount of odd, randomly orientated actin bundles and cables occur in the genes AtFH1, AtFH6, and AtFH10, which are uniquely activated in giant cells. In conclusion, the regulation of host gene involved in cell cycle, cell wall expansion and cytoskeleton remodeling can be considered as a signature for giant cell induction, development and maintenance.

Keywords: Meloidogyne spp., giant cell formation, genes, cell cycle control, cytoskeleton organization, molecular basis, cellular basis.

***Author for Correspondence**
Gurja Belay
E-mail: gurjab@sc.aau.edu.et

[1]Research Scholar, Department of Biodiversity Conservation and Ecotourism, Oda Bultum University, P. O. Box, Chiro, Ethiopia.
[2]Research Scholar, Department of biochemistry, Abdul wali khan university Mardan. Mardan-, Pakistan
[3]Research Scholar, Department of Clinical biochemistry, COMSAT University Sahiwal, Pakistan

Received Date: April 10, 2024
Accepted Date: July 02, 2024
Published Date: July 12, 2024

Citation: Abdulaziz Abdujabar Issa, Awais Ali, Uzma manzoor, Gurja Belay. the Induction, Formation, and Establishment of Giant Cell in Plant-Parasitic (Meloidogyne spp.)-Host Interactions: A Molecular and Cellular Basis. Research & Reviews: A Journal of Pharmacognosy. 2024; 11(2): 34–46p.

INTRODUCTION

Root-knot nematodes (RKN), also known as Meloidogyne spp., are obligatory, sedentary endo-parasites of more than 3000 plant species. They are responsible for significant crop losses that cost the global economy $70 billion annually. RKN are obligate biotrophic pathogens that can only consume living cells, making them plant parasites. The second stage of juveniles (J2) emerges from the eggs in response to host-plant root exudates, and they invade the root directly behind the apex, ideally in the differentiation and elongation zone [1–10].

RKNs engage in long-lasting, close associations

with their host plants during parasitism (up to six weeks), frequently resulting in intricate morphological and physiological changes of the host cell into specialized cells known as Giants (Figure1). The repeated cycles of mitosis without cytokinesis result in the formation of giant cells, which are huge multinucleated cells. More than 100 polyploid nuclei can be found in fully differentiated giant cells, which may also have undergone substantial endo-reduplication (Wiggers,et al., 1990) [30]. The process of generating and preserving giant cells entails physiological alterations in the root, such as cell enlargement, nuclear division, increased metabolic activity, growth and subcellular membrane of the cell wall, increased metabolic activity and cytoplasmic density, multiple small central vacuoles replacing one large one, numerous large nuclei of increased size, and the proliferation of organelles such as plastids, ribosomes, endoplasmic reticulum, Golgi stacks, and mitochondria (Sobczak, et al., 2011) [26]. Fully differentiated giant cells are essential to fulfill the nematode nutritional demands for growth and reproduction.

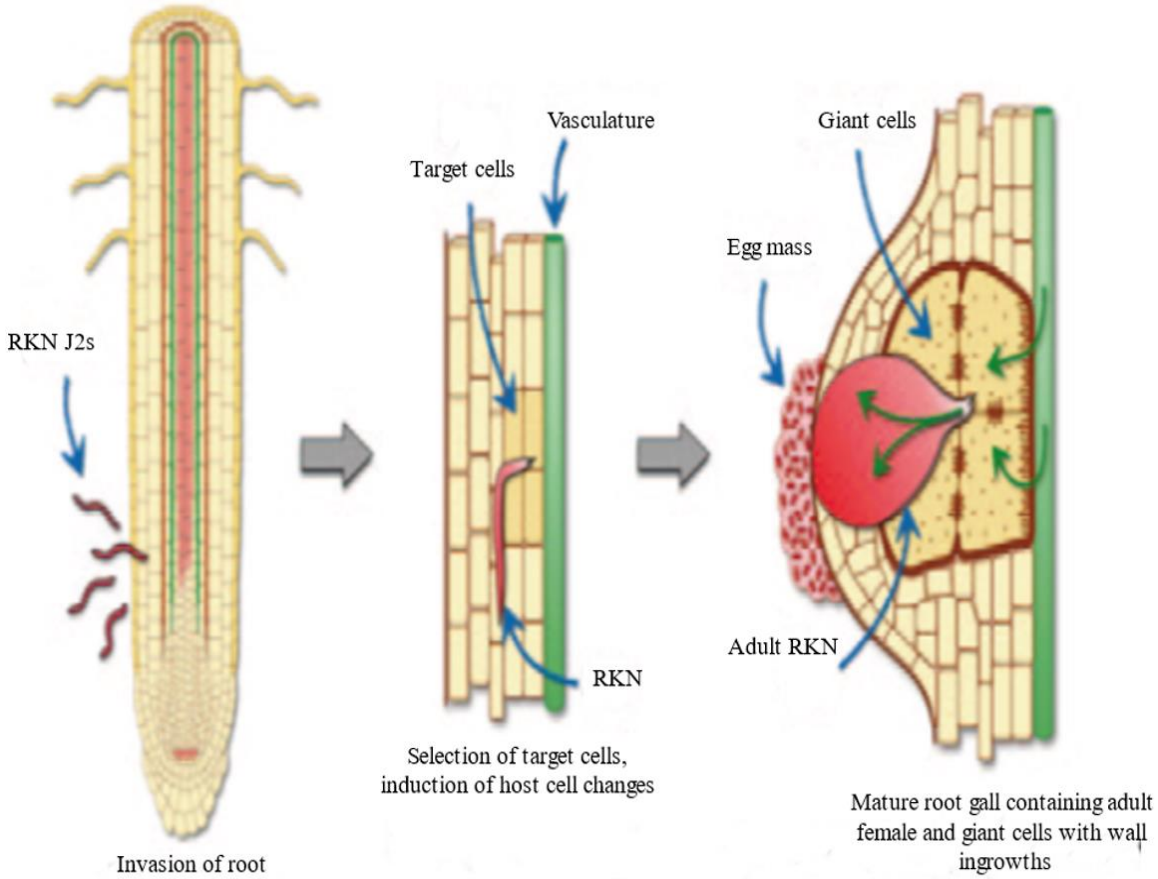


Figure 1. Schematic representation of the life cycle of root-knot nematodes. J2 root-knot nematodes (RKN) migrate to and enter a host root in the zone of elongation. An individual nematode then migrates to pro-vascular 'target cells' where it re-programs them by stimulating mitosis and cell expansion to form giant cells from which it feeds and becomes surrounded by a gall. After three moults within the root (not shown), the adult female becomes spherical and lays eggs in a gelatinous egg mass. The giant cells are multinucleate 'transfer cells' with wall ingrowths that amplify their plasma membranes to enhance the flow of solutes to the nematode from vascular tissues (adapted from Abad,et al., 2003) [1].

