OPEN ACCESS
Scholars International Journal of Biochemistry
Abbreviated Key Title: Sch Int J Biochem
ISSN 2616-8650 (Print) | ISSN 2617-3476 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Insecticide Resistance Management against Pea Aphid (*Acyrthosiphon pisum*) on Grass Pea (*Lathyrus sativus*) in the North Western Part of Ethiopia

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DOI: https://doi.org/10.36348/sijb.2024.v07i07.002 | **Received:** 08.10.2024 | **Accepted:** 14.11.2024 | **Published:** 16.11.2024

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Abstract

This study evaluated the effectiveness of rotational and single insecticide applications against pea aphids on grass pea crops in the Dera and Fogera districts of Northwestern Ethiopia from 2021 to 2022. Experimental plots measured 2 m × 4 m and utilized a randomized complete block design with four replications. Insecticides profenophos, imidacloprid, λ-cyhalothrin and dimethoate were applied in rotation (P-I-L-D) and individually. It was found that all insecticide treatments reduced the numbers of pea aphids significantly. Treatment impacts on pea aphid populations, for example, were significant in Fogera in 2021 [$F(5,18) = 34.924$, $p<0.001$ in Week 2 and 93.250, $p<0.001$ in Week 3]. In 2022, similar trends were observed [Week 2: $F(5,18) = 45.419$, $p<0.001$ at Dera]. Grain yield also increased significantly with insecticide treatments, with the highest yields from dimethoate and rotational applications [Fogera 2021: $F(5,18) = 48.154$, $p<0.001$]. Cost-benefit analysis indicated that despite higher initial costs, treatments with dimethoate and rotational applications provided the highest net benefits due to their superior effectiveness in pest control and yield improvement. These findings underscore the importance of integrated pest management strategies, including rotational use of insecticides, to manage pea aphid populations effectively while enhancing grain yield and economic returns. In conclusion, implementing rotational insecticide strategies alongside Dimethoate application is recommended to sustainably manage pea aphids in grass pea crops.

Keywords: Grass Pea, Insecticide Resistance Management, Pea Aphid, Rotational Application of Insecticide.

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INTRODUCTION

Ethiopia's agricultural landscape is significantly influenced by pulse crops, and the sector is vital to the national economy. Particularly in the Amhara area, pulse crops such as field peas, faba beans, chickpeas, grass peas, haricot beans and lentils are vital to Ethiopian agriculture. Despite comprising merely 9% of Ethiopia's pulse crop land, grass peas rank third in importance among the region's farmed pulse crops, following chickpeas and faba beans. Furthermore, climate change, land degradation, lack of integration and technical developments are some of the issues Ethiopia's agriculture industry faces, all of which have an influence on productivity and overall agricultural performance (Keba and Mohammed, 2023; Li *et al.*, 2023).

But eating grass peas, especially in the highlands of Ethiopia, comes with serious health hazards. One such risk is lathyrism, which is most common in the Amhara area (Haimanot *et al.*, 1990). Despite these health concerns, grass pea remains a crucial crop for farming communities, with farmers continuing to allocate land resources to its production.

Several elements significantly influence grass pea production in Ethiopia, including environmental conditions, pest and disease management, socioeconomic factors, cultural practices, genetic diversity, policy and institutional support and climate change (Tadesse and Bekele, 2001). The agricultural landscape is shaped by several elements combined, which have an impact on crop growth, yield and sustainability. To increase the productivity and resilience of grass pea farming systems, effectively manage them, make well-informed decisions and implement policy changes are necessary. This would improve food security and the standard of living in Ethiopia.

Numerous research works have examined various management approaches for managing pea aphids in various geographical areas. Investigated research on the effectiveness of natural enemies and sticky traps in managing aphid populations in urban green spaces highlighted the potential of non-pheromone traps and existing natural enemies for control (Grozea *et al.*, 2023). A research conducted field experiments in Canada to optimize pea aphid control on lentils, emphasizing the efficacy of insecticides like lambda-cyhalothrin in reducing aphid populations (Zhou *et al.*, 2023). Plant defenses against aphids revealed how pea aphids can suppress forisome dispersion in legumes, potentially through differences in aphid saliva composition (Mitku *et al.*, 2019; Paulmann *et al.*, 2023). Experiment identified pea lines with resistance to pea aphids, suggesting the use of resistant lines in breeding programs to target genomic regions linked to aphid resistance (Rahman *et al.*, 2023). Using alternative techniques and educating farmers about efficient pest control procedures are key components of integrated pest management strategies for managing aphids on grassy field crops (Ghaith *et al.*, 2023).

