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Review

Caenorhabditis Elegans as a Model Organism in Toxicology, Resistance and Anti-aging Research

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ABSTRACT

Caenorhabditis elegans (c. Elegans), a nematode worm, has established itself as an indispensable model organism in biological research, particularly in the realms of toxicology, resistance mechanisms and anti-aging studies. In this paper, we analysed the basic characteristics that make c. Elegans a versatile and powerful tool for scientific inquiry. We explore its adaptive responses to a range of environmental stresses, including high salt, high fat and heat stress, as well as the intricate processes involved in aging. Additionally, we discussed the progress in capsaicin tolerance research, aiming to provide a reference for a deeper understanding of its biological characteristics and application potential.

Keywords: Caenorhabditis Elegans, Model Organism, Toxicology, Resistance, Tolerance, Aging

1. Introduction

Caenorhabditis elegans (C. elegans) is an ideal model organism for scientific research due to several advantageous characteristics[1]. It shares genetic similarities with humans, including common regulatory and expression mechanisms, making it useful for studying gene function[2,3], transcriptional regulation[5-6] and RNA interference[6,7]. Its simple structure, small number of cells and fully sequenced genome facilitate detailed molecular-level studies. The transparent body of C. elegans allows for high-resolution imaging and easy observation, while its low cultivation costs and short lifespan enable the study of its entire life cycle and genetic phenomena within a manageable timeframe.

C. elegans has been extensively used in toxicology[1] to understand and evaluate the toxic effects of various chemicals on organisms[8-13]. This research provides critical insights into the potential risks these substances pose to human and environmental health, with significant implications for drug development and food safety[14-23]. Additionally, C. elegans is a valuable tool for studying resistance to various stresses, such as high salt[24-28], fat[29] and heat shock[30,31]. For example, researchers have identified specific peptides and compounds that enhance salt resistance, mitigate sugar toxicity and combat high-fat conditions[24-28]. In heat shock studies, C. elegans helps parse the molecular mechanisms of heat resistance, leading to the development of new drugs and strategies to enhance tolerance to high-temperature environments[30,31].

Aging research is another area where C. elegans has made significant contributions. By studying aging-related pathways, such as the insulin/IGF-1 signaling (IIS) and target of rapamycin (TOR) pathways[36,39-42], researchers have developed important drugs like metformin and spermidine[37,43-45]. These findings have advanced our understanding of the aging process and contributed to the development of therapeutic strategies to extend lifespan

and improve health span. Furthermore, C. elegans is being explored for capsaicin tolerance, which has applications in food science, flavoring and medicine[38,46,47].

2. Applications of C. elegans in Toxicology Research

2.1. Toxic Organic Substances

2.1.1. Organic Industrial Raw Materials: Research on toxic organic substances in C. elegans includes organic industrial raw materials organic pesticides and pharmaceutical components. Castro-Sierra and his colleagues researched three fluorescent brighteners (DAST, FB-28 and FB-71) derived from stilbene[14]. Researchers used molecular docking and molecular dynamics simulations to determine their respective protein targets and experimentally evaluated their effects on certain physiological behaviors in C. elegans.

Specifically, the wild-type N2 larvae L1 or L4 were used to assess the lethality, body length, motility and reproductive capacity. Additionally, transgenic green fluorescent protein (gpx-4::GFP (BC20305), gpx-6::GFP (BC17553), sod-4::GFP (BC20333), hsp-4::GFP (SJ4005) and gst-1::GFP (BC20316)) strains were used to estimate changes in relative gene expression.

Castro-Sierra et al. reports that exposure to DAST, FB-71 and FB-28 in C. elegans had more pronounced inhibitory effects on growth, motility and reproduction in terms of lethality. The results from the transgenic strains suggested that this might be due to the induction of oxidative stress and the production of reactive oxygen species (ROS) in C. elegans. The most important genes involved in ROS expression were those related to oxidative stress, gpx-4 and sod-4. C. elegans experienced physiological changes due to the accumulation of ROS within cells.

