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Management of late blight (*Phytophthora infestans*) of potato (*Solanum tuberosum*) through efficient spray schedule of fungicides in the north-eastern Himalayan region of India

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ABSTRACT

Phytophthora infestans (Mont.) de Bary, belongs to order Peronosporales is one of the most destructive phytopathogen causing late blight disease of potato (*Solanum tuberosum* L.). The disease symptoms appear on leaf, petiole, stem, and tubers at any stage of crop growth and may cause severe disease epidemics leading to complete defoliation and extensive yield loss. The field experiments were conducted during 2020–21 and 2021–22 at Chesrimai GP, Charilam block, Sepahijala, Tripura to find out the effective management strategies with fungicides to mitigate the losses caused by the devastating disease. The experiment was laid out in a randomized block design (RBD) in 3 replications with 8 treatments having different fungicides in different combinations for determining the best spray schedule against late bight disease. Results revealed that one spraying of Mancozeb 75% @0.25% at 35 days after sowing (DAS), second spraying of Cymoxanil 8% + Mancozeb 64% @0.25% at 42 DAS, and third spraying of Mancozeb 75% @0.25% at 49 DAS and fourth spraying of Cymoxanil 8% + Mancozeb 64% @ 0.25% at 56 DAS recorded the best performing treatment, with the least mean disease severity (10.54 and 7.30%), the least mean disease incidence (15.00 and 12.75%), the least coefficient of disease index (CODEX) value (1.58% and 0.93%), and highest tuber yield (21.27 and 21.68 t/ha) during 2020–21 and 2021–22, respectively. In addition, there were 26.6 and 27.7% increase in yield over control during 2020–21 and 2021–22, respectively and the pooled incremental cost benefit ratio (ICBR) of 1:16.09 was found to be highest among all other treatments. Efficient spray schedule of prophylactic/ preventive spray with contact fungicide followed by spraying with translaminar/systemic + contact fungicide can effectively manage the late blight disease of potato under field conditions.

Keywords: Fungicides, Late blight, *Phytophthora infestans, Solanum tuberosum,* Spray schedule

Potato (*Solanum tuberosum* L.) being the fourth important non-cereal crop in India after rice, wheat, and maize (FAOSTAT 2017), is also popularly known as 'The King of Vegetables'. It is popularly grown in the North Eastern region (NER) of India for its high nutritional content. The crop is cultivated in more than 150 countries in the world. The cultivation area under the potato crop is 165 million ha, with a total production of 359 million metric tons (FAOSTAT 2020). In India, potato is cultivated in an area of 2.16 million ha, with production and productivity of 51.3 million tonnes and 23.77 tonnes/ha, respectively (FAOSTAT 2022). In the NER of India, Assam leads in the area of potato cultivation while, Tripura leads in the productivity (17.80 tonnes/ha). Nevertheless, the average potato productivity of Tripura is below the average national productivity of 22.10 tonnes/ha (NHRDF 2016).

The oomycetes phytopathogen, *Phytophthora infestans* (Mont.) de Bary, causing qualitative and quantitative losses in potatoes. In India, potato tuber yield losses due to late blight disease ranges between 11–74% depending on climatic factors (Khalid and Grover 2021). Due to changing climatic patterns, late blight disease has become a frequent phenomenon every year in the plains of Tripura, with moderate to high disease severity. Management of the disease is a challenging task considering the unique

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capacity of the pathogen to cause cell death, which occurs within 2–4 days under favourable weather conditions, and gradually the entire crop collapses under favourable conditions. The use of a resistant variety is the best option to combat this disease, despite that the pathogen is more aggressive and highly adaptive in the environment, and a breakdown of resistance is reported (Haverkort *et al*. 2009). So, the most reliable strategy left is the use of integrated disease management (IDM) for the disease, of which fungicides are an important component. Keeping these views in mind, the present study aimed to reveal efficient spray schedule against late blight of potato under *in vivo* conditions.

MATERIALS AND METHODS

The experiment was conducted during 2020–21 and 2021–22 at Chesrimai GP, Charilam block, Sepahijala, Tripura. The crop was grown under humid sub-tropical characterized by high rainfall. The average humidity ranges from 93.1–99.6% (morning), 48.0–78.6% (evening), and the average rainfall ranges from 0–122.4 mm prevailed during the cropping season.

