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Spider Distribution and Seasonal Incidence in Onion Ecosystems: A Study in West Bengal's Red Lateritic Zone

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Abstract
Background: Biological control using spiders is an effective method to reduce dependence on chemical pesticides and manage insect pests in onion crops. This study aimed to investigate the seasonal occurrence and distribution patterns of spiders in the onion fields of Sriniketan, West Bengal, India, during the rabi season of 2021-22. To monitor the seasonal presence and spread of spiders, weekly field inspections were conducted. Various dispersion indices, including mean, variance, variance-mean ratio, dispersion parameter 'K,' David and Moore's index, Lexis Index, Charlier coefficient, Index of dispersion, and Lloyd mean crowding index, were calculated using pooled data to analyze the distribution pattern of the predatory spiders.
Results: The spider population peaked in the fourth week of January and the second week of February, reaching about 2.71 spiders per plant. Dispersion indices confirmed a clumped distribution pattern, with the highest values observed during periods of moderate temperatures and high relative humidity. This aggregative distribution suggests that spiders cluster in specific areas within the onion fields, influenced by abiotic factors.
Conclusion: The study demonstrated that spiders exhibit an aggregated distribution pattern in the onion ecosystem, influenced by abiotic factors. This finding supports the implementation of integrated pest management (IPM) strategies that enhance natural predator populations, such as spiders, to reduce pest incidence and minimize chemical pesticide use. The results advocate for an IPM framework that integrates habitat management to create optimal conditions for natural predators, contributing to sustainable agriculture.

Keywords: Onion, Spiders, Biological control, Dispersion indices, Integrated Pest Management (IPM), Aggregated distribution, Abiotic factors, Sustainable agriculture

Background

Onion (Allium cepa L.), a member of the Alliaceae family, is widely considered the most significant crop globally, serving both as a vegetable and a spice. The onion bulb, utilized as a spice, contains minerals such as phosphorus (39 mg), calcium (27 mg), sodium (1.0 mg), iron (0.7 mg), and potassium (157 mg), along with carbohydrates (11.0 g), proteins (1.2 g), fiber (0.6 g), moisture (86.8 g), and several vitamins, including vitamin A (0.012 mg), vitamin C (11 mg), thiamine (0.08 mg), and riboflavin (0.01 mg) (Suresh, 2007) [93]. Chemical methods can eradicate onion insect pests, but controlling them in crops poses a challenge. Moreover, various regions have reported pesticide resistance due to the indiscriminate use of chemicals for pest control (Rueda and Shelton, 1995) [94]. The misuse of chemical pesticides adversely affects ecosystems, human health, and beneficial insects/pests (Rola and Pingali, 1993; Antle and Pingali, 1994; Tjornhom *et al*., 1997) [95, 96, 97]. Due to their vulnerability to a wider range of diseases and pests compared to other crops, the improper use of chemical pesticides in vegetable crop production is more pronounced (Tjornhom *et al*., 1997) [97].

Spiders, belonging to the class Arachnida and the phylum Arthropoda, have distinct characteristics, including a divided body into the abdomen and cephalothorax, which features four pairs of legs and is tougher than the relatively soft, unsegmented abdomen (Palem *et al*., 2017) [98]. Being carnivorous, they prey on insects and other terrestrial creatures

(Dharmaraj *et al*., 2018) [99]. Without teeth, spiders consume their prey in liquid form. They use chelicerae, pointed appendages located in front of the cephalothorax, to catch prey and inject venom (Cohen, 1995) [100]. Digestive enzymes further liquefy the prey. Biological control using spiders is an effective method to reduce the need for chemical pesticides and manage insect pests. For example, Lang *et al*. (1999) [101] reported that spider populations in maize crops gradually reduced insect pests such as thrips, aphids, and leafhoppers. Similarly, spiders from the Lycosidae family were found to significantly reduce the population of plant-sucking insects in tropical rice paddies (Fagan *et al*., 1998) [102]. Spiders are noted for their predatory capabilities, including a high kill rate per unit time and excellent hunting skills.