Simultaneously, the OBs used in the experiment also showed a reduction in microbial respiration rates, leading to incomplete electron transfer in the respiratory chain and the formation of ROS. With the increased use of OBs, it is necessary to investigate their different sources, such as detergents, textiles, plastics and paper products and to establish appropriate regulatory frameworks.

In other studies, researchers have also used C. elegans to study the toxicity of other substance. Yuting Shao et al. researched aged polylactic acid microplastics (enhanced germline cell apoptosis, altered expression of ced-9, ced-4, ced-3 and egl-1)[15]；Ana De la Parra-Guerra and Jesus Olivero-Verbel researched nonylphenol (interference with the normal development of the gonad arms)[16]; Haibo Chen et al. hexabromocyclododecane (increased expression of oxidative stress and apoptosis-related genes hsp-16.2, hsp-16.48, sod-1, sod-3 and cep-1)[17]. These researches provide guidance for production and life.

2.1.2. Organic Pesticides: For organic pesticides, a wide range of pesticides have been studied, including monostrophes, dimethoate, dichlorvos, chlorpyrifos, glyphosate, malathion and cypermethrin[18]. P S Rajini et al. started with common toxicological methods for *C. elegans*, exposing them to different concentrations of pesticides in the culture medium for 4, 6, 12, 24, 36, 48 and 72 hours to observe mortality, growth and development, motility, reproduction, ROS levels, apoptosis, aging and changes in the nervous and reproductive systems, to explore the mechanisms of pesticide toxicity. Pesticides exhibit varying degrees of toxicity due to differences in structure, physical and chemical properties. Current research is also focused on observing the toxicity of mixed pesticides, the genetic impact of pesticides on multiple generations of worms and toxicological responses at the molecular level, such as gene and protein expression.

2.1.3. Organic Drugs: Organic drugs, represented by paclitaxel, one of the mechanisms of action of paclitaxel as an anticancer drug is to promote the expression of apoptotic protein Caspase-3, leading to cell apoptosis. experiments performed by Sakaguchi Y et. al have shown that when exposed to paclitaxel at a concentration of 400 mg/mL, the level of cell apoptosis in C. elegans significantly increases and the motility of the same group of worms is markedly reduced[19]. In addition to inducing apoptosis, paclitaxel has a significant neurotoxic effect on C. elegans, with a dose-response relationship. The experiment reflected changes in neurological function through behavioral changes. It was found that as the concentration of paclitaxel increased, the head-swinging frequency, body-bending ability and pharyngeal pumping frequency of C. elegans all decreased progressively.

Among these, except for the 0.4 mg/L concentration group, where the head-swinging and body-bending frequencies were slightly affected, the behavioral abilities of the other experimental groups were significantly reduced. The decrease in pharyngeal pumping frequency may be due to irreversible damage to the nerves or muscles of the pharynx of C. elegans, leading to feeding disorders.

In other studies, Li DanQing's team has also used similar methods to study the toxicity of Hedyotis diffusa water extract which has a heat-clearing and detoxifying effect and is toxic to the reproduction and development of C. elegans[20].

2.2. Toxic Inorganic Substances

2.2.1. Heavy Metals: Heavy metals, represented by cadmium (Cd), have been studied by Sun Na and her Colleagues[21]. To clarify the toxic effects of cadmium (Cd) on soil invertebrates, C. elegans and the differences in Cd toxicity in different types of soils, the growth, fertility and reproduction of C. elegans were used as endpoints to study the toxic effects of exogenous Cd in red soil from Yingtan, Jiangxi, paddy soil from Suzhou, Jiangsu and black soil from Changchun, Jilin.

The results showed different toxicity thresholds: in paddy soil, when the theoretical total Cd content reached 10, 50 and 150 mg·kg-1, the growth of C. elegans began to show a significant decrease compared to the control group. It can be seen that the sensitivity of C. elegans to Cd toxicity, from high to low, is reproduction, fertility and growth. Correlation analysis showed that soil pH, cation exchange capacity organic matter, calcium carbonate and manganese oxide content are the main factors affecting Cd toxicity in soil.