The finding of cell cycle genes being expressed during the giant cell's start implies that host cells get ready for mitotic cell division, in which the chromosomes and all other components of the cell are duplicated. Nevertheless, the mitotic preparations do not stop until the cell division is completed. Rather, a shortcut in the cell cycle compels the cell to begin yet another round of incomplete cell

division preparations [11-20]. After a few iterations of this procedure, big cells with a high DNA content are produced. Beside, histological observation of anatomical, physiological as well as cytological change in giant cell indicated that the process of giant cell formation follows a typical developmental pathway, which differs of course from the cellular differentiation that would normally take place. Based on profound anatomical and physiological transformations that initial root cells experience to become nematode giant cells, researcher suggested that root-knot nematode therefore must interact with and re-program fundamental host cell functions to their own benefit. Researchers showed that significantly reprogrammed gene transcription in host cells results in cytological alterations in nematode-induced giant cells (Gheysen and Fenoll, 2002) [13]. The mechanisms used by Root Knot nematodes to re-program host fundamental machinery process in order to transform that initial cell into morphologically distinct cell types called giant cells is, is a striking example of elaborated mechanism of parasitism or RKN-host plant interaction. Hence, understanding molecular and cellular biology involved in induction and maintenance of giant cell might provide idea of how to develop new and safe disease control strategies [21].

Molecular and cellular mechanisms underlying feeding site formation is very complex process that involve director indirect interaction between RKN-host which trigger different pathway. Moreover, the fundamental question of "how Root Knot nematodes induce giant cell site development" remains a puzzle with many missing pieces and also knowledge of the complex molecular mechanisms underlying giant cell formation still remains fragmentary [22-25]. In addition, single study could not able to answer the question "how RKN induce feeding site (giant cell)."Considering that, we planned to conduct systematic review to identify status, progress & future perspective of molecular and cellular mechanism of RNN-host plant interaction, with emphasis on induction and maintenance of giant cell formation. Therefore, understanding cellular & molecular mechanism used by RNN to establish feeding cell (giant) might provide idea of how to develop new and safe disease control strategies. However, knowledge molecular and cellular mechanisms underlying feeding site formation remains a puzzle and fragmentary with many missing pieces. In this review, therefore, we have summarized recent advance in molecular genetics and cell biology of giant cell initiation, development and maintenance. Specifically, hosts and parasitic genes & their product that participated in giant cell formation as well their mechanism of action were reviewed. Moreover, host plant genes specifically regulated (up regulated or dawn regulated) by pathogen effectors to induce and maintain giant cell formation along with their mechanism action of interaction were summarized. Several previous reviewers have reviewed the anatomy and cytology of giant cells and as well as the ontogeny and physiology of giant cell formation (Bleve-Zacheo and Melillo, 1997, Grundler and Böckenhoff, 1997, Jones and Payne, 1978). However, the present reviews are largely concerned on molecular genetics and cell biology of the mechanism of giant cell initiatation, formation and maintenance.

ANATOMY OF ROOT-KNOT NEMATODES'S GIANT CELLS

Numerous researchers have reported the sophisticated change in anatomy of giant cells by using light, scanning and transmission electron. Data emerged from these studies revealed that the anatomical and physiological features that have been changed in giant cell formation are includes; the increase of metabolic activity and cytoplasmic density, the large number of small sized vacuoles, the large number of number nuclei, the replication of cellular organelles such as ribosomes, golgi apparatus, mitochondria, endo-plasmicreticulam and plastids (Figures:2) (Berg, et al.,2008, Sobczak,et al., 2011, Vieira, et al., 2013) [8,26-29].

These authors are also reported that the structural modifications in giant cells such as cell walls thickening and ingrowths of cell wall results in labyrinths finger like protuberances (Figure: 2). The increased in growth of cell wall in giant cell as well as the intensive vascularization around the giants cell may contributed large nutrient access for RKN (Bartlem, etal., 2014) [7]. All these modification in structural and physiological modification of giant cell is mediated by various host gene induction as

well as cross-talk between plant precursors cells which accompanied by un known nematodes effectors (Truong, etal., 2015).

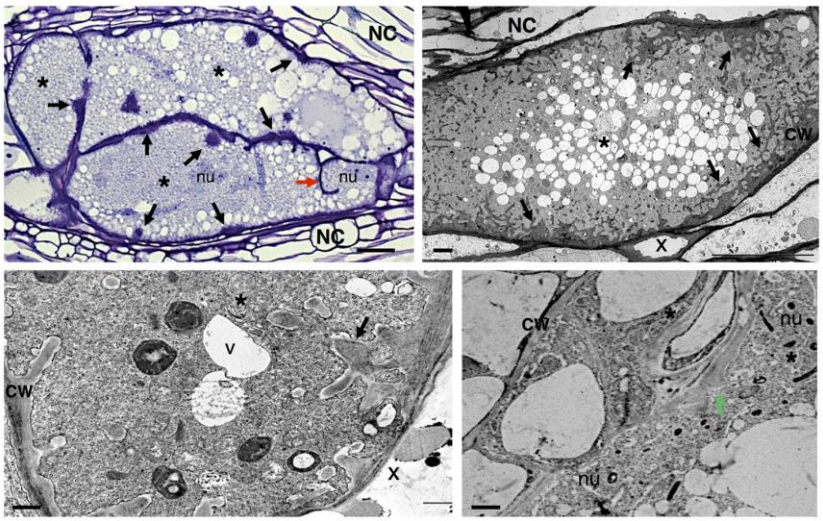


Figure 2. Anatomy of Meloidogyne incognita-induced giant cells in Arabidopsis thaliana roots. (A) Light microscopy image of sectioned giant cells embedded in gall and stained with toluidine blue. Cell wall thickenings (black arrows), and cell wall stub (red arrow) indicating arrest of cytokinesis. (B–D) Ultra-structure of giant cell sections showing cell wall in growths (black arrows) along regions predominantly flanking the vascular tissue. Note the xylemelements with thickened cell walls and dense cytoplasm containing numerous organelles including asymmetrically shaped nuclei and small vacuoles. (D) Detailed giant cells showing a PD (green arrow). Asterisk, giant cell; NC, neighboring cells; x, xylem; CW, cell wall; V, vacuole; nu, nucleus. Bars = (A) 25 μm and (B–D) 5 μm, adapted from Rodiuc, et al., 2014) [24].