The potato tuber cultivar Kufri Jyoti (Susceptible) was planted in a plot size of 3 m × 3 m at a spacing of 50 cm × 15 cm. Tubers were planted in the second week of October, and standard agronomic practices were followed (Roy 2015). The experiment was laid out in a randomized block design (RBD) in 3 replications with 8 treatments having different fungicides in different combinations for determining the best spray schedule against late bight disease (Table 1).

Table 1 The various spray schedules (treatment) and doses

Treatment
T_1, Mancozeb 75% WP @0.25% (2.5 g/litre): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_2, Chlorothalonil 75% WP @0.125% (1.25 g/litre): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_3, Cymoxanil 8% + Mancozeb 64% WP @0.25% (2.5 g/litre): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_4, Copper Oxychloride 50% WP @0.25% (2.5 g/L): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_5, Metalaxyl 4% + Mancozeb 64% WP @0.25% (2.5 g/litre): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_6, Famoxadone 16.6% + Cymoxanil 22.1% SC @0.10% (1.0 ml/litre): 4 sprays (1st spray at 35 DAS and 2nd, 3rd, and 4th sprays at 7 day intervals)
T_7, One spraying of Mancozeb 75% @0.25% (2.5 g/litre) at 35 days after sowing (DAS), second spraying of Cymoxanil 8% + Mancozeb 64% @0.25% (2.5 g/litre) at 42 DAS, and third spraying of Mancozeb 75% @0.25% (2.5 g/litre) at 49 DAS and fourth spraying of Cymoxanil 8% + Mancozeb 64% @0.25% (2.5 g/litre) at 56 DAS
T_8, Control

DAS, Days after sowing.

In the control treatment, an equal amount of sterile water was sprayed.

Disease incidence was calculated using a formula stated by Mayee and Datar (1986). Per cent disease index (PDI) was calculated based on numerical rating or scores observed (Mc Kinney 1923).

$$\text{PDI} = \frac{\text{Summation of numerical ratings}}{\text{No. of leaves/plants observed} \times \text{Maximum rating}} \times 100$$

Randomly 50 plants were selected from each plot for recording data. Furthermore, one top leaf, one middle leaf, and one lower leaf were tagged properly in each plant for estimation of the severity of the disease. A 0–9 rating scale was used for recording the disease severity data (Shutong *et al*. 2007). At the physiological maturity stage, the crop was harvested and treatment-wise tuber yield was recorded. The results were tested for their significance (Gomez and Gomez 1984). The critical difference (CD) was calculated at the 5% significance level.

Further, per cent disease reduction over control (PDC) was calculated as:

$$\text{PDC} = \frac{\text{PDI in control plot} - \text{PDI in treatment plot}}{\text{PDI in control plot}} \times 100$$

The coefficient of disease index (CODEX) was calculated as (Santosh *et al*. 2021):

$$\text{CODEX} = \frac{\text{Per cent disease incidence} \times \text{Per cent disease index}}{100}$$

RESULTS AND DISCUSSION

The results revealed that all the fungicides under study were superior, resulting in a significant decrease in late blight disease incidence, late blight disease severity index and CODEX as compared to control; however, T_7 proved to be the best performing treatment.

The disease appeared as small, light to dark green, circular to irregular-shaped water-soaked lesions, usually at the tips or edges of lower leaves (Supplementary Fig. 1) and stems (Supplementary Fig. 2). Under favourable conditions of cool (15–18°C) and moist weather (RH≥80%), these lesions enlarge quickly into dark brown necrotic lesions (Supplementary Fig. 3) resulting in the drying of plants (Supplementary Fig. 4) and at early morning whitish cottony growth were observed on the abaxial leaf surface (Supplementary Fig. 5). A typical lemon-shaped sporangium of *P. infestans* has been observed under microscope (Fig. 1A and Fig.1B) along with detached sporangiophore (Fig. 1C). A similar trend was also confirmed by the views of Wiik (2014), Hembram *et al*. (2018), Al Harethi *et al*. (2023) and Pasalkar *et al*. (2024). Infection or germination takes place through zoospores or germ tubes.