Spiders are generally considered polyphagous predators, which has led to doubts about their efficiency in pest control (Debach and Rosen, 1991) [103]. However, in China, these invertebrate predators are preserved to combat specific pests (Zhao, 1993) [104]. Additionally, in Israeli and European apple orchards, spiders have been found to significantly reduce insect damage to crops (Mansour *et al*., 1980; Marc, 1993) [105, 106]. Marc and Canard (1997) [107] redefined the role of spiders in agroecosystems, noting that they can be regarded as specialist predators based on their hunting strategies and habitat. Thus, not all spider species are effective against every insect, but maintaining their diversity is essential for managing various pests. Different functional groups can be identified by analyzing the hunting techniques, biological cycles, and environmental localization of spider communities in vineyards (Isaia *et al*., 2006) [108] and orchards (Marc, 1993) [106]. This affects the type of prey consumed. For example, in orchards, nocturnal wandering spiders such as Anyphaena accentuata (Anyphaenidae), Clubiona brevipes, C. corticalis, and C. leucaspis (Clubionidae) effectively target non-flying aphids and Lepidoptera larvae. Diurnal wandering species like Ballus depressus (Salticidae) prey on non-flying aphids and Cicadellidae, while ambush species such as Philodromus aureolus (Philodromidae) and Diaea dorsata (Thomisidae) target adult and larvae of Hymenoptera and Lepidoptera.

The black and yellow garden spider, Argiope aurantia Lucas, is a common orb-weaving spider found in the eastern United States, the west coast of North America, and Central America. This species inhabits various environments, including dense perennial vegetation, dry grassy hillsides, vegetable gardens, roadside margins, deciduous woodlands, and areas near ponds, streams, and swamps. Observations have detailed the distribution, systematics, and general life behaviors of A. aurantia and related species. It has been demonstrated that wandering spiders are crucial in maintaining herbivore populations in agricultural fields, including Cicadellidae, Thysanoptera, and Aphididae (Lang *et al*., 1999) [101].

Integrated Pest Management (IPM) promotes reducing chemical pesticide use and increasing non-chemical control measures due to the known environmental and health risks associated with chemical pesticides. A natural ecosystem comprises the dynamic interplay of biotic and abiotic components in a specific space. Biotic elements include plants, insects (pests, decomposers), microorganisms, and other living things, while abiotic elements encompass climatic factors such as temperature, relative humidity, wind, sunshine, rain, and soil. Each component in the system has unique properties and functions that influence the distribution and population of living organisms over time and location. However, improper pesticide use disrupts this equilibrium by killing other organisms and natural enemies and reducing soil fertility. Therefore, the present investigation was conducted to understand agroecology within an agricultural ecosystem.

The spatial distribution of natural enemies helps to recognize the pest–natural enemy relationship in the field. Natural enemies, such as parasitoids and predators, can spread out and locate high pest concentration areas in a field. Understanding the spatiotemporal dynamics of pests and their natural enemies is crucial for the conservation and release of biological agents in the field, as biological management is more successful with a spatiotemporal overlap of prey and natural enemies. Despite the usefulness of spatiotemporal distribution tools in understanding pest and natural enemy ecology, few studies have explored the spatiotemporal associations of pests and their key natural enemies.

The spatial distribution of natural enemies can be characterized using various methods, including the variance-mean ratio, dispersion parameter 'K,' David and Moore’s index, Lexis Index, Charlier coefficient, Index of dispersion, and Lloyd mean crowding index. Each method has strengths and weaknesses, and combining these methods is recommended in ecological studies. In onion fields, important natural enemies like hover flies, ladybird beetles, dragonflies, damselflies, and spiders prey on major insect pest complexes. These predator groups play a vital ecological role in balancing prey–natural enemy dynamics in onion fields. Therefore, this study aimed to characterize the population, spatial, and temporal distribution of spiders in the onion ecosystem and develop a comprehensive sampling plan for their population assessment.