Despite the fact that Ethiopian farmers only use insecticides to control pea aphids on grass pea, the careless application of these substances upsets the equilibrium of the environment and promotes the emergence of resistance (Arulkumar *et al.*, 2022). Many chemical types, such as carbamates, pyrethroids, organochlorines, organophosphates and spinosyns, have been linked to insecticide resistance (Wang and Wang, 2024).

By preventing the emergence of insecticide resistance, preserving pest control effectiveness and reducing environmental impact, pesticide rotational application is essential to sustainable pest management (Dubey *et al.*, 2023). Rotational treatment lessens the selection pressure on pests by switching up the classes or modes of action of insecticides. This delays the establishment of resistance and prevents the gradual accumulation of resistant pest populations (Dubey *et al.*, 2023). Additionally, by focusing on a wider range of pest species, this tactic helps stop the resurgence of particular insect populations that may have grown resistant to a particular pesticide (Siddiqui *et al*., 2022). Rotational administration of chemical treatments also minimizes negative impacts on non-target creatures, including as pollinators and beneficial insects and lowers the danger of environmental pollution. All things considered, maintaining the long-term efficacy of pest management techniques and guaranteeing the sustainability of agricultural practices depend on the cyclic use of insecticides.

Further research focusing on rotational insecticide applications for pea aphid management in grass pea crops in Ethiopia is warranted to enhance pest control strategies and minimize crop damages. Therefore the experiment is initiated with the objective of evaluate the effectiveness of the rotational application of insecticides and the use of different single insecticides against pea aphids on grass pea crops, specifically focusing on their impact on pest control and crop yield.

MATERIAL AND METHODS

The research was conducted in the Dera and Fogera districts of Northwestern Ethiopia from 2021 to 2022, within the South Gondar zone. The experimental plots, measuring 2 m × 4 m, used locally prevalent grass pea varieties to simulate typical farming conditions. The study utilized a randomized complete block design with four replications to reduce variability and ensure reliable results. Standard agricultural practices were consistently followed to maintain uniformity and minimize external influences.

Four insecticides, each from different classes and approved for use in Ethiopia, were applied in rotation using various sequences. Profenophos (Organophosphates), imidacloprid (Neonicotinoids), λ-cyhalothrin (Pyrethroids) and dimethoate (Organophosphates) were the insecticides employed. Farmers in southwest Ethiopia frequently use them to manage pea aphids in grass pea harvests. Additionally, a rotational application strategy was incorporated to prevent pest resistance and enhance long-term effectiveness. The rotation pattern involved alternating insecticides from different classes (P-I-L-D).

Data collection encompassed various parameters: Aphid count per 130 cm^2 board, insecticide application dates, damaged and undamaged pod counts from 20 randomly selected plants, meteorological data and grass pea grain yield.

Insecticide sprays were applied when the pea aphid population reached the economic threshold level. Aphid counts began before spray on 10/11/2021(D/M/Y) and 17/11/2022 in Fogera and on 22/11/2021 and 11/11/2022 (D/M/Y) in Dera district. Counts were conducted at 8-day intervals and ceased when the population fell below the economic threshold level.

Data analysis aimed to assess the effectiveness of the insecticides in local pest management. This comprehensive approach considered environmental and agronomic factors to evaluate the efficacy of the insecticides within the local agricultural context.

RESULTS AND DISCUSSION

In the Fogera plain of Ethiopia, especially in the highlands where the climate and agro-ecological conditions are favourable for these crops, farmers have been practicing rice-grass pea relay and rice vegetable rotation in one cropping season (rice main season and vegetable via irrigation). Grass pea, or Lathyrus sativus, is a leguminous crop that grows well in parts of Ethiopia's Fogera plain because it can withstand cold temperatures and is resistant to drought. This is a summary of Ethiopia's output of rice and grass peas.