Late blight disease incidence: Results revealed that the late blight disease incidence was recorded in the range of 19.00–41.33%, 16.67–46.33%, 14.00–48.67% and 10.33–54.00% at 50, 57, 64, and 71 DAS, respectively in different

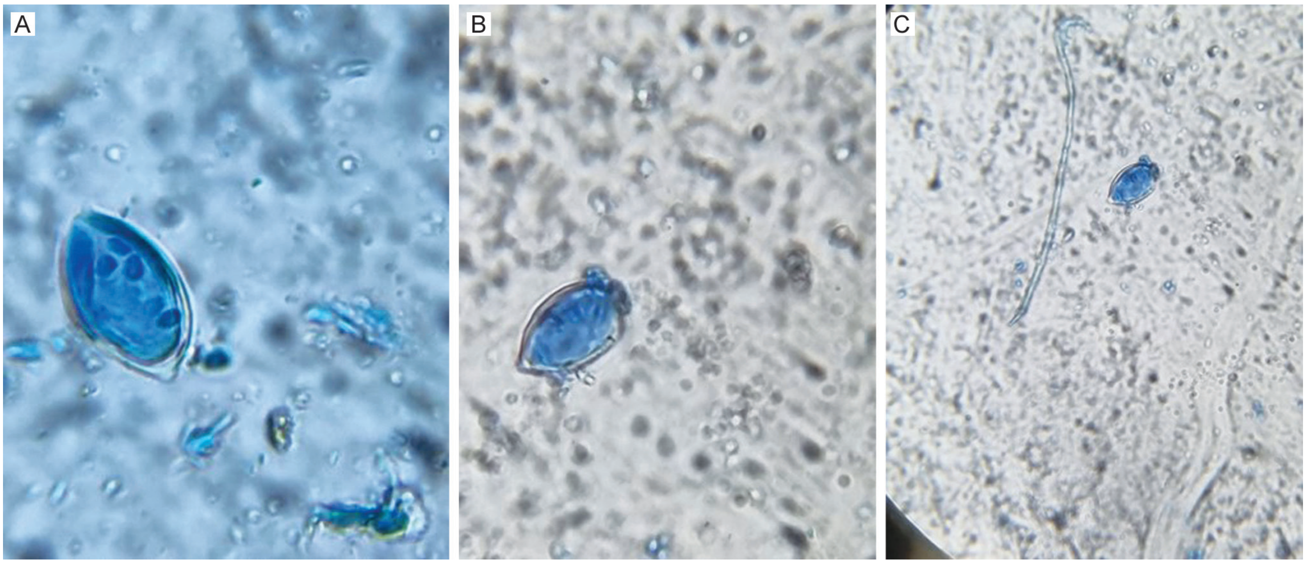

Fig. 1 (A) Lemon-shaped sporangium (40X magnification); (B) Sporangium of *Phytophthora infestans* (40X magnification); (C) Sporangium detached from sporangiophore (40X magnification)

treatments (Fig. 2A). Least late blight disease incidence of 19.00%, 16.67%, 14.00%, and 10.33% were recorded with T_7 at 50, 57, 64, and 71 DAS, respectively, followed by T_3 (28.67, 25.33, 22.67, and 19.67%, respectively) as compared to control. Both treatments, T_7 and T_3, were statistically significant with each other (CD at 5% level 3.35, 3.19, 3.09 and 3.37). In addition, the mean per cent disease reduction over control was observed to be highest in T_7 (69.85), followed by T_3 (48.24) (Fig. 2A). The mean late blight disease incidence was recorded in the range of 12.75–43.67% with the mean per cent disease reduction over control in the range of 33.22–69.73 (Fig. 2B). Moreover, in case of pooled data, the mean late blight disease incidence was recorded in the range of 13.88–45.63% with the mean per cent disease reduction over control in the range of 34.19–68.63 (Fig. 2C). This may be due to the protection of foliage by a combination of protective and systemic fungicides. The findings of present study are