2.2.2. Arsenic (As): Arsenic (As) is a metalloid widely distributed in the Earth's crust, primarily found in drinking water and foods like rice, fish and vegetables. Inorganic arsenic is a known human carcinogen and has been linked to various health issues, including neurotoxic effects, peripheral vascular diseases, diabetes and cancer. Chronic arsenic exposure can lead to cognitive decline, mood disorders and neurodegenerative phenomena such as demyelination and altered chemical transmission.

Studies by Lantz et al. have shown that low-dose chronic arsenic exposure in mice negatively correlates with RAGE expression, a finding also observed in humans. Recent research suggests that arsenic exposure may contribute to Alzheimer's disease (AD) through Aβ production and accumulation. In a rat model, chronic arsenic exposure from fetal development to 4 months of age led to behavioral impairments and elevated levels of RAGE and Aβ in the brain[21].

2.3. Development of Antidote Drugs

Lentinan, a β-1,3-glucan extracted from shiitake mushrooms, has been previously confirmed to enhance the antioxidant capacity of C. elegans and reduce oxidative damage in the worm by K M Lee' team[22]. The experiment chose to study the effect of lentinan on C. elegans under flupyradifurone stress. Flupyradifurone is a novel non-fumigant nematicide that effectively controls southern root-knot nematodes. The extensive use of flupyradifurone may pose potential risks to the ecological environment and non-target organisms. It has been reported that sublethal doses of flupyradifurone exposure increase the generation of reactive oxygen species (ROS) in C. elegans, inducing oxidative stress and causing oxidative damage. The experiment chose lentinan as an exogenous antioxidant to assist the body in combating excess ROS. The results showed that the addition of lentinan significantly upregulated the expression levels of oxidative stress-related genes daf-16 and skn-1 and their downstream genes (sod-3, hsp-16.2, gst-4 and gcs-1) in C. elegans under flupyradifurone-induced damage. In daf-16 and skn-1 knockout mutants, the treatment of flupyradifurone + lentinan had no significant effect on the expression of downstream genes under flupyradifurone-induced damage. Therefore, it was confirmed that lentinan has a protective effect against the toxicity of flupyradifurone in C. elegans.

3. Applications of C. elegans in Stress Resistance Research

3.1. High Salt Resistance

C. elegans, with a relatively small number of neurons, facilitates the depiction of the neuronal circuits responsible for its behavior, making it a preferred model organism for studying high salt and high osmolarity resistance. Studies by Oliver Hobert have shown that ASE neurons are the primary salt-sensing neurons in C. elegans[23].

Structurally, ASE neurons appear symmetrical on both sides, but they respond asymmetrically to certain stimuli. The left ASE (ASEL) primarily senses Na+, Mg2+ and Li+, while the right ASER (ASER) primarily senses K+, Cl-, Br- and I-. ASEL and ASER respond differently to changes in NaCl concentration: ASEL responds to increases in NaCl concentration, while ASER responds to decreases in NaCl concentration. Additionally, ASH neurons, which are nociceptive neurons, can sense high NaCl concentrations, mediating the avoidance of high concentrations in C. elegans. According to studies by Liu Yu' team, WNK-1 and GCK-3 plays a role in the avoidance of high salt concentrations in the ASH neurons of C. elegans[24]. Furthermore, Thomas J Jentsch and Michael Pusch ClC reported that -Ka/-Kb are plasma membrane Cl channels, whereas ClC-3 through ClC-7 are 2Cl/H-exchangers in endolysosomal membranes[25].