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Agro-Ecological Zones

In Ethiopia's highlands where the temperature and altitude support the growth of both crops, the relay farming system of rice and grass pea is widely used. This is particularly true in the districts of Fogera, Dera and Libokemkem (the plain of Fogera). Ethiopian farmers choose grass pea and rice cultivars that are most suited to the region. Because of this adaptability, both crops are guaranteed to flourish in the particular agro climatic zones in which they are grown.

When the rice crop reaches a specified growth stage, the relay cropping technology is utilised to sow grass peas either inside the rice field or in the intervals between the rice plants. Grass peas not only make a valuable second crop but also enrich the soil with fixed nitrogen from the environment. The relay cropping method can raise farmers' standards of living and boost food security by giving them a range of crops and income sources (Pushnya *et al*., 2023).

Pea Aphid Population (Fogera District) in 2021 Season

In the 2021 season at Fogera, statistical analysis of table 1 shows significant effects of insecticide treatments on pea aphids in grass pea over different weeks. Pea aphids were significantly affected by the therapy in Week 1 (November 01, 2021) [$F(5,18) = 7.418$, $p<0.001$]. The therapy had a significant impact on pea aphids in Week 2 (November 11, 2021) [$F(5,18) = 3.623$, $p = 0.019$], despite a rather high residual variation. The treatment had a highly significant effect on pea aphids in Week 3 (November 18, 2021) [$F(5,18) = 34.924$, $p<0.001$], with a significantly smaller residual variance. The fourth week of the treatment, which ended on November 25, 2021, demonstrated a statistically significant impact on pea aphids [$F(5,18) = 93.250$, $p<0.001$]. Overall, insecticide treatments, including Profenophose, Dimethoate, Karate, Comander and rotational applications, significantly reduced pea aphid populations compared to the control (Rahman *et al*., 2023). Dimethoate and rotational application were particularly effective, supporting previous research on pest monitoring and resistance management (Siddiqui *et al*., 2022). Grain yield (kg ha-1): Treatment significantly affected grain yield [$F (5, 18) = 48.154$, $p<0.001$], with a low residual variance. Use of insecticides with varying modes of action in rotation is a tried-and-true way to slow down the development of resistance in insect populations by lowering selection pressure (Siddiqui *et al*., 2022).

Table 1: The effect of insecticides on pea aphids in grass pea at different weeks in 2021 at Fogera on station

Treatments	**Number of pea aphid/ 130 m^2 board**					
	Before spray	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Grain yield^{-1} (kg ha^{-1})**
Profenophose	59.75^{a}	17.50^{a}	12.25^{a}	9.50^{ab}	4.50^{a}	832.20^{bc}
Dimethoat	80.00^{ab}	12.50^{a}	9.25^{a}	6.75^{a}	9.00^{a}	1457.80^{d}
Karate	112.00^{bc}	19.00^{a}	18.50^{a}	20.00^{c}	20.75^{a}	703.20^{b}
Comander	55.50^{a}	20.00^{a}	14.00^{a}	15.00^{bc}	13.25^{a}	940.00^{c}
Rotational application (P-I-L-D)	81.25^{ab}	18.50^{a}	12.50^{a}	7.00^{a}	9.75^{a}	1350.20^{d}
Control	122.25^{c}	53.50^{b}	80.50^{b}	72.50^{d}	50.00^{b}	427.00^{a}
CV (%)	30.80	66.80	38.10	24.10	68.40	11.90

The examination of letters with similar characters suggested that there was no statistically significant difference, as the p-value exceeded 0.05; where the P-I-L-D, represent is profenofos, imidacloprid, λ-cyhalothrin and Dimethoate, respectively.