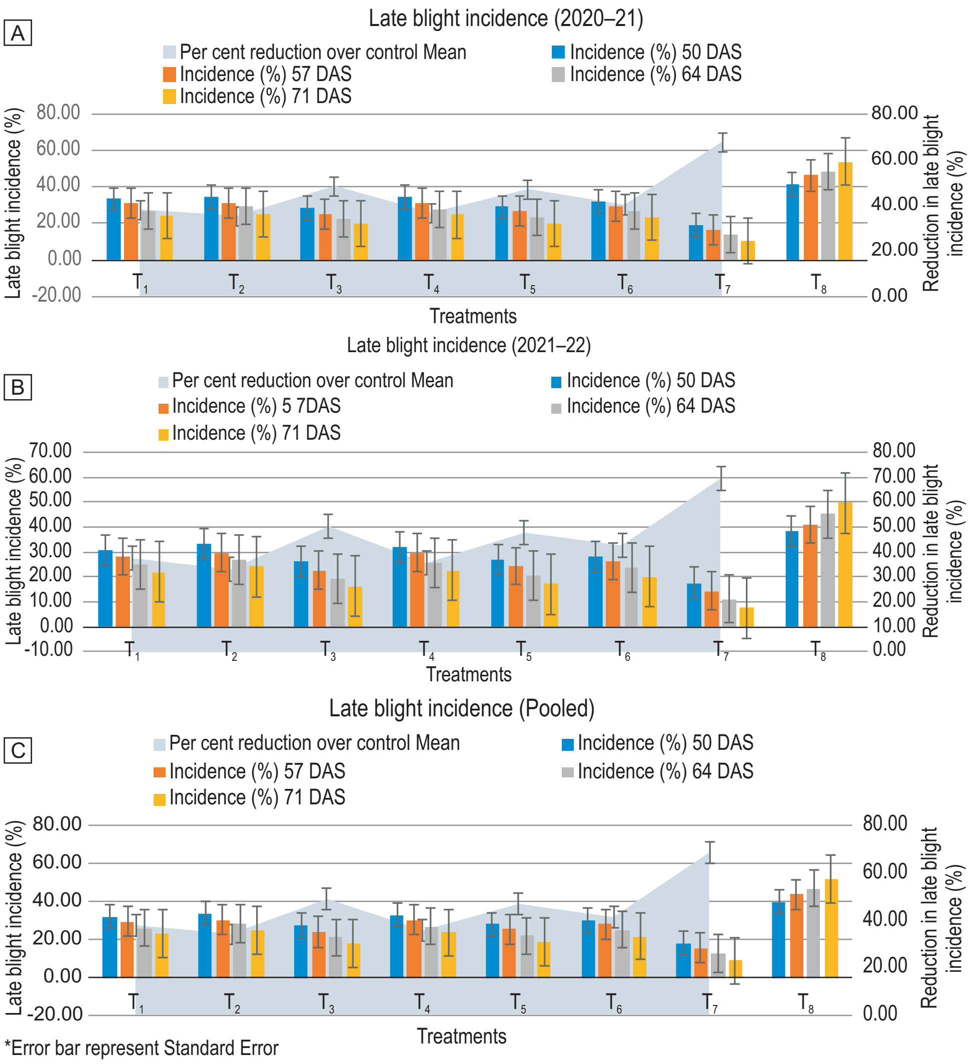

Fig. 2 Effect of fungicides on potato late blight incidence and per cent reduction over control during 2020–21 (A); 2021–22 (B); and pooled (C).
Treatments details are given in Table 1. DAS, Days after sowing.

in agreement with the work of earlier researchers, Rani *et al*. (2009) and Chakraborty and Mazumdar (2012). A similar trend was noticed by Sharma and Saikia (2013), who observed that effective management of the potato late blight disease was recorded with prophylactic sprays with Mancozeb @0.25%, followed by curative sprays with Dimethomorph @0.1% and Cymoxanil+Mancozeb @0.3%.