Materials and Methods

A field experiment was conducted to study the seasonal incidence and distribution pattern of insect pests on onion during the rabi season of 2021-22. This research took place at the Horticulture Research Farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, West Bengal, located at 23.24º North latitude and 87.42º East longitude, with an elevation of 40 meters above mean sea level. Throughout the crop's growing season, all recommended agronomical practices were followed, except for plant protection measures. In the second half of November, one-month-old seedlings of the Sukh Sagar variety were transplanted into plots, maintaining a row spacing of 40 cm and plant spacing of 30 cm.

Data Collection

Observations of the population buildup of natural enemies were conducted in situ using a random sampling technique, selecting 10 plants at random from each of the 21 plots. Data were gathered from three leaves per plant, representing the top, middle, and bottom canopies. These observations were made weekly, starting from the 51st standard meteorological week to the 11th standard meteorological week, with consideration of specific weather parameters during the crop growth period. All weather data, including temperature, relative humidity, rainfall, and sunshine hours, were obtained from the Meteorological Office in Sriniketan, Bolpur, West Bengal.

Statistical Analysis and Calculation

In this study, we recorded the insect populations within the agroecosystem to assess the prevalence of insect pests and their natural enemies on crops. The collected data were analyzed using Microsoft Excel 2010 to compute averages, means, and graphical representations. The data were then organized into a frequency distribution with several indices such as mean ($\bar{X}$), variance (S^2), variance-mean ratio ($S^2/\bar{X}$), dispersion parameter 'K' [$\bar{X}^2 / (S^2 - \bar{X})$], David and Moore's index [$(S^2 / \bar{X}) - 1$], Lexis Index [$\sqrt{(S^2 / \bar{X})}$], Charlier coefficient [$\sqrt{(S^2 - \bar{X})} / \bar{X}$], Index of dispersion [$(n-1) * (S^2 / \bar{X})$], and Lloyd mean crowding index [$\bar{X} + \{(S^2 / \bar{X}) - 1\}$], as per the procedure outlined by Elliot (1977). The degree of crowding experienced by individuals was calculated using Lloyd's method (1967) and is presented as Lloyd's index of mean crowding [$\bar{X} + \{(S^2 / \bar{X}) - 1\}$] and Lloyd's index of patchiness [$\bar{X} + \{(S^2 - 1) / \bar{X}\}$].

i) Ratio of Variance to Mean (VMR)

The simplest method for calculating insect dispersion is the variance to mean ratio (VMR), proposed by Patil and Stiteler (1974). VMR = $S^2 / \bar{X}$, where S^2 is the variance and $\bar{X}$ is the mean. For a Poisson distribution, VMR equals 1; for a positive binomial distribution, it is less than 1; and for a negative binomial distribution, it is greater than 1. Values greater than 1 indicate a clumped distribution, less than 1 indicate regular distribution, and equal to 1 indicate random distribution.

ii) David and Moore's Clumping Index (IDM)

The clumping index (IDM) by David and Moore (1954) confirms the distribution pattern using the formula IDM = $(S^2 / \bar{X}) - 1$. For a Poisson distribution, IDM returns a value of zero, while for a negative binomial distribution, it returns a positive value.

iii) The Lexis Index

The Lexis Index is calculated using the formula $\sqrt{(S^2 / \bar{X})}$ to determine the dispersion of natural enemies. The index values indicate >1 for clumped distribution, 1 for random distribution, and <1 for regular distribution.

iv) Dispersion Index (ID)

Patil and Stiteler's "Index of Dispersion" (1974) confirms the distribution pattern. ID = $(n-1) * (S^2 / \bar{X})$, where n is the number of samples drawn, and ID is the dispersion index.

v) Mean Crowding Index (X*) According to Lloyd

Mean crowding (X*), as suggested by Lloyd, illustrates the expected impact of interpersonal rivalry or interference (1967). The formula for mean crowding (X*) is $X^* = \bar{X} + \{(S^2 / \bar{X}) - 1\}$, where values greater than zero indicate an over-distributed or regular distribution, and values less than one indicate an under-distributed distribution. Mean crowding heavily depends on the indexes of clumping intensity and population density.