Pea Aphid Population (Fogera District) in 2022 Season

In the 2022 season at Fogera on Station, table 2 shows a significant effect of treatment on pea aphids before spray application [$F (5, 18) = 7.516$, $p<0.001$], indicating notable differences among treatments. In Week 1 (November 25, 2022), pea aphids showed significant response to treatments [$F(5,18) = 19.019$, $p<0.001$]. Likewise, Weeks 2 and 3 (December 03, 2022 and December 11, 2022, respectively) [$F(5,18) = 9.939$, $p<0.001$] and 8.972, $p<0.001$] were discovered, and Week 4 (December 19, 2022) [$F(5,18) = 12.342$, $p<0.001$] also highlighted significant advantages, demonstrating the therapies' long-term efficacy. Treatments also significantly improved grain yield (kg ha^{-1}) [$F(5,18) = 42.840$, $p<0.001$]. Insecticides, particularly Dimethoate and rotational treatments, significantly increased grain yield in both Fogera and Dera districts, reducing pest pressure and boosting crop productivity. The choice of insecticides is critical, which are less harmful to non-target species, can effectively manage pest populations while supporting plant health (Horowitz and Ishaaya, 2004). Studies have shown that reducing pest populations, such as pea aphids, enhances plant health and productivity, emphasizing the critical role of proper insecticide selection in promoting optimal crop performance (Barlow *et al*., 1977).

Table 2: The effect of insecticides on pea aphids in grass pea at different weeks in 2022 at Fogera on station

Treatments	Number of pea aphid/ 130 m^2 board						
	Before spray	Week 1	Week 2	Week 3	Week 4	Week 5	Grain yield^{-1} (kg ha^{-1})
Profenophose	29.75^a	14.75^a	16.75^a	8.00^a	6.50^{ab}	4.50	923.00^b
Dimethoate	32.75^a	5.50^a	9.00^a	6.00^a	3.50^a	3.00	1692.00^d
Karate	28.25^a	23.00^a	22.50^a	23.25^a	23.25^b	17.75	860.00^b
Comander	24.25^a	11.75^a	15.50^a	12.75^a	14.25^{ab}	12.00	1204.00^c
Rotational application (P-I-L-D)	31.75^a	9.75^a	11.25^a	5.00^a	5.50^{ab}	7.75	1597.00^d
Control	36.0^a	154.50^b	138.50^b	70.50^b	73.75^c	46.25	472.00^a
CV (%)	27.7	96.20	42.20	67.90	56.90	58.70	16.60

The examination of letters with similar characters suggested that there was no statistically significant difference, as the p-value exceeded 0.05; where the P-I-L-D, represent is profenofos, imidacloprid, λ-cyhalothrin and Dimethoate, respectively.

Pea Aphid Population (Dera District) in 2021 Season

Prior to spraying or applying the treatment in November 2021, table 3's preliminary results from 2021 showed no discernible variations in pea aphid populations among treatments [$F(5,18) = 1.103$, $p = 0.393$]. On November 29, 2021, however, notable variations became apparent [$F(5,18) = 10.920$, $p<0.001$], and they continued until December 7, 2021 [$F(5,18) = 45.419$, $p<0.001$], demonstrating the therapies' long-term effectiveness. The rotational use of insecticides with distinct modes of action is a recognized strategy to mitigate resistance development in insect populations by minimizing selection pressure (Yamamura, 2021), widely adopted across global cropping systems. Table 3 further details grain yield (kg ha^{-1}) per treatment, indicating higher yields with Dimethoate and Rotation compared to Profenophose and the Control, with a low coefficient of variation (CV) of 11.5%, suggesting consistent yield despite varying pea aphid populations.

Table 3: The effect of different insecticide and rotational application of insecticide on pea aphid and resultant yield in Dera in 2021

Treatments	Number of pea aphid/ 130 m^2 board					
	Before spray	Week 1	Week 2	Week 3	Week 4	Grain yield^{-1} (kg ha^{-1})
Profenophose	120.50^d	17.50^{ab}	9.25^{ab}	31.00^a	16.50^{ab}	786.00^b
Dimethoat	75.75^{bc}	4.75^a	22.50^{ab}	3.75^a	4.00^a	1450.90^c
Karate	94.75^{cd}	20.25^{ab}	26.75^{ab}	23.50^a	29.50^b	899.60^b
Comander	27.50^a	22.25^b	36.50^b	33.75^a	22.00^{ab}	949.70^b
Rotational application (P-I-L-D)	20.00^a	4.25^a	8.25^a	10.75^a	7.00^a	1375.30^c
CONTROL	50.75^{ab}	72.50^c	87.25^c	110.75^b	72.75^c	463.30^a
CV (%)	44.20	49.00	58.00	72.30	56.50	11.50

The examination of letters with similar characters suggested that there was no statistically significant difference, as the p-value exceeded 0.05; where the P-I-L-D, represent is profenofos, imidacloprid, λ-cyhalothrin and Dimethoate, respectively.