Late blight disease severity index: The least late blight disease severity index of 14.70%, 12.53%, 9.45%, and 5.48% with per cent reduction over control of 60.35%, 70.34%, 78.59%, and 80.86% at 50, 57, 64, and 71 DAS, respectively, was observed in T_7 as compared to control (Table 2). This was followed by T_3 which recorded a late blight disease severity index of 24.38%, 21.24%, 18.14%, and 14.82% with per cent reduction over control of 34.26%, 49.72%, 58.92%, and 63.58% at 50, 57, 64, and 71 DAS, respectively. Whereas, T_7 recorded least late blight disease severity index of 13.29%, 5.83%, 6.65%, and 3.43% with per cent reduction over control of 61.13%, 82.22%, 83.78% and 92.44% at 50, 57, 64 and 71 DAS, respectively during 2021–22. At 64 DAS, the late blight disease severity index was slightly increased because of wet conditions from rainfall. The mean per cent disease reduction over control was found to be highest in T_7 (88.85), followed by T_3 (69.85) (Table 3). The results obtained in the present studies are in conformity with Muchiri *et al*. (2009), Bhat *et al*. (2009), Alexandrov (2011), Chakraborty and Banerjee (2016), Manjunath *et al*. (2017) and Singh *et al*. (2023). Chakraborty and Mazumdar (2012) reported that Mancozeb @0.25% as a prophylactic spray, followed by Cymoxanil+Mancozeb or Dimethomorph+Mancozeb @0.3% as a curative spray can effectively managed the late blight disease of potato.

CODEX: The data depicted in, implies that the lowest CODEX value (1.58%) was observed in T_7 as compared to the control (20.53%), followed by T_3 (4.73%) (Supplementary Table 1). The present observations of the treatments statistically differed among themselves as compared to control. Santosh *et al*. (2021) evaluated different treatments against the late blight of potato and recorded that the combined application of treatments reduces late blight disease incidence (%), disease intensity (%) and CODEX (%) over control.

Tuber yield: The data revealed that all the treatments significantly reduced late blight disease incidence and severity, and thereby resulting to maximum tuber yield (Supplementary Table 1). The per cent increase in yield over control was found in the range of 3.6–26.6 and 9.2–27.7% with rhizome yield in the range of 17.40–21.27 t/ha and 18.55–21.68 t/ha during 2020–21 and 2021–22, respectively. In the field trials, maximum tuber yield was obtained from T_7 (21.27 and 21.68 t/ha) followed by T_3 (20.15 and 20.65 t/ha) which were statistically on par with each other during both the consecutive years as compared to control (16.80 and 16.98 t/ha). It is clear from the two consecutive years that with an increasing late blight severity, there is a decrease in tuber yield. The similar findings were reported by Chakraborty and Banerjee (2016), Lal *et al.* (2017), Haveri *et al.* (2018). Khadka *et al*. (2020) evaluated alone

Table 2 Effect of fungicides on late blight severity in potato

Treatment	Per cent disease index*									
	2020–21				Mean	2021–22				Mean
	50 DAS	57 DAS	64 DAS	71 DAS		50 DAS	57 DAS	64 DAS	71 DAS	
T_1	29.09 (32.64)	26.91 (31.25)	22.48 (28.31)	19.53 (26.23)	24.50 (29.67)	26.61 (31.06)	19.41 (26.14)	21.01 (27.28)	18.20 (25.25)	21.31 (27.49)
T_2	30.36 (33.43)	27.23 (31.46)	25.20 (30.13)	20.48 (26.91)	25.82 (30.54)	28.88 (32.51)	22.51 (28.33)	23.32 (28.88)	20.99 (27.27)	23.93 (29.28)
T_3	24.38 (29.59)	21.24 (27.44)	18.14 (25.21)	14.82 (22.64)	19.64 (26.31)	20.95 (27.24)	14.30 (22.22)	15.07 (22.84)	12.35 (20.57)	15.67 (23.32)
T_4	30.06 (33.25)	27.26 (31.47)	23.46 (28.97)	19.82 (26.44)	25.15 (30.10)	27.74 (31.78)	21.34 (27.51)	22.18 (28.10)	19.12 (25.93)	22.60 (28.38)
T_5	24.57 (29.71)	22.53 (28.34)	18.83 (25.72)	15.14 (22.90)	20.27 (26.76)	21.94 (27.93)	16.06 (23.63)	17.12 (24.44)	14.05 (22.01)	17.29 (24.57)
T_6	27.42 (31.58)	25.58 (30.38)	22.18 (28.10)	18.81 (25.70)	23.50 (29.00)	24.09 (29.39)	17.90 (25.03)	20.25 (26.74)	17.01 (24.36)	19.81 (26.43)
T_7	14.70 (22.55)	12.53 (20.73)	9.45 (17.90)	5.48 (13.54)	10.54 (18.94)	13.29 (21.38)	5.83 (13.97)	6.65 (14.94)	3.43 (10.67)	7.30 (15.68)
T_8	37.09 (37.52)	42.24 (40.54)	44.15 (41.64)	49.17 (44.52)	43.16 (41.07)	34.19 (35.78)	32.76 (34.92)	41.00 (39.82)	45.35 (42.33)	38.33 (38.25)
SEm (±)	1.19	1.13	1.13	1.26	--	1.15	1.44	1.19	1.46	--
CD (*P*=0.05)	3.62	3.44	3.42	3.83	--	3.47	4.37	3.62	4.44	--