Result and Discussion

Spider Population Dynamics

The spider population (Table-01) was first observed in the third week of December (51st SMW), with approximately 1.29 spiders per plant. During this period, the abiotic conditions included a maximum temperature of 23.67°C, a minimum temperature of 10.33°C, relative humidity at 79%, no rainfall, and 6.24 hours of sunshine. The highest spider population was recorded during the fourth week of January and the second week of February, reaching about 2.71 spiders per plant. The abiotic conditions at this peak were a maximum temperature of 22.26°C and 21.29°C, minimum temperatures of 13.8°C and 12.94°C, relative humidity levels of 86.29% and 85.86%, rainfall of 0.77 mm and 6.8 mm, and sunshine hours of 2.79 and 5.44, respectively. The second highest spider population was observed in the first week of February (5th SMW) with about 2.43 spiders per plant. During this period, the maximum temperature was 21.31°C, the minimum temperature was 8.9°C, relative humidity was 71.86%, there was no rainfall, and there were 4.84 hours of sunshine.

Table 1: Seasonal incidence of Spider (Araneae: Araneidae) seen on onion ecosystem with respect to certain abiotic parameters during the year 2021-22

Standard Week	Population of Spider/ Plants	Important Weather Parameters As Recorded During The Respective Standard Week				
		Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Rain Fall (mm)	Sunshine Hours
51st	1.29	23.67	10.33	79	0.0	6.24
52nd	1.57	24.53	13.74	89.14	0.34	2.64
1st	1.86	23.27	10.47	93	0	5.74
2nd	2.14	24.24	14.56	92.14	2.7	2.04
3rd	2.43	22.43	10.77	87.14	0	6.11
4th	2.71	22.26	13.8	86.29	0.77	2.79
5th	2.43	21.31	8.9	71.86	0	4.84
6th	2.71	21.99	12.94	85.86	6.8	5.44
7th	2	24.5	11.67	77.86	3.22	8.69
8th	1.14	27.69	13.76	74.29	0	7.27
9th	1	28.65	17.33	84.75	5.53	7.25

Table 2: Spatial distribution pattern of Spider (Araneae: Araneidae) in Onion ecosystem in red lateritic zone of West Bengal (2021-22)

Sl. no.	Standard week	Mean ($\bar{X}$)	Varience (S^2)	Varience -mean ratio ($S^2/\bar{X}$)	Dispersion parameter 'K' {$\bar{X}^2/(S^2-\bar{X})$}	Reciprocal of K (=1/K)	David Moore's index {$(S^2/\bar{X})-1$}	Lexis index $\sqrt{(S^2/\bar{X})}$	Index of dispersion {$(n-1)(S^2/\bar{X})$}	Charlier coeeficient [100 {$\sqrt{(S^2-\bar{X})}$}/ $\bar{X}$]	Lloyd mean crowding index [$(\bar{X})+\{(S^2/\bar{X})-1\}$]	Llyod patchiness index [$\bar{X}+\{(S^2/\bar{X})-1\}$]/ $\bar{X}$
1	51st	1.29	1.57	1.22	5.94	0.17	0.22	1.10	7.30	41.02	1.51	1.17
2	52nd	1.57	1.62	1.03	49.30	0.02	0.03	1.02	6.19	14.24	1.60	1.02
3	1st	1.86	2.14	1.15	12.36	0.08	0.15	1.07	6.90	28.45	2.01	1.08
4	2nd	2.14	2.33	1.09	24.10	0.04	0.09	1.04	6.53	20.37	2.23	1.04
5	3rd	2.43	2.95	1.21	11.36	0.09	0.21	1.10	7.28	29.68	2.64	1.09
6	4th	2.71	3.57	1.32	8.54	0.12	0.32	1.15	7.90	34.22	3.03	1.12
7	5th	2.43	3.24	1.33	7.29	0.14	0.33	1.15	8.00	37.04	2.76	1.14
8	6th	2.71	3.9	1.44	6.17	0.16	0.44	1.20	8.63	40.25	3.15	1.16
9	7th	2	2.67	1.34	5.97	0.17	0.34	1.16	8.01	40.93	2.34	1.17
10	8th	1.14	1.48	1.30	3.82	0.26	0.30	1.14	7.79	51.15	1.44	1.26
11	9th	1	1.67	1.67	1.49	0.67	0.67	1.29	10.02	81.85	1.67	1.67