Pea Aphid Population (Dera District) in 2022 Season

In 2022, table 4 indicates that prior to treatment application on November 11, 2022, there was no significant effect of treatment on pea aphid populations [$F(5,18) = 1.103$, $p = 0.393$]. This suggests that initially, the variation in pea aphid population among treatments was not statistically significant. However, one week after treatment application (November 18, 2022), Table 4 shows a notable impact of treatments on pea aphid populations [$F(5,18) = 10.920$, $p<0.001$], indicating a statistically significant influence during the first week, with a highly significant p-value of less than 0.001. Similarly, in the second week post-treatment (November 25, 2022), table 4 demonstrates a significant effect of treatments on pea aphid populations [$F(5,18) = 45.419$, $p<0.001$], underscoring continued efficacy with a very high level of significance. Regarding grain yield (kg ha^{-1}), the table illustrates varying effects across treatments, with 'Dimethoate' and 'Rotation' yielding higher than 'Profenophose' and the 'Control'. The coefficient of variation (CV) for yield is relatively low at 11.5%, indicating consistent yield across treatments despite fluctuations in pea aphid populations. Effective pest management, as observed in reducing pea aphid populations, can positively impact plant health and productivity (Najar-Rodríguez *et al.*, 2007).

Table 4: The effect of different insecticide and rotational application of insecticide on pea aphid and on the resultant yield in Dera district in 2022

Treatments	Number of pea aphid/ 130 m² board						Grain yield^{-1} (kg ha^{-1})
	Before spray	Week 1	Week 2	Week 3	Week 4	Week 5	
Profenophose	37.25^{a}	34.00^{a}	15.75^{ab}	15.25^{ab}	15.00^{a}	6.50	841.00^{ab}
Dimethoat	35.00^{a}	35.25^{a}	9.00^{a}	10.00^{a}	9.25^{a}	4.50	1397.00^{cd}
Karate	31.00^{a}	33.50^{a}	18.50^{b}	25.50^{b}	23.00^{a}	23.75	918.00^{b}
Comander	36.25^{a}	34.00^{a}	13.75^{ab}	22.75^{ab}	10.25^{a}	8.75	1230.00^{bc}
Rotational application (P-D-R-L)	33.5^{a}	26.50^{a}	9.50^{a}	16.50^{ab}	9.75^{a}	13.00	1800.00^{d}
Control	42.5^{a}	47.5^{a}	89.50^{c}	79.50^{c}	74.75^{b}	52.50	424.00^{a}
CV (%)	29.3	30.8	20.20	32.80	40.50	25.50	27.10

The examination of letters with similar characters suggested that there was no statistically significant difference, as the p-value exceeded 0.05; where, rotational application of I-P-λ-D; represents Imidacloprid, Profenofos, λ-cyhalothrin and Dimethoate, respectively.

Cost Benefit Analysis

Table 5 represents the cost benefit results, net benefit (US $), Dimethoat shows the highest average grain yield among individual insecticides, but also has the highest chemical and protection costs. The cost-benefit analysis revealed that treatments with higher initial costs, such as Dimethoat and rotational applications, resulted in higher net benefits due to their superior effectiveness in controlling pea aphids and increasing grain yield. Although these treatments incurred higher chemical and protection costs, their enhanced performance translated into better economic returns compared to treatments with lower initial costs but less effectiveness, such as Profenophose and Karate. Furthermore, the control treatment, which incurred no chemical costs, still yielded positive net benefits, highlighting the economic value of pest management interventions even in comparison to untreated crops. These results align with previous findings, which demonstrate that while certain insecticides may have higher upfront costs, their effectiveness in pest control and yield protection can lead to higher net returns compared to untreated or less effective treatments (Alam *et al*., 2017). Cost-effectiveness analyses of different insecticide treatments, including rotational approaches, have been conducted in various agricultural contexts. These studies provide valuable insights into the economic viability of different pest management strategies and help farmers make informed decisions based on both efficacy and cost considerations (Mohapatra and Schiewer, 1998). By considering the findings of previous research in insecticide resistance management, pest control and economic analysis, we can further support the conclusions drawn from the research on pea aphid management in grass pea crops in Ethiopia. These findings underscore the importance of implementing integrated pest management approaches, including the rotational use of insecticides, to effectively manage pest populations while maximizing yield and economic returns in agricultural systems.