Molecular And Cellular Basis of The Induction, Development and Maintainance of Root-Knot Nematodes's Giant Cells

Root-knot nematodes (RKN) detect chemical gradients in root diffusates and use intercellular movement to begin a delicate interaction with their hosts. The second-stage juvenile (J2), the infective parasitic form of RKNs, enters the root's elongation zone through a combination of mechanical force applied by the stylet and the release of cell wall hydrolytic enzymes from their subventral glands into the apoplast, such as endo-glucanases, endo-xylanases, and pectatelyases (Perry and Moens, 2011) [23]. The J2 then migrates toward the vascular cylinder through the root meristem area. There, a few cells in a vascular cylinder grow into gigantic cells, which feed on the root and give it a knot-like form (Figures 3). (Almeida Engler et al.,2012) [28]. Nuclear and cellular hypertrophy resulted from giant cells regenerating through repeated cycles of DNA replication and successive mitosis without cytokinesis (Almeida Engler, et al., 2012) [28] (Figure 3)

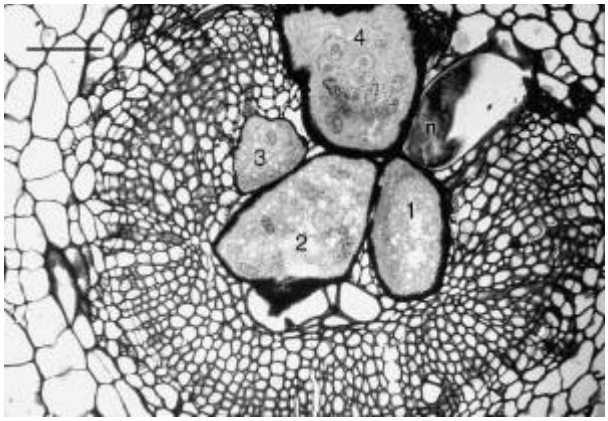
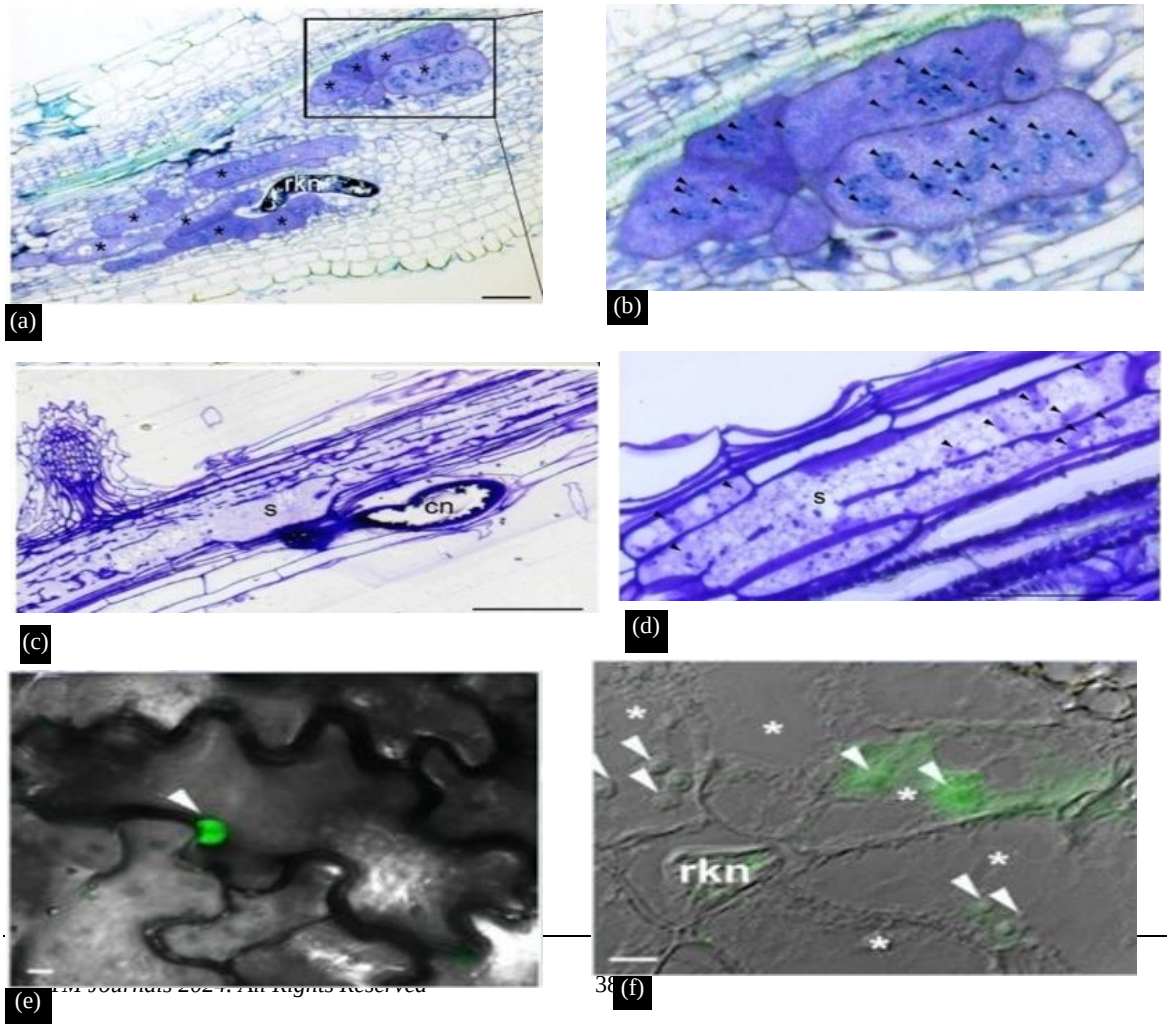


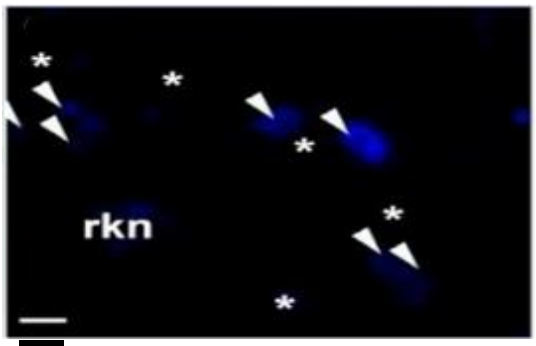
Figure 3. Giant cells induced by root-knot nematode (Meloidogynejavanica) in tomato (Lycopersicon esculentum) roots. Four giant cells (1–4) are evident. The nematode (n) has contracted during fixation. Scale bar = 50 μm.

MECHANISM OF INDUCTION OF ROOT-KNOT NEMATODES' GIANT CELL

Root-knot nematodes (RKN) are obligated bio-trophs plant parasites which feed on only the cytoplasm of living cells. RKN form a close bond with their host plants, causing root cells to re-differentiate into giant cells, which are specialized multinucleate feeding cells (Figure 4). One of the earliest indications of giant cell induction is the first appearance of bi-nucleated cells. Then these bi-nucleated cell undergo repeated nuclear division without cell division (Caillaud, et al., 2008b). However, there is emerging evidence that the cytokinesis is initiated at the end of the mitosis as the alignment of cell plate vesicles between two daughter nuclei in giant cells has been observed, and then followed by the dispersal of these vesicles and arrest of cytokinesis.