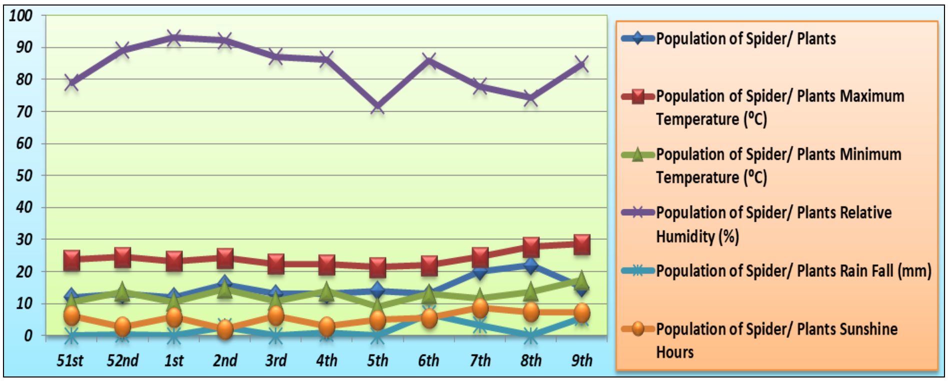

Fig 1: Incidence of Spider (Araneae: Araneidae) influenced by different abiotic factors in onion ecosystem of red lateritic zone (2021-22)

Confirmation of negative bionomial distribution of spider population

Index of dispersion

Index of dispersion(Id) value generally depart from unity i.e the values of this index were 7.30, 6.19, 6.90, 6.53, 7.28, 7.90, 8.00, 8.63, 8.01, 7.79 and 10.02 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively. The Index of Dispersion (ID) values for the spider population across different standard meteorological weeks (SMW) were consistently greater than one. This indicates a non-random, aggregated distribution pattern of the spider population. The ID values ranged from 6.19 to 10.02, significantly deviating from unity, which would denote a Poisson distribution. These results substantiate the aggregative distribution of spiders throughout the study period, confirming that spiders tend to cluster rather than distribute randomly across the onion fields.

Dispersion parameter "K"

'K' of the negative binomial is an index of aggregation in the population and the present observed values for most of the week's found to be either below 8 or slightly exceeding 8 indicating clumping behaviour of individuals. However, the findings were 5.94, 49.30, 12.36, 24.10, 11.36, 8.54, 7.29, 6.17, 5.97, 3.82, and 1.49 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively. In this study, the "K" values were mostly below or slightly above 8, further confirming the clumped distribution of the spider population. The observed values ranged from 1.49 to 49.30. According to Southwood (1978), 'K' values under 8 typically indicate aggregation, and our findings align with this theory, showing a tendency for spiders to aggregate in specific areas of the onion fields.

Reciprocal of "K"

Reciprocal of 'K' were found to be more than zero with positive sign for all the weeks. The range of this parameter was 0.17, 0.02, 0.08, 0.04, 0.09, 0.12, 0.14, 0.16, 0.17, 0.26, and 0.67 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively which implied contagious nature of distribution of spider (Araneae: Araneidae) on the red lateritic zone.

David and Moore's index

David and Moore's index signifies regularity in distribution when the values lies below zero but in the above experiment the calculated values always found to be more than zero i.e. 0.22, 0.03, 0.15, 0.09, 0.21, 0.32, 0.33, 0.44, 0.34, 0.30, and 0.67 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively. The values ranged from 0.03 to 0.67, reinforcing the conclusion that the spider population exhibited a non-random, clumped distribution pattern. These positive values are indicative of an aggregated distribution, further supporting the findings from the other indices.