To confirm the role of ASE neurons in sensing NaCl concentration, Hukema RK' team tested the behavioral changes in che-1 and ceh-36 mutant animals[26]. che-1 is primarily expressed in ASE neurons and occasionally in other neurons. The zinc finger protein, similar to the Drosophila GLASS transcription factor, causes che-1 mutants to lack functional ASE neurons due to the absence of the zinc finger protein. ceh-36 encodes an Otx-related homeodomain protein expressed in ASE and AWC neurons, determining the identity of these neurons. The results confirmed that ASE neurons are essential for NaCl chemotaxis.

xrs5 cells (Ku86-deficient) are derived from CHoK1 cells through ethyl methanesulfonate mutagenesis, resulting in the loss of Ku86. Exposure to high concentrations of NaCl causes dramatic morphological changes in xrs5 cells-C. elegans transforms from an epithelial to a fibroblast-like morphology, enlarging, flattening and becoming multinucleated within two days, with the cell cycle permanently arrested. To test whether the cells have senesced, Dmitrieva NI' team stained them to express senescence-associated β-galactosidase (SA-β-gal)[27].

3.2. High Fat Resistance

Obesity is a metabolic disease characterized by the excessive accumulation of fat and triglycerides, leading to overweight and obesity. Excessive lipid accumulation can induce the development of many diseases, such as hyperlipidemia, type 2 diabetes and cardiovascular diseases. Currently, how to effectively prevent and improve obesity and hyperlipidemia is a significant challenge in scientific research.

For example, the hypolipidemic effect of fermented buckwheat was studied. A high-fat model of C. elegans was established using high glucose (10 mmol/L) induction[28]. Perez MA' team found that after intervention with fermented buckwheat, the maximum lifespan of the high-fat worms was significantly increased by 30.90% and their locomotion ability was significantly improved by 28.57%, with an increase in egg production. MDA, a free product of polyunsaturated fatty acid peroxidation in cells, is often used to evaluate the degree of lipid peroxidation and oxidative stress. The higher the MDA content, the more severe the oxidative damage. The results showed that the MDA content in the high-fat model group of C. elegans was significantly higher than that in the control group, indicating that high glucose induction reduces the anti-lipid peroxidation ability of C. elegans. Compared to the high-fat model group, feeding C. elegans with buckwheat and fermented buckwheat significantly reduced the MDA content in high-fat worms, with fermented buckwheat showing the most significant reduction. This may be due to the rich flavonoids, polyphenols and other antioxidants in fermented buckwheat, which show anti-lipid peroxidation effects in high-fat C. elegans, thereby reducing oxidative stress damage. Additionally, fermented buckwheat significantly increased the activity of antioxidant enzymes, reduced MDA content and ROS levels and significantly improved the ability to resist oxidative stress. Moreover, fermented buckwheat significantly reduced the triglyceride and free fatty acid content in high-fat C. elegans, with reductions of 56.58% and 130.54%, respectively. Based on these observations, fermented buckwheats can enhance resistance to oxidative stress and reduce fat deposition.

3.3. Heat Resistance

C. elegans, as a model organism, has been widely used in biological research, including studies on heat resistance. The universally conserved heat shock response regulated by the

transcription factor HSF-1 is considered an effector mechanism, but its role and possible interactions with other cellular processes are still limited. Using C. elegans as a model, Caroline Kumsta's team found that heat treatment induces the overexpression of HSF-1 protein, triggering autophagy. Autophagic genes are also necessary for the protein suppressive effects of HSF-1 overexpression[29]. Studies have shown that the cellular recycling mechanism of autophagy is essential for the beneficial effects of heat stress and HSF-1 overexpression on stress resistance, lifespan and protein aggregation.

Overall, hormonal heat shock and HSF-1 overexpression induce autophagy, improving protein aggregation in vivo, which promotes the healthy lifespan of C. elegans. We propose that the interaction between stress-induced processes may enhance the organism's ability to cope with stress (such as heat and proteotoxicity) and aging.

