Influence of Abiotic Factors on Efficacy of Entomopathogenic nematodes

Abstract:

Entomopathogenic nematodes (EPNs) are potential biocontrol agents against many insect pests. The infective juveniles (IJs) dwell in soil ecosystem in a free-living state which is responsible for pest suppression under certain environmental condition. These IJs are faced with a wide range of environmental conditions during this stage. Abiotic factors such as temperature, moisture/relative humidity, soil texture and structure, ultraviolet radiationinfluence the survival,growth and development, andreproduction of entomopathogenic nematodes and ultimately their performance on bioefficacy against insect pests.

Key words: Abiotic factors,Biocontrol agents,Bioefficacy,Entomopathogenic nematodes(EPNs),Movement,Reproduction,Survival.

Introduction

Entomopathogenic nematodes(EPNs) in the genera *Steinernema* and *Heterorhabditis* are well known biocontrol agents against a wide range of insect pests.The infective juveniles(IJs) are obligate parasites, dwelling in soil ecosystem.They are associated with a symbiotic bacteria, *Xenorhabdus* (*Steinernema* spp.) and *Photorhabdus* (*Heterorhabditis* spp.), and the nematode-bacterium complex together kills the target insect within 24-48 hrs. They are safe to environment and human, domestic animals and plants, and not inducer of insect resistance. Therefore they are considered as safe alternative to chemical insecticides.However, their efficacy greatly depends on their host range, host finding strategy, and above all they are susceptible to environmental factors.The soil has a highly complex physical, chemical and biotic environment that responds to external environment as well.The majorities of susceptible target pests is within the soil environment and aresupposed to spend at least part of theirlife-cycle in the soil.Thussoil environment influences the EPNs population.

Response of Entomopathogenic nematodes (EPNs) to various abiotic factors

Temperature:

Different species and/or strains of EPNs have different optimum temperatures for survival, movement,reproduction and infection[1].“At low temperature (< 10-15^{o}C), their movement is restricted and at high temperature (>30-40^{o}C) lethal to many species.IJs are non-feeding, depend

on their lipid reserves, which vary (32-38%) in composition amongst EPN species. IJsordauerlarval stage has lower levels of metabolic activity than other stages of their life-cycle.The low temperature induces inactivity in IJs, due to the decreased metabolicactivity. Extreme ambient temperatures can lead to desiccation, increased metabolic rate and as a result more use of lipid reserves by EPNs, which leads to decreased infectivity with shorter reproduction rate of such nematodes"[2]."However, in the soil environment, IJs are generally buffered from temperature extremes depending on soil quality.Optimum temperature range for storage of IJs is 5-15^{o}C.It has been observed thatactivity of steinernematid species is more at lower temperatures than heterorhabditid species. At below 9°C and above 20°C storage of*S.carpocapsae*, the proteins reserves (42-46%) decreased by metabolism, stress and cytoskeleton.Catalase andcopper oxide dismutase, the stress enzymes increased in abundance after storage at low temperature. IJs may enhance their survival in colder conditions by reducing metabolic activities which produce these free radicals by damaging cells and increasing their stress response against them.Some *Steinernema* species are reported to be well-adapted to warm temperaturesof their original habitat, e.g., *S.riobrave*and *S.glaseri"*[3]."Similarly, *H. bacteriophora* (IS-5) which was isolated from the Negev Desert exhibits heat tolerancedue to the presence of heat shock proteins (HSP)"[4]. Shapiro *et al.* [5] improved "a heat tolerant hybrid strain from *H. bacteriophora* (IS-5) and *H. bacteriophora* (Hp88) usingheat shock proteins (HSP) throughgenetic methods and the resulting hybrid strain could able to kill *G. mellonella* larvae at 32°C".In general, freezing temperatures can be tolerated better by the IJs than high temperatures (above 37°C) by usingsome mechanisms[6] like freeze-avoiding mechanism: The sheath of *H. zealandica* prevents the IJ from super-cooling (-32°C) [7];*S. feltiae* and *H. bacteriophora*shows freezing tolerant mechanism[8], and cryoprotective dehydration mechanism[9]. Wright [10]observed that "reproductive rate of many EPNs at low temperature was correlatedwith the bacterial symbiont growth rate e.g. *H.megidis,*and *S.feltiae"*. Tailliez *et al.* [11]observed that "some *Xenorhabdus* species may have become adapted to either tropical or temperate regions as influenced by their nematode host.The following table.1 shows required temperature range for survival, reproduction and infectivity of EPNs and application during conditions within this range will result in better performance".