In order to study the mechanism by which normal cell are initiated and transformed in to unique feeding cell, giant cell, numerous researchers had carried out the studies on pattern of host genes uniquely expressed in micro-environment of giant cell. Numerous genes involved in basic host processes, including cell wall remodeling, cell cycle regulation, hormone production, and defensive responses, have been identified by these research and shown to express differently in giant cells. (Caillaud, et al., 2008a, Barcala, et al., 2010)[6]. The detail explanation of the mechanism by which RKN induce the fundamental host process involved in feeding cell induction and maintenance of will be discussed somewhere in next sub-topic. It is now well acknowledged that secreted nematode effectors play important roles in parasitism, even if it is still unknown how this developmental switch allows plant-parasitic RKN to generate and produce gigantic cells that differ in appearance and physiology from normal cell (Davis, et al., 2004) [10]. It has been proposed that since RKNs have very wide host range, any model for giant cell induction have to be consistence with any mechanisms of induction.





(g)

Figure 4. Multinucleate and hypertrophied feeding cells induced by endoparasitic plant nematodes and nuclear localization of a RKN effector in planta. (A) In pepper, giant cells initiated by M.chitwoodi . (B) Several nuclei are observed in the giantcells. (C,D) H.schachtii initiated syncytium in Arabidopsis. Toluidine blue-stained show cellwall integration (A,B) or Crystal Violet stained (C,Dlongitudinal slices of the infected roots seven (A, B) or ten (C, D) days following vaccination. (E) Following agro infiltration, the RKN effector MiEFF1:GFP accumulates in the nucleus (arrowhead) of tobacco epidermal leaf cells. (F) 14 days after inoculation, immunolocalization of the secreted MiEFF1 in tomato galls. A stationary parasitic juvenile's stylet tip and the nuclei (arrowheads) of large cells both exhibit FITC signaling. (G) Nuclei from the slice shown in (F) stained with DAPI. * Giant Cells; syncytium; cn, cyst nematode; rkn, root-knot nematode. 50 μm (A–D) or 10 μm (E–G) bars.

Differential regulation of host gene by RKN has been proposed as the mechanism by RKN induces giants cells. The identification and functional characterized host gene with parasitic effectors involved in giant cell induction will be discussed under different sub-heading.

Root-Knot Nematodes Giants Cells' Development and Maintenance

It is now widely accepted that the development and maintenance of fully differentiated giant cells arevery critical to fulfill the nematode nutritional demands during the development of second stage juvenile (J2) larva into adult (molt three times and developed in to adults, three weeks) as well as to produce normal number of eggs (reproduction).These cells derive from root parenchyma cells, acquiring meristematic characters of proliferation without cytokinesis, and high cytoplasmic density, under the influence of a number of genes associated with these phenomena in meristematic cells. More than 100 polyploid nuclei, which may have undergone significant endo-reduplication, are found in fully differentiated giant cells (Wiggers et al., 1990) [30]. At maturity the size of gaint cell is about 400 times that of normal cell. In addition, giant cells show an increase in cytoplasmic density and a loss of normal vacuolization. Development of the extensive vascular network surrounding giant-cells, and the concomitant development of thickened walls and transfer cell labyrinths of the giant-cell, is central to acquisition of nutrients by the giant-cell and successful nematode parasitism. It is now apparent that vacuolar dynamics have a role in giant-cell expansion and subsequent replacement of the vacuole by cytoplasm. As the role of cell cycle genes and the cytoskeleton in this process is explored, coupled with a successful search for feeding site-specific promoters and the application of RNA interference technology (Bakhetia, et al., 2005) [5]. The identification of secreted nematode effectors that alter or manipulate plant cell division will enhance our understanding of fundamental cellular mechanisms engaged in giant cell development and maintenance in plants cells. The timing and levels of expression of genes acting at different phases of the mitotic cell cycle and endocycle will ensure activation or inhibition at the proper time during gall development, bearing in mind that nematodes must maintain the host root cells live to nourish during their development. Since Meloidogyne spp. can induce giant cells in thousands of plant species in a similar manner, they probably interact with and manipulate fundamental host functions to their own benefit. Several recent studies have identified

many genes which differentially expressed in giant cells. These genes are involved in host fundamental process such as cell wall remodeling, cell cycle control, cytoskeleton organization, phytohormons and defense responses (Caillaud, et al., 2008a, Barcala, et al., 2010) [6].

Remodeling of cell wall in root-knot nematode feeding sites

The development and maintenance of fully differentiated giant cells are very critical for RKN development and reproduction. In addition, the development of the extensive vascular network surrounding giant-cells, and the concomitant development of thickened walls and transfer cell labyrinths of the giant-cell, is central to acquisition of nutrients by the giant-cell and successful nematode parasitism. Root-knot nematode brought all these modification on cell wall architecture in giant cell, through the induction a series of controlled host cell wall modifying genes (Gheysen and Mitchum, 2009, Barcala,et al., 2010, Damiani,et al., 2012).[6].

The large repertoire of host genes encoding plant cell wall modifying enzymes differentially up regulated in giants might involved in thickening of cell walls, and elaborate cell wall labyrinths of combined reticulate or flange architecture. These cell wall modifying enzymes include, anextensin, expansin gene family, apectinacetyleesterase, pectatelyases and endoglu-canases. According to Sampdro and Cosgrove (2005), plant hydrolases and expansions may be crucial in loosening the cellulose/cross-linking glycan network that causes the cellulose microfibrils in the plant cell wall to slip. Plant cell walls are quickly extended by expandsin proteins by weakening the non-covalent connections that keep them intact. The expression of the gene LeEXPA5 in gall cells next to the giant cells of tomato expansin has been demonstrated. (Gal, et al., 2006). In addition, all regulated A. thaliana pectate lyases, and most of the polygalacturonases and pectinesterases, are also activated in response to M. incognita infestation (Jammes,et al., 2005). Goellner, et al. (2001) have validated the idea that cell wall- modifying enzymes of plant origin, such as endo-b-D-glucanases, are implicated in feeding cell formation. Many genes encoding cell wall proteins (e.g. hydrolases and structural proteins) have been identified as potentially induced or repressed upon infestation (Jammes et al., 2005).It is fascinating to see how cell wall ingrowths multiply as RKN mature before degenerating after the worms have finished their life cycle. Young gigantic cells have cell walls that resemble syncytia. This suggests that nematodes and plant hosts are in constant molecular communication and may play a crucial role in maintaining the physiological condition of large cells (Jones and Northcote, 1972a).