Another study case involved Panax ginseng. It is a valuable traditional Chinese medicine in Northeast China. The active component, ginsenoside, has not been extensively studied for its effects on aging and its mechanisms. In this study, Xiaoxuan Yu et al. investigated the effects of total ginsenoside (TG), a mixture of primary ginsenosides from Panax ginseng, on the lifespan of C. elegans. They found that TG extended C. elegans' lifespan and reduced lipofuscin accumulation. Additionally, TG increased survival under heat and oxidative stress by reducing reactive oxygen species (ROS). RNA-seq analysis showed that TG is involved in longevity-regulating pathways. qPCR confirmed upregulation of key genes such as nrh-80, daf-12, daf-16, hsf-1 and their downstream targets[30].

3.4. Others Tolerance

Some drugs can mimic various environmental stressors, including oxidative and thermal stress. Therefore, investigating the tolerance of C. elegans to multiple drugs is of significant importance, as it can provide valuable insights into the organism's response to diverse and complex stress conditions.

Chili peppers, with both medicinal and culinary uses, have important research value due to their main active component, capsaicin, which can be used for the prevention and treatment of various diseases. Clinically, capsaicin is mainly used for analgesia in muscle and neuropathic pain. Pain is the most common symptom of many diseases and currently, the variety of analgesics available clinically is limited and most have weak analgesic effects and/or significant adverse reactions such as addiction and tolerance, leading to a large number of patients with pain not receiving effective treatment.

Emerging human pain models are expected to bridge the gap between animal experiments and clinical research in drug development. The capsaicin-induced pain model is a safe, non-invasive model with stable, persistent and reproducible stimulation, capable of producing primary and secondary pain, which can be used to explore the mechanisms of pain, evaluate the efficacy of analgesic drugs and provide more scientific clinical research plans. C. elegans, as a simple biological model, with its transparent body wall and ease of genetic manipulation, makes it an ideal tool for studying the mechanisms of capsaicin perception and capsaicin tolerance.

Research on capsaicin tolerance in C. elegans is still in its initial stages, but this model organism has shown potential in revealing the mechanisms of capsaicin perception. Particularly, by studying the TRPV1 channel in C. elegans, it can reveal the molecular mechanisms of capsaicin perception, providing an important foundation for establishing pain models. TRPV1 is a transmembrane protein that can sense thermal and chemical stimuli such as capsaicin, playing a key role in capsaicin perception and pain transmission. Capsaicin, a transient receptor potential vanilloid subtype 1 (TRPV1) agonist, is a non-selective ligand-gated cation channel. When TRPV1 binds to capsaicin, the channel is activated, causing an influx of calcium ions, increasing intracellular calcium ion concentration, leading to depolarization and activating a series of intracellular signals.

The structure of capsaicin contains a vanillyl group, which can interact with TRPV. Vanilloid receptors play a crucial role in the perception of pain, fever and inflammation and mediate the analgesic effects of capsaicin. Lahaise M's studies have indicated that prolonged exposure to capsaicinoids A (Can A) and B (Can B) can cause desensitization of vanilloid receptors and impair the nociceptive response to noxious thermal stimuli[31].

According to research of Elkhedir A's team, an intake of 50 μg/ml capsaicin-glycoside (CG) effectively protects C. elegans from oxidative, thermal stress and reactive oxygen species (ROS), thereby enhancing the survival rate of the worms under stress[32].

By combining electrophysiological recordings (whole-cell and single-channel) and behavioral analysis of transgenic C. elegans expressing rat TRPV1 (rTRPV1), it has been shown that DkTx induces a unique TRPV1 gating mode, controlled by the turret of the channel pore, leading to different responses at the molecular and behavioral levels[33].

Determining the impact of phosphatidylinositol lipids on TRPV1 function through a combination of genetic anatomy, diet and behavioral, biochemical and functional analyses in C. elegans has shown that when the content of phosphatidylinositol lipids is reduced, TRPV1 activity is enhanced and the C-terminal domain is key to in vivo agonist response[34].

In neurons expressing only OSM-9, the labeled OSM-9 protein resides within the cell body and acts on sensory adaptation rather than sensory transduction. Animals expressing mammalian TRPV1 channels in ASH nociceptor neurons can avoid TRPV1 ligand capsaicin, thereby selectively activating specific behaviors[35].