Table.1.Effect of temperature on survival,reproduction and infectivity of Entomopathogenic nematodes

Entomopathogenic nematodes	Survival	Reproduction	Infectivity	References
Steinernema glaseri	15-30°C	28°C	15-35°C 10-32ºC 0-25°C	[2], [3],[12]
S.carpocapsae *S. carpocapsae* (Pocheon) *S. carpocapsae* (PDBCEM 6.11)	9 - 20°C	20-24°C	10-32ºC 24°C 5-25°C 25-32°C	[2],[13-15]
S. feltiae	15°C	12-25°C 18°C	10-15°C 10^{o}C	[1], [16-19]
S. anomali (= *S. arenarium*),	can tolerate sub-zero temperatures	23 ^{o}C	23 ^{o}C	[20-21]
S. riobrave	35 ºC	20-35ºC	10-39º C 29°C	[21-22]
S. siamkayai Thailand strain *S. siamkayai* Tiruchirappalli strain	25-30 ºC	25-30ºC 20-35ºC	25-30ºC 37.5°C	[11] ,[23]
S. scapterisci	In warm climates	20-32 ºC	30ºC	[24]
H. bacteriophora	-19 -30°C	15 - 30ºC	10ºC-35ºC	[21] [25-26]
H. zealandica	15-30°C	15-30°C	15-30°C	[27-28]
H. megidis	9- 20°C	15-25°C	15°C 29°C	[2-3] ,[29-30]
H. merelatus	Warm climate	29°C	29°C	[2-3],[30]

Moisture:

Moisture or relative humidity levelis the most important abiotic factor influencing EPN population behaviorwhich may vary among nematode species and isolates in different soil types [31-32].Moisture also influences aeration of soil.EPNrequire adequate soil moisture levels for their survival, movement and infectivity[33].Under low moisture condition,some species viz.,*Steinernema*spp. reduce their body surface area by lowering their rate of metabolism, the survival strategy is known as anhydrobiosis.*S.carpocapsae* and *S.glaseri* survival was good at

low soil moisture of 2 and 4% respectively [3].Gradual water removal from the infective juveniles gives them time to adapt to the water lossconditions and thereby nematodes are resistant to desiccation.Natural soils are such kind of soil that allows the IJs to persist longer time.IJs may survive in desiccating conditions inside the host cadaver until the favorable soil moisture situation arise[34].In order to minimize desiccation,spraying should be done during the evening and using supplemental wetting before and after application by using irrigation or rainfallthat helps inrecovery of nematode infectivity and virulence [38]. For movement nematodes need a water film in soil pore. In saturated soil,oxygen levels decrease and nematode movement is restricted[35,36].“Several studies indicate that soil moisture also influences the bioefficacy of EPNs. There must be a continuous filmof water between nematode and targetinsect forinfection to occur. Nematode infectivity is highest at moderate soil moistures (−10 to −100 kPa), and lower in wet (−1 kPa) and dry (−1000 kPa) soil”[37].“Infectivity of *H. bacteriophora*, *S. carpocapsae*, *S. feltiae,* and *S. glaseri* increased with moderate soil moisture in sandy loam soil”[39].Similarly,*H. bacteriophora*DI and *S. glaseri* KG [40] and *S. glaseri* NC and *S. carpocapsae* ALL [35]showed lower infectivity in low and high soil moistures. Studies have also shown that *H.bacteriophora* is less susceptible on *Popillia japonica* 3rd instar as the season changes from rainfall to spring [41]. Under high humidity (RH) and moderatetemperature,*S. virgalemense* is highly susceptible to female *Planococcus ficus* and mortality rate of *P.ficus* decreases with decreasing relative humidity levels[42].At least 8-24 h of RH(> 90%) is necessary for infection in case of above ground pests. Both inoculative and inundative application of IJs will work properly in habitats with high relative humidity. EPN formulation also requires suboptimal moisture level.Nematodelife span increases when the nematode enters in a state of partial anhydrobiosis.Irrigation or rainfall can rehydrates formulatednematodes and they resume function as virulentindividuals, ready to be applied in the field.