Table 1. Genes encode cell wall remodelingenzymes secreted into host by plant-parasitic root-knot nematode.

Genes	Cellular localization in Parasite	Root-knot nematodes species	Expected Functions	Reference
Mi-pel-1 and Mi-pel-2	Esophageal gland cells of J2s	M. incognita	Pectatelyases (facilitate the penetration and intercellular migrationby cell-wall-degradation)	Huang, et al., 2003
Mi-pel3	J2s subventraloesophageal glandsalong their cytoplasmic extensions,and in the ampullae	M. incognita	Cell wall modifications	Vieira, et al., 2011

This data is suggestive of both unique and apparently common mechanisms orchestrated by these nematodes to provoke adaptations of the plant cell wall to facilitate feeding cell expansion and function (Table 1).

Regulation of Cell Cycle in Root-Knot Nematodes' Feeding Sites

Anatomical and physiological change that transform normal cell into giant cell show defects at the majors sites of cell cycle control, G1/S transition without prior completion of mitosis; failure to pass from metaphase to anaphase (resulting in endo-reduplicated nuclei); and failure to complete the

anaphase to telophase transition (resulting in multinucleate cells). Extensive data emerging from recent studies in Arabidopsis revealed that genetically and chemical inhibition of these three stages of the cycle results in abortion or arresting of giant cell development (Gheysen, et al., 1997) [12]. Both the mitotic and the endo-reduplication cycles are propelled by analogous cell cycle machinery. Cell cycle activity is achieved by the interaction of cyclin-dependent kinase (CDK) with cyclins. Identification of cell cycle gene expressed in giant cell helps us in study cell cycle progression in giant formation. Cyclins provided a crucial hint about the basic mechanism of the cell cycle.De Almeida Engler (1999) performed expression analysis 61 core cell cycle genes in model plant Arabidopsis, in order to identify the genes involved in induction of the cell cycle machinery involved in giant cell formation. Both cell cycle activators and cell cycle inhibitor genes play an important role in induction and maintenance of giant cells.

The eukaryotic cell cycle control take place at four stage of cell cycle: DNA synthesize (S) phase, next Mitosis (M) phase, then cytokinesis, and cell division. The G1 phase (first gap), which links the end of mitosis to the beginning of DNA synthesis, and the G2 phase (second gap), which links the end of DNA synthesis to the beginning of mitosis, intercalate these. (Figure 5). Plant cell cycle molecular basis has been extensively explored using A. thaliana as a model plant (Veylder, 2011).

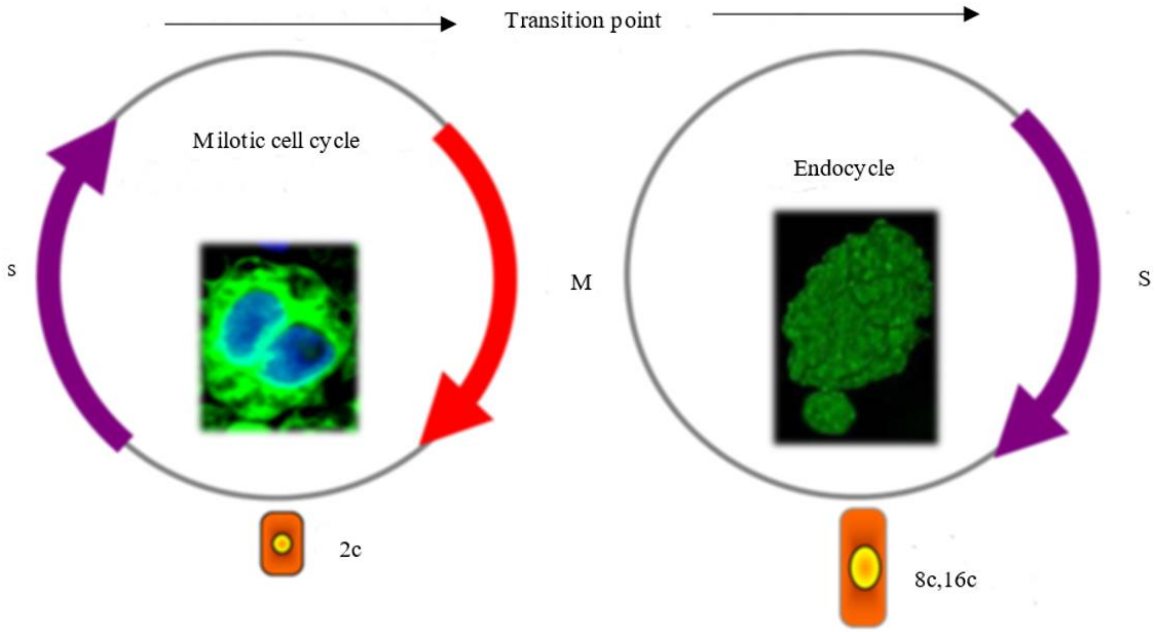


Figure 5. Scheme of the mitotic cell cycle and the endocycle phases occurring during gall development. S, DNA synthesis phase; M, mitosis. Image on the left side illustrates a binuclear giant cell after the first nuclear division and image to the right shows a large nucleus of a giant cell with morphological invaginations and right bellow a nuclei of a significantly smaller of a neighboring cell, respectively. A 8C to higher ploidy levels in giant cell nuclei is observed following several endocycles.

Promoter activities of cell cycle, cyclin dependent kinases genes, CDKA;1 and CDKB1;1 which probably play a role in induction of giant cell were detected in early stage infection of the root by the second Juvenile stage of RKN, few hours after penetration(Niebel,et al., 1996).Similarly, transcription activity of mitotic cyclin, CYCB2;1and CYCB1;1are observed during the same stage(de Almeida-Engleret,etal., 1999).

It has been determined that the modulation of CDK inhibitors (CKI) that are members of the Kip-Related Proteins (KRP) family, also known as interactors/inhibitors of CDK (ICK), occurs. Promoter activities of CDK inhibitors, KRP2, KRP4, KRP5 and KRP6 have been detected in giant cell

formation. Both cell cycle activators genes as well as cell cycle inhibitors genes are play an important role in promoting giant cell development (Inzé, etal., 2006, Vieira, etal., 2013) [19,29]. The potential cell cycle controls of giant cell by using over expressing or knockout cell cycle machinery KRP line have been evaluated. Ectopic expression KRP2 gene and non-expressed KRP1, KRP2 & KRP4 gene of Arabidopsis lead to a significant reduction of gall development. The inhibition of both mitotic and endo-reduplication activity was experimentally connected to the reduction in giant cell size in plants over-expressing KRP1, KRP2, and KRP4, which had an impact on the development of RKN (Viera, etal., 2014) [24]. Some studies showed that that KRP6 plays an unanticipated role during mitosis and that several KRPs regulate the plant cell cycle in different ways. Additionally, the different nuclear sizes in giant cells inside their host roots may be inferred from nuclear fusion and irregularly-sized nuclei seen in cell cultures ectopically expressing KRP6. The participation of KRP6 in the cytokinesis suppression observed in huge cells is further supported by the observation of cell wall stubs in KRP6 loss-of-function lines, cytokinesis inhibition on cell suspension, and root cells of Arabidopsis over-expressing KRP6 (Vieira, and de Almeida Engler, 2015) [2].