4. C. elegans in Geriatric Medicine Research

C. elegans as a simple yet well-characterized model system has provided significant insights into the mechanisms of lifespan extension and the identification of bioactive phytochemicals with anti-aging properties. The use of C. elegans in aging research is supported by its short lifespan, ease of genetic manipulation and well-documented developmental and physiological processes[39-47].

4.1. C. elegans as a tool for testing Bioactive Phytochemicals and Their Properties

One of the key areas of research involving C. elegans is the identification and study of bioactive phytochemicals that have the potential to extend lifespan and improve health quality. Okoro et al. (2021) reviewed various bioactive phytochemicals that have been studied in C. elegans, highlighting their roles

in improving health quality and extending lifespan through multiple mechanisms, including antioxidant, anti-inflammatory and neuroprotective effects. These phytochemicals, which can be found in herbs and functional foods, have shown significant potential in mitigating the risk factors associated with aging and age-related diseases[36].

For example, one such promising compound is 3-methyl-3-buten-1-ol (isoprenol). Pandey et al. (2022) demonstrated that isoprenol can extend the mean lifespan of C. elegans by 25% and enhance stress tolerance. The study showed that 0.5 mM isoprenol not only extended the lifespan but also significantly improved the survival of worms under various stress conditions, such as oxidative and thermal stress. The longevity-promoting effects of isoprenol were associated with improved age-associated physiological behavior and reduced intracellular reactive oxygen species (ROS) accumulation[37].

Further, the study revealed that the pro-longevity transcription factors DAF-16 and SKN-1 were involved in the mechanism, with simultaneous over-expression of GST-4 and SOD-3 in isoprenol-treated worms. In silico analysis also indicated the binding affinity of isoprenol with DAF-16 and SKN-1 transcription factors, suggesting a direct interaction and activation of these key regulators of longevity. The involvement of DAF-16 and SKN-1 in the lifespan extension by isoprenol highlights the importance of these transcription factors in mediating the beneficial effects of bioactive compounds.

4.2. C. Elegans as a tool for discovery Molecular Mechanisms

In addition to the identification of specific compounds, recent studies have also focused on the underlying molecular mechanisms that contribute to lifespan extension in *C. elegans*. Lan et al. (2023) explored the translational regulation of non-autonomous mitochondrial stress response, showing that reducing mRNA translation can activate the intestinal mitochondrial unfolded protein response (UPRmt) and AMP-activated kinase (AMPK), leading to synergistic lifespan extension. The study used polysomal profiling to identify translationally regulated ribosomal and cytochrome c (CYC-2.1) genes as key mediators of longevity[38].

Knockdown of cyc-2.1 significantly extended the lifespan of C. elegans by activating UPRmt, mitochondrial fission and AMPK. Interestingly, the germline was identified as the key tissue for cyc-2.1 to regulate lifespan and germline-specific knockdown of cyc-2.1 non-autonomously activated intestinal UPRmt and AMPK. The RNA-binding protein GLD-1, which mediates the translational repression of cyc-2.1 in the germline, was found to be crucial for the non-autonomous activation of UPRmt. This finding underscores the importance of inter-tissue communication and the role of the germline in regulating lifespan.

Aging research in C. elegans has also focused on other critical pathways, such as the insulin/IGF-1 signaling (IIS) pathway and the target of rapamycin (TOR) pathway. Reported by Loboda A et al., Mutations in key components of the IIS pathway, such as the daf-2 gene (which encodes the insulin/IGF-1 receptor), have been shown to significantly increase the lifespan of the nematode. These findings have led to the development of drugs like metformin, which targets the IIS pathway and has been shown to have anti-aging effects in various model organisms, including humans[10].