Consistent with these findings, cost-benefit analyses have shown that treatments with higher initial costs, such as Dimethoat and rotational applications, lead to superior effectiveness in controlling pests like pea aphids and increasing grain yield, resulting in higher net benefits (Mohapatra and Schiewer, 1998). While these treatments incur higher chemical and protection costs, their enhanced performance translates into better economic returns compared to less effective treatments like Profenophose and Karate. Even the control treatment, with no chemical costs, yielded positive net benefits, emphasizing the economic value of pest management interventions. Previous research on insecticide resistance management and economic analyses in agriculture supports the importance of integrated pest management strategies, including rotational insecticide use, to effectively manage pests and maximize economic returns in agricultural systems.

Table 5: The cost benefit result of the experiment

Grain yield	Insecticide	Mean value (US$)	Std. Deviation
Average grain yield (kg ha^{-1})	Comander	1080.93	12.622
	Control	446.575	4.137
	Dimethoat	1499.43	106.738
	Karate	845.2	89.944
	Profenophose	845.55	45.326
	Rotational application (P-I-L-D)	1530.63	80.646
Chemical cost	Comander	311.5	0
	Control	0	0
	Dimethoat	309	0
	Karate	314	0

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	Profenophose	320.25	0
	Rotational application (P-I-L-D)	313.688	0
Protection cost (US$)	Comander	702.601	8.204
	Control	290.274	2.689
	Dimethoat	974.626	69.38
	Karate	549.38	58.464
	Profenophose	549.608	29.462
	Rotational application (P-I-L-D)	994.906	52.42
Net benefit (US$)	Comander	391.101	8.204
	Control	290.274	2.689
	Dimethoat	665.626	69.38
	Karate	235.38	58.464
	Profenophose	229.358	29.462
	Rotational application (P-I-L-D)	681.219	52.42

Where, the P-I-L-D, represent is profenofos, imidacloprid, λ-cyhalothrin and Dimethoate, respectively.

CONCLUSION

In conclusion, this study demonstrates the significant efficacy of Dimethoate and rotational insecticide applications in reducing pea aphid populations and improving grain yield in grass pea over two consecutive years. Both treatments showed consistent results, significantly outperforming other insecticides and control groups in terms of aphid reduction and yield enhancement. The superior performance of Dimethoate and the P-I-L-D rotational application is supported by recent literature, which highlights their broad-spectrum activity and ability to mitigate resistance development. Furthermore, the economic analysis confirms that the higher initial costs of these treatments are justified by their substantial net economic benefits. According to integrated pest management and sustainable agriculture, these findings highlight the possibility for sustainable pest management techniques through the targeted application of pesticides.

Recommendations

The results of the study suggest that rotational pesticide strategies such as switching between multiple modes of action should be prioritised in addition to the use of dimethoate as a substitute insecticide. Insecticide resistance can be reduced when managing pea aphids on grass peas using rotational pesticide techniques. Throughout the cropping season, ongoing pest population monitoring is crucial for early diagnosis and prompt intervention. Supporting integrated pest management (IPM) strategies, which combine chemical, biological, and cultural control approaches, can help increase the sustainability of pest management programs. It is important to develop programs that instruct farmers on the most effective ways to control pests, including how to properly apply insecticides and strike a balance between pest management and environmental and public health concerns. Cost-benefit analyses of different pest management strategies, such the usage of dimethoate and rotating pesticide applications, can assist farmers in selecting tactics that optimise financial advantages and pest control efficacy.

Acknowledgment

The author would like to thank the Ethiopian Institute of Agricultural Research (EIAR), this experiment financed by EIAR, Addis Ababa, Ethiopia.

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