Lexis index

Lexis index calculated was more than one in all the weeks i.e. all values departed towards positive side from the unity. The pooled values of this parameter were 1.10, 1.02, 1.07, 1.04, 1.10, 1.15, 1.15, 1.20, 1.16, 1.14, and 1.29 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively. The pooled values for this parameter ranged from 1.02 to 1.29 across the weeks, suggesting that the spider population followed a non-random, aggregated distribution pattern. The positive departure from unity highlights the tendency of spiders to cluster in certain areas of the onion fields.

Charlier coefficient index

The Charlier coefficient index, which would be imaginary in the case of a regular distribution, was found to be significantly greater than zero in this study. This indicates a contagious nature of the spider distribution. The positive values of the Charlier coefficient further confirm that the spider populations were clumped rather than evenly or randomly distributed.

Mean Crowding Index

The Mean Crowding Index (X*) values for the spider population in the onion ecosystem varied significantly across different standard meteorological weeks (SMW), indicating dynamic aggregation behavior. Starting at 1.51 in the 51st SMW, the index peaked at 3.15 in the 6th SMW, reflecting high population density and optimal environmental conditions, including moderate temperatures and high relative humidity. The values then declined to 1.44 by the 8th SMW, suggesting dispersal due to resource depletion or changing conditions, before stabilizing at 1.67 in the 9th SMW. These trends highlight the importance of maintaining favorable habitats and prey availability to support natural predator populations for effective integrated pest management (IPM) in onion cultivation.

Lloid patchiness index

The Lloyd patchiness index reflects the degree of aggregation within a population.The range varied from 1.17, 1.02, 1.08, 1.04, 1.09, 1.12, 1.14, 1.16, 1.17, 1.26, and 1.67 for 51st SMW, 52nd SMW, 1st SMW, 2nd SMW, 3rd SMW, 4th SMW, 5th SMW, 6th SMW, 7th SMW, 8th SMW and 9th SMW respectively. In this study, the values for this index varied from 1.02 to 1.67, supporting the conclusion that the spider distribution was aggregative. These values indicate that spiders were more likely to be found in patches rather than being evenly distributed across the onion fields.

Conclusion

The comprehensive study conclusively demonstrated that the spider population within the onion ecosystem exhibits an aggregated distribution pattern throughout the entire growing season. This distinct clustering behavior is significantly influenced by various abiotic factors, with spider populations peaking during periods characterized by favorable weather conditions such as moderate temperatures, high relative humidity, and sufficient sunshine hours. The statistical analysis, utilizing multiple indices, consistently confirmed the non-random, aggregative nature of the spider population, highlighting the intricate relationship between environmental conditions and spider distribution. These findings have profound implications for integrated pest management (IPM) strategies in onion cultivation. The presence of a substantial spider population suggests that maintaining and enhancing natural predator populations could be a crucial component in reducing pest incidence and, consequently, minimizing the reliance on chemical pesticides. The observed aggregation of spiders in specific areas within the onion fields indicates that targeted conservation practices could be effectively implemented to support these natural enemies. By fostering a favorable environment for spiders and other natural predators, farmers can enhance biological control mechanisms, leading to more sustainable and environmentally friendly pest management practices.

The significance of these results extends beyond immediate pest control benefits. Promoting the conservation of natural predators like spiders can contribute to long-term ecological balance within agricultural ecosystems. This approach not only helps in managing pest populations but also supports biodiversity, soil health, and the overall resilience of the farming system. The study's findings advocate for an IPM framework that integrates habitat management, such as maintaining vegetation diversity and avoiding indiscriminate pesticide use, to create optimal conditions for natural predators. Moreover, understanding the aggregative distribution of spiders can help in developing precise monitoring and management practices. Farmers can use this information to identify key areas within their fields where natural predator conservation efforts should be concentrated. Such targeted interventions can optimize the effectiveness of biological control, reducing the need for chemical inputs and promoting a healthier agricultural environment.

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