According to report from McCormick MA et al., the TOR pathway, another critical regulator of aging, controls cell growth, proliferation and survival. Inhibition of the TOR pathway through drugs like rapamycin has been shown to extend the lifespan of C. elegans and other model organisms. Rapamycin works by inhibiting the mTOR (mechanistic target of rapamycin) kinase, which plays a central role in nutrient sensing and cellular metabolism. This inhibition leads to a reduction in protein synthesis and an increase in autophagy, both of which are associated with longevity[47].

One of the most exciting areas of research in C. elegans is the study of dietary restriction and its effects on aging. Lakowski & Hekimi reported that dietary restriction or caloric restriction, has been shown to extend the lifespan of C. elegans and other organisms. This effect is thought to be mediated through several mechanisms, including the activation of stress response pathways, the enhancement of autophagy and the modulation of metabolic processes. Understanding these mechanisms can provide insights into how dietary interventions can be used to promote healthy aging in humans[48].

4.3. Role of the Nervous System in Aging

Alcedo & Kenyon used C. elegans to study the role of the nervous system in aging. Neuronal signaling, particularly through neurotransmitters like serotonin and dopamine, has been shown to play a crucial role in modulating lifespan. For example, increasing the activity of certain neurons in C. elegans can extend lifespan, while reducing their activity can shorten it. These findings highlight the importance of the nervous system in regulating the aging process and open up new avenues for developing interventions that target the brain to promote longevity[49].

4.4. Limitations of C. elegans as a Model Organism

Despite the numerous advantages of using C. elegans in aging research, there are also limitations to consider. Thomas E. Johnson discussed the advantages and disadvantages of C. elegans for future progress in aging research. While the nematode offers a simple and well-characterized model system, it lacks some of the complexity and diversity seen in higher organisms. For example, C. elegans does not have an adaptive immune system and its relatively short lifespan and limited number of cells may not fully capture the intricacies of aging in more complex organisms. Additionally, while many metabolic pathways are conserved between C. elegans and humans, there are still significant differences that must be considered when translating findings from the nematode to human biology[50].

4.5. Summary

In conclusion, C. elegans continues to be a valuable model organism for aging research, providing insights into the mechanisms of lifespan extension and the identification of bioactive phytochemicals with anti-aging properties. The use of C. elegans has led to the discovery of key pathways and interventions, such as the IIS and TOR pathways and the role of bioactive compounds like isoprenol. Additionally, the study of dietary restriction and the role of the nervous system in aging has provided further understanding of the complex processes involved in aging.

However, it is important to recognize the limitations of this model and to complement C. elegans studies with research in

other organisms to gain a more comprehensive understanding of aging and its associated processes. By integrating findings from C. elegans with those from other model systems, researchers can develop more effective strategies to promote healthy aging and extend human lifespan.

5. Conclusion

C. elegans has proven to be an invaluable model organism in various research fields, including aging, toxicology, resistance and capsaicin tolerance. In aging studies, C. elegans has been instrumental in elucidating the mechanisms by which bioactive phytochemicals extend lifespan through the activation of key transcription factors. Additionally, it has provided insights into the role of translational regulation in longevity. In toxicology, C. elegans is widely used for high-throughput screening and toxicity assessments, enabling the rapid identification of compounds with potential adverse effects. In resistance studies, C. elegans helps uncover the genetic and molecular mechanisms that confer resistance to various stressors. Furthermore, its use in capsaicin tolerance research offers valuable insights relevant for pain management.

Despite its limitations, such as the lack of an adaptive immune system, C. elegans remains a powerful tool for initial discoveries. Its well-characterized genetic and physiological processes, combined with its short lifespan and rapid life cycle, make it an ideal system for high-throughput experiments and mechanistic studies. Future research can further leverage C. elegans by integrating advanced technologies, such as CRISPR-Cas9 for precise gene editing, RNA sequencing for transcriptomic analysis and sophisticated imaging techniques. These approaches will enhance our ability to identify novel genes and pathways and provide deeper insights into the biological processes under study. By complementing more complex model systems, C. elegans will continue to play a crucial role in advancing our understanding of aging, toxicology, resistance and capsaicin tolerance.

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