THE ENDOCYCLE

Endo-reduplication cycle is an alternative cycle for normal cycles when cell switched off from normal cycle and involved in continuous replication of genome DNA without mitosis (Gutierrez, 2009) [16]. The Endocycles similar to mitotic are propelled by analogous cell cycle machinery. Cyclin-dependent kinase (CDK) with cyclins regulates the activities of cell cycle. Since the plant homolog of the archaeal DNA topoisomerase VI, or RHL1, is a crucial component of the multiprotein complex that binds to DNA, it is highly likely that this protein is involved in the decatenation reaction of topo VI. CCS52genes, along with DEL1 and RHL1, are involved in the active development of both types of feeding sites, according to functional analysis carried out in roots infected by root-knot and cyst nematodes. Galls and syncytia were found to have high expression levels of both CCS52 genes (Figure 6A). Comparable examination of DEL1, which functions as a particular endocycle repressor, revealed low expression levels (Figure 6B).

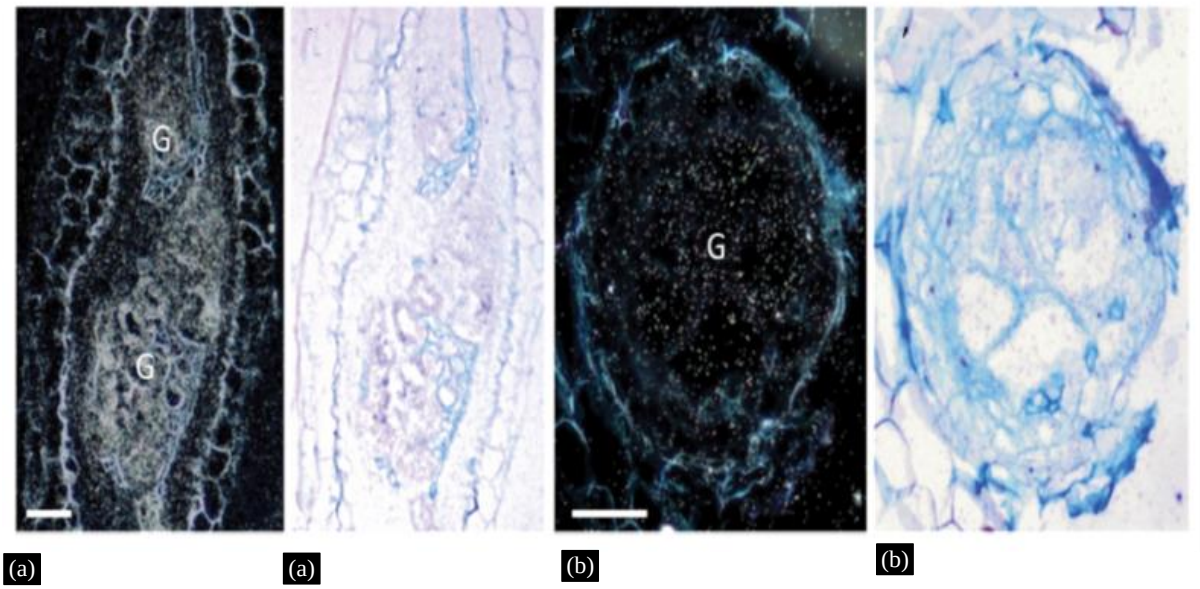


Figure 6. In situ transcript localization of genes involved in the endocycle control in galls. The different expression levels, high for CCS52A (A and A') and low for DEL1 (B and B'), in nematode-induced galls suggest that root-knot nematodes make use of the cell cycle machinery of the plant host. Hybridization signals are visible as white dots under dark-field optics and black dots under bright-field optics. Bars = 50 μm.

A transgenic study using Arabidopsis model plants engineered to up-regulate the CCS52 genes (35Spro:CCS52 lines) reveals that the nuclei of root tissues with elevated CCS52 levels indicated larger amounts of DNA, 32C and 64C, than those typically found in Arabidopsis roots of the wild type (up to 16C). RNA interference knockdown lines and dawn regulation of the CCS52 gene consistently demonstrated lower levels of ploidy in plant tissues at feeding areas with low expression levels of CCS52 genes. The same research, employing DEL1 overexpression lines or CCS52 knockdown, consistently demonstrated a major decline in reproduction and a delay in nematode growth (Vieira, et al., 2013) [29]. As suggested by ALi et al., 2023; Dinh et al., 2023; Manzoor et al., 2023; Saleem Naz Babari et al., 2024; and other studies, severely inhibiting the endocycle through CCS52 knockdown or DEL1 overexpression resulted in a reduced food source and consequently affected nematode development (Figure 7) [31-34].