Soil texture and structure

Texture of soil is decided by the proportion of sand, silt and clay inherited by it during its formation. Soil structure determines the number, size and distribution of pore spaces in soil crumbs.These pores are partly or wholly filled with soil moisture.Soil texture and structure can have various effects onEPNs.Movement [43], infectivity of IJs[44]and survival or persistenceof IJ[45]are positively correlated with soil structure[37].In general,nematode movement and

survival is better in sandy soils, whereas survival rates are poor in clay soils because of reduced aeration in the small soil pores [24].*H. bacteriophora*, *S. carpocapsae*, and *S. glaseri*survival and movement weremore in sandy loam than silty clay loam soils.Similarly, bulk density of soil also influences survival and infectivity of nematodes e.g., survival of *H. bacteriophora* decreased,and survival of *S. glaseri* increased withbulk density.The infectivity of *S. carpocapsae* increased but did not vary for *H. bacteriophora* and *S. glaseri.*Establishment of EPNs may vary with species and isolate with different soil type. Koppenhofer *et al*., [46] reported that "establishment of *S. scarabaei* was more in sandy loam soil compared to clay loam soil". Campos-Herrera and Gutiérrez [47] observed that "infection behavior varied among 14 different populations of *S. feltiae* in the same soil texture". Shelmith *et al*., [48]observed that "survival of *S. karii* was 22-67%, with the highest occurrence being in clay soil, moderate in sandy clay and clay loam and the lowest being in the sandy clay soil".Campos-Herrera and Gutiérrez [49] observed that"virulence of the Rioja isolate of *S. feltiae*negatively affected mortality of*Spodoptera littoralis* larvae in heavy soils".The proportion of organic matter (OM) content in the soil along withmineral component affects nematode movement asOMcontent of soil improves soil structure, loweringbulk density, increasing the available space throughthe distribution of aggregates and pore size, thusOM content and soil compaction may influenceEPNs infection behavior[50], andpersistence in the soil [51]. Therefore, knowledge about soil structure and texture requirement of an EPN species/isolate is critical to optimizing their performance as biological control agents in the field.

Salinity

Soil salinity has aninsignificant effect on IJs survival.EPNs appear to tolerate a wide range of salinities. Several *Heterorhabditis* species/strainshave been isolated from soils near the seashore; thereforeseawater has no negative impact on the survival of IJs. However, tillage and herbicide applications suppress EPN numbers, the movement of EPNs is restricted and their ability to find and recognize their host is reduced. Bednarek [52] observed that application of mineral fertilizers had negative impact on EPN population density. $CaCl_2$and KCI had no effect on the survival, movement orpenetration behaviour of*H. bacteriophora* but moderate concentrations of these salts may enhanced the virulence. Although seawater has no negative effect on IJs, high concentrations of NaCl, $CaCl_2$, and KCl inhibit themovement and infectivity of *S. glaseri* [40].

Oxygen and pH

Oxygen is also a limiting factor on EPN population behavior, low oxygen level that can occur in water-saturated soils, clay soils (because of small pores) and soils with high organic matter content. As far as EPNs as a formulated product is concerned, the presence of interstitial spaces in formulations is beneficial to such nematodes, as it supports gas exchange. Soil moisture and aeration affect the soil pH. IJs can survive in a wide range of pH. Soil pH between 4 and 8 did not have an adverse effect on IJ survival, but a pH of 10 or higher was harmful. Kung *et al*., [53] observed in laboratory trials that pH 10 reduced steinernematid nematodes survival. *S.bicornutum* was found only in neutral soils, and *S. silvaticum* only in acidic environments[54].

UV radiation

UV radiation effect on the survival, virulence, or reproduction of EPNs. Shapiro-Ilan *et al.* [55] investigated "UV tolerance of nine different EPN species and fifteen strains for survival and virulence. Their results showed that there was a significant variation in UV tolerance among EPN strains and species. Steinernematidscommonly displayed higher levels of UV tolerance compared with the heterorhabditids. Furthermore, it has been reported that shorter wavelengths (254 nm) had a negative effect on virulence compared to longer wavelengths (366 nm)".

Conclusion

For successful utilization of EPNs, ecology of the target pest should match with the activity of IJs. Therefore, a better understanding of ecological strategies of IJs for its efficiency in biological control in the local agro-climatic conditions is needed. However, nematode establishment in adverse environment is based on IJs behavioural and physiological adaptation.The impact of temperature or moisture on EPN efficacy can be changed, by choosing the right EPN strain and applying these nematodes at the right time of the year, or postponing application until temperatures or moisture are optimal for the specific EPN strain used.The biological study of EPNs is advancing rapidly. Isolation and description of new species and described species still need to be studied in detail for their potential use as biological control agent.Thus the selectivity and safety of these biocontrol agent by minimizing their effects on other biocontrol agents and will facilitate their incorporation into IPM programsand ultimately contribute to the chemical-free management of many kind of target insect pests.

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