*, Average of replications; **, Figures in parenthesis are Arc sine transformed values. Treatment details are given under Table 1. DAS, Days after sowing.

Table 3 Effect of fungicides on late blight disease reduction over control in potato

Treatment	Per cent reduction over control*									
	2020–21				Mean	2021–22				Mean
	50 DAS	57 DAS	64 DAS	71 DAS		50 DAS	57 DAS	64 DAS	71 DAS	
T_1	21.56	36.30	46.81	54.94	60.27	22.15	40.77	48.76	59.87	42.89
T_2	18.15	35.53	42.92	53.09	58.34	15.51	31.28	43.12	53.72	35.91
T_3	34.26	49.72	58.92	63.58	69.85	38.71	56.35	63.25	72.77	57.77
T_4	18.95	35.47	49.12	54.32	59.68	18.85	34.87	45.90	57.85	39.37
T_5	33.76	46.66	57.35	62.96	69.20	35.81	50.98	58.24	69.03	53.52
T_6	26.06	39.43	49.76	56.17	61.74	29.54	45.37	50.62	62.49	47.01
T_7	60.35	70.34	78.59	80.86	88.85	61.13	82.22	83.78	92.44	79.89
T_8	--	--	--	--	--	--	--	--	--	--

*, Average of replication. Treatment details are given under Table 1. DAS, Days after sowing.

and different combinations of fungicides in which they revealed that combinations of fungicides were effective for managing the disease with high tuber yield.

Economic assessment: Treatment T_7 and T_3 recorded the highest pooled ICBR of 16.09 and 9.74 as compared to other treatments (Supplementary Table 1). In comparison to T_3, 65.2% higher ICBR was obtained in T_7 which indicates the enhancement of gross income. It was witnessed from pooled data that T_1 recorded a higher ICBR of 8.22 as compared to T_5 and T_6 because of the lower total cost of plant protection (₹3,140/ha). Nevertheless, yield was higher under T_5 and T_6 as compared to T_1 over consecutive years. Chakraborty and Mazumdar (2012) reported that first spay with Mancozeb @ 0.25% followed by Cymoxanil+Mancozeb or Dimethomorph+Mancozeb @0.3% and Mancozeb @0.25% showed the best performing treatment for the management of late blight disease in West Bengal. A similar trend of results was also observed in the present study. In addition, these findings are also in agreement with those of Chakraborty and Banerjee (2016), Lal *et al.* (2017), and Mhatre *et al.* (2021). Prophylactic spray with contact fungicide and second spraying with translaminar/systemic + contact fungicide when the first symptoms appeared, followed by third spraying with contact fungicide and fourth spraying with translaminar/systemic + contact fungicide effectively managed the late blight disease than post-symptomatic sprays under field conditions. Protective fungicides inhibit the germination of zoospores or sporangia of *P. infestans* (Bruck *et al*. 1980). A combination of systemic and contact fungicides may be attributed to fungistatic activity and exhibit the formation of *sporangia* and the production of zoospores. Timely application of both preventive and curative fungicides acts as the best solution to combat this deadly menace.

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