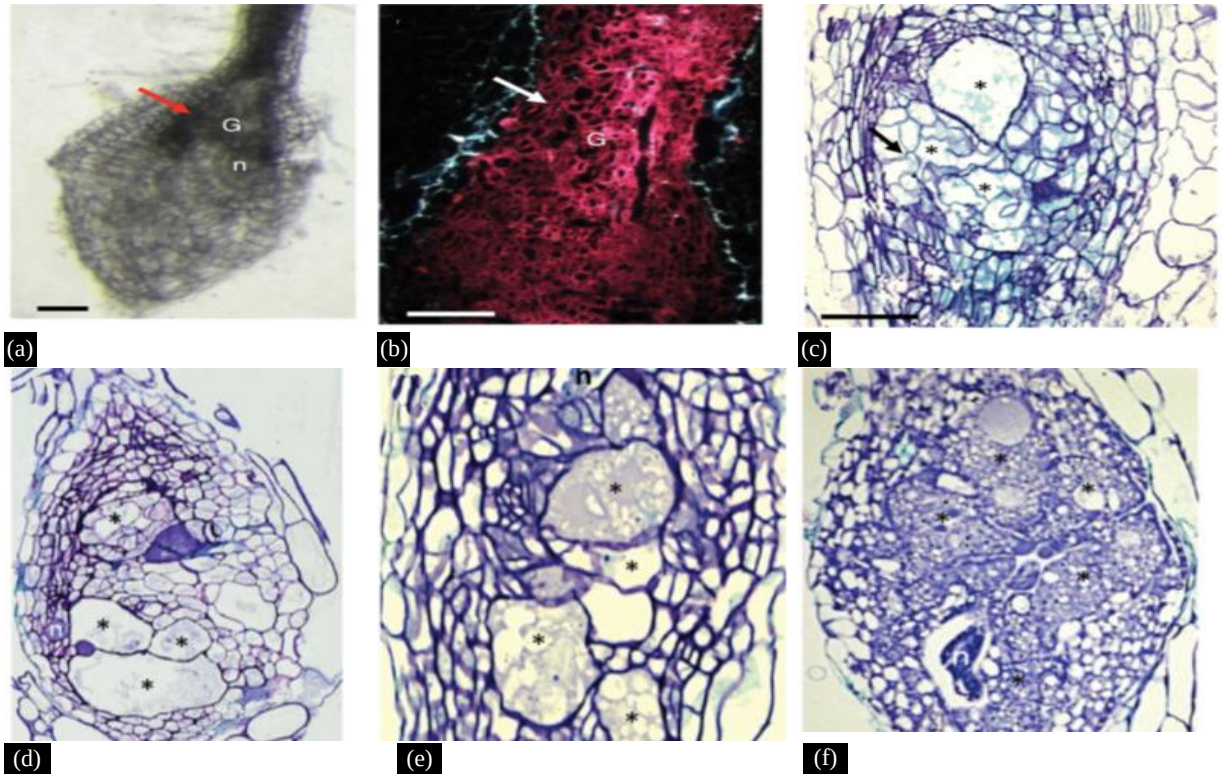


Figure 7. The progression of the mitotic and endocycle in galls is impacted by ectopic expression or knockdown of DEL1 and CCS52, respectively. (A–C) As demonstrated by enhanced root swelling (A), elevated CDKB1;1 expression (B), and an attempt at giant cell division (C, black arrow), DEL1 overexpression results in increased mitotic activity. The endocycle is disrupted by CCS52B knockdown (D) and overexpression (E), which has an impact on gall development. A wild-type gall with extremely multinucleate large cells and characteristic thick cytoplasm is depicted in image (F). Astrophile, large cell; gall, nematode; and asterisk, gall. Bars measure 50 μm.

CONCLUSION

Root-knot nematodes (Meloidogyne spp) are small endo-parasites with a wide host rangethat includes almost all flowering plants. During parasitism, the motile second stage Juvenile hatch from egg and enter the host roots and migrate inter-cellularly, there inject pathogen effectors that induce specialized feeding cell called Giants cell.The ability RNN induce and maintain giant cell is an example of elaborated mechanism of parasitism (or survival adaptation) of RKN-host interaction. The timing and levels of expression of genes acting at different phases of the mitotic cell cycle and endocycle will ensure activation or inhibition at the proper time during gall development, bearing in mind that nematodes must maintain the host root cells live to nourish during their development.

Recent studies have identified many genes which differentially expressed in giant cells that include genes involved in host fundamental process such as cell wall remodeling, cell cycle control, cytoskeleton organization, phytohormons and defense responses (Barcala, et al., 2010) [6]. Transcriptional activation of the cell cycle markers cdc2a, whichencodes a cyclin-dependent kinase, and cyclAt, which encodesa mitotic cyclin, is observed in Arabidopsis roots after infectionby root-knot nematodes (Niebel,et al., 1996). Several transcriptomic analyses reported the large number of significantly downregulated genes, particularly at early infection stages (Portillo, et al., 2013). In tomato expansin, the gene LeEXPA5 has been shown to be expressed in gall cells adjacent to the giant cells. A decrease in LeEXPA5 expression affected the ability of the nematode to complete its life cycle (Gal, et al., 2006). In addition, Goellner, et al. (2001) have proposed that endo-b-D-glucanasesare implicated in feeding cell formation.During giant cell expansion, the actin cytoskeleton displays a particular organization, with large numbers of unusual, randomly oriented actin bundles and cables (de Almeida Engler, et al., 2004). Three formin genes, AtFH1, AtFH6 and AtFH10, are specifically induced in giant cells. Chemical treatments blocking cytoskeleton dynamics result in the arrest of nematode development (de Almeida Engler, et al., 2004). Gene knockout experiment identified gene essential for giant cell formation – rpe, encoding a key enzyme in the pentose phosphate pathway (Favery, et al., 1998). In conclusion, the regulation of host gene involved in cell cycle, cell wall expansion and cytoskeleton remodeling can be considered as a signature for proper nematode establishment and feeding site formation.

LISTS OF ABBEREVATIONS

- RkN Root-Knot Nematode
- NAMP Nematode Associated Molecular Pattern
- NTI NAMP Triggered Immunity
- PPN Plant Parasitic Nematode
- J2 Second Stage Juvenile

REFERENCES

1. Abad, P., Favery, B., Rosso, M.N. and Castagnone-Sereno, P. (2003). Root-knot nematode parasitism and host response: molecular basis of a sophisticated interaction. Mol. Plant Pathol. 4: 217–224.
2. Almeida-Engler, J., Vieira, P., Rodiuc, N., Grossi, M.F. and Engler, G. (2015). Plant nematode interactions: a view on compatible interrelationships. In: Escobar C, Fenoll C (eds.). Advances in Botanic research. Academic Press, New York, 440 pp.
3. Almeida-Engler, J., Rodiuc, N., Smertenko, A. and Abad, P. (2010). Plant actin cytoskeleton re-modeling by plant parasitic nematodes. Plant Signaling & Behavior. 5: 213-217.
4. Almeida-Engler, J., Kyndt, T., Vieira, P., Van Cappelle, E., Boudolf, V., Sanchez, V., Escobar, C., De Veylder, L., Engler, G., Abad, P. and Gheysen, G. (2012). CCS52 and DEL1 genes are key components of the endocycle in nematode-induced feeding sites. The Plant Journal. 72: 185-198.
5. Bakhetia, M., Charlton, W., Atkinson, H.J. and McPherson, M.J. (2005a). RNA interference of dual oxidase in the plant nematode Meloidogyne incognita. Mol Plant Microbe Interact18: 1099-1106.
6. Barcala, M., García, A., Cabrera, J., Casson, S., Lindsey, K., Favery, B., García-Casado, G., Solano, R., Fenoll, C. and Escobar, C. (2010). Early transcriptomic events in microdissectedArabidopsis nematode-induced giant cells. Plant. J. 61: 698–712.
7. Bartlem, D.G., Jones, M.G.K. and Hammes, U.Z. (2014). Vascularization and nutrient delivery at root-knot nematode feedings sites in host root. J. Exp. Bot. 65: 1789-1798.
8. Berg, R.H., Fester, T. and Taylor, C.G. (2008). Development of the root-knot nematode feeding cell. In: Berg RH, Taylor, C.G. (eds) Cell biology of plant nematode parasitism. Springer, Berlin, pp: 115–152.

9. Damiani, I., Baldacci-Cresp, F., Hopkins, J., Andrio, E., Balzergue, S., Lecomte, P., etal. (2012). Plant genes involved in harbouring symbiotic rhizobia or pathogenic nematode. New Phtol. 194: 511-522.
10. Davis, E.L., Hussey, R.S. and Baum, T.J. (2004). Getting to the roots of parasitism by nematodes. Trends in Parasitology, 20: 134–141.
11. Gal, T.Z., Aussenber, E.R., Burdman, S., Kapulnik, Y. and Koltai, H. (2006). Expression of a plant expansinis involve in the establishment of root-knot nematode parasitism in tomato. Planta. 224: 155-162.
12. Gheysen, G., de Almeida Engler, J. and van Montague, M. (1997) Cell cycle regulation in nematode feeding sites. In: Fenoll, C., Grundler, F.M.W. and Ohl, S.A. (eds) Cellular and Molecular Aspects of Plant–Nematode Interactions.
13. Gheysen, G. and Fenoll, C. (2002). Gene expression in nematode feeding sites. Annual Review of Phytopathology 40: 191–219.
14. Gheysen, G. and Mitchum, M.G. (2009). "Molecular insight in the susceptible plant response nematode infection", inPlant Cell Monographs. Cell Biology of Plant Nematode Parasitism, eds R.H. Bergand, C.G. Taylor (Berlin Heidelberg: Springer), 45-81.
15. Goellner, M., Wang, X. and Davis, E.L. (2001). Endo-b-1,4-glucanas expression incompatible plant-nematode interactions. Plant Cell. 13: 2241-2255.
16. Gutierrez, C. (2009). The Arabidopsis Cell Division Cycle. The Arabidopsis book. American Society of Plant Biologists, pp 1–19.
17. Huang, G., Gao, B., Maier, T., Allen, R., Davis, E.L., Baum, T.J., etal. (2003). A profile of putative parasitism gene expressed in the esophageal gland cells of the root-knot nematode Meloidogyne incognita. Mol. Plant Microbe Interact. 16: 376-381.
18. Huang, C.S. and Maggenti, A.R. (1969). Root-knot nematode induced mitotic aberrations and nuclear changes of developing giant cells in Vicia faba. Phytopathol 59:447–455.
19. Inzé, D. and De Veylder, L. (2006). Cell cycle regulation in plant development. Annu. Rev Genet. 40:77-105.
20. Jammes, F., Lecomte, P., deAlmeida-Engler, J., Bitton, F., Martin-Magniette, M-L., Renou, J.P. etal. (2005). Genome-wide experession profiling of the host response to root-nematode infection in Arabidopsis. Plant J. 44: 447-458.
21. Niebel, A., Almeida-Engler, J., Hemerly, A., Ferreira, P., Inze, D., Van Montagu, M. and Gheysen, G. (1996). Induction of cdc2a and cyc1At expression in Arabidopsis thaliana during early phases of nematode-induced feeding cell formation. The Plant Journal.10: 1037-1043.
22. Peres, A., Churchman, M.L., Hariharan, S., Himanen, K., Verkest, A., Vandepoele, K., Magyar, Z., Hatzfeld, Y., Van Der Schueren, E., Beemster, G.T., et al. (2007). Novel plant- specific cyclin-dependent kinase inhibitors induced by biotic and abiotic stresses. J. Biol. Chem. 282: 25588-96.
23. Perry, R.N. and Moens, M. (2011). Survival of parasitic nematodes outside the host. In: Perry RN, Wharton DA (eds) Molecular and physiological basis of nematode survival. CABI Publishing, Wallingford.
24. Rodiuc, N., Viera, P., Banora, M.Y. and Almeida Engler, J. (2014). On the track of transfer cell formation by specialized plant-parasitic nematodes.www.frontiersin.org.
25. Sampedro, J., and Cosgrove, D. J. (2005). The expansin superfamily. Genome Biol. 6: 242.
26. Sobczak, M., Kurek, W. and Grymaszewska, G. (2011). The structure of syncytia. In: Fenoll, C., Grundler, F.M.W. and Ohl, S.A. (eds) Cellular andMolecular Aspects of Plant–Nematode Interactions. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 80–97.
27. Veylder, L., Larkin, J.C. and Schnittger, A. (2011). Molecular control and function of endoreplication in development and physiology. Trends in Plant Science, 16: 624-634.
28. Vieira P, Engler G, de Almeida Engler J. (2012). Whole-mount confocal imaging of nuclei in giant feeding-cells induced by root-knot nematodes in arabidopsis. New Phytol. 195:488-96.
29. Vieira, P., Kyndt, T., Gheysen, G. and de Almeida Engler, J. (2013). An insight into critical endocycle genes for plant-parasitic nematode feeding sites establishment. Plant Signal Behav. 8: 224-223.

30. Wiggers, R.J., Starr. J.L. and Price, H.J. (1990). DNA content and variation in chromosome number in plant cells affected by Meloidogyne incognita and M. arenaria. Phytopathology80: 1391–1395
31. ALi, A., Manzoor, U., Ali, S. L., Marsool, M. D., Parida, P. K., Marsool, A. D., & Swathi, N. L. (2023). CURRENTLY TRENDING AND FUTURISTIC BIOLOGICAL MODALITIES IN THE MANAGEMENT OF DIFFERENT TYPES OF DIABETES: A COMPREHENSIVE REVIEW. Journal of Population Therapeutics and Clinical Pharmacology, 30(18), 2948–2970.
32. Dinh, P., Tran, C., Dinh, T., Ali, A., & Pan, S. (2023). Hsa_circRNA_0000284 acts as a ceRNA to participate in coronary heart disease progression by sponging miRNA-338-3p via regulating the expression of ETS1. Journal of Biomolecular Structure and Dynamics, 1–14.
33. Manzoor, U., Ali, A., Ali, S. L., Abdelkarem, O., Kanwal, S., Alotaibi, S. S., Baazeem, A., Baiduissenova, A., Yktiyarov, A., Hajar, A., & Olzhabay, A. (2023). Mutational screening of GDAP1 in dysphonia associated with Charcot-Marie-Tooth disease: clinical insights and phenotypic effects. Journal of Genetic Engineering and Biotechnology, 21(1). https://doi.org/10.1186/s43141-023-00568-9
34. Saleem Naz Babari, I., Islam, M., Saeed, H., Nadeem, H., Imtiaz, F., Ali, A., Shafiq, N., Alamri, A., Zahid, R., & Ahmad, I. (2024). Design, synthesis, in-vitro biological profiling and molecular docking of some novel oxazolones and imidazolones exhibiting good inhibitory potential against acetylcholine esterase. Journal of Biomolecular Structure and Dynamics, 1–18.

