



Financial viability of Peste des Petits Ruminants (PPR) control programme (PPR-CP) implemented in Madhya Pradesh, India

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ABSTRACT

Madhya Pradesh (MP) state in India had practiced focussed vaccination against *Peste des Petits Ruminants* (PPR) from 2006-07 to 2015-16 and adopted PPR-Control Programme (PPR-CP) with 100% coverage during first year followed by 30% bi-annual vaccination for two years since 2016-17. This study evaluated the impact of PPR-CP using secondary data and cross-sectional survey data collected from 410 and 340 flocks before (during 2015-16, survey-I) and after PPR-CP implementation (during 2018-19, survey-II), respectively. Besides the incidence and disease cost, Incremental Benefit Cost Ratio (IBCR) was calculated to assess the financial viability of PPR-CP implementation in MP state under actual vaccination coverage after PPR-CP (scenario-I) and as per defined PPR-CP strategy (scenario-II). The number of PPR affected flocks declined significantly from 14.9% to 4.6% and the disease incidence declined from 27.5% to 10.2% in sheep and 18.8% to 0.64% in goats, in survey-I and II, respectively. The projected loss before and after PPR-CP was ₹ 3260 million (₹ 326 crore) and ₹ 476 million (₹ 47.6 crore), respectively. Financial viability of PPR-CP revealed an IBCR of 69.8:1 and 39.4:1 under scenario-I and II, respectively. Estimated incremental benefits outweighed the incremental cost in both vaccination scenarios, however, as per current vaccination plan (scenario-I), no fresh cases were reported for two years following PPR-CP, but reoccurred during 2019-20, as the state did not comply with PPR-CP Strategy. Therefore, selecting the right vaccination strategy and its diligent implementation may aid in eradicating PPR by 2030 in India in line with PPR global strategy.

Keywords: Incremental Benefit Cost Ratio (IBCR), Madhya Pradesh, PPR-Control programme (PPR-CP), PPR Incidence

Peste des Petits Ruminants (PPR) is an important contagious viral diseases of sheep and goats commonly referred as ‘goat plague or small ruminant plague’. The PPR was first reported in 1942 in Côte d’Ivoire, since then the disease has spread to different regions in Africa, Arabian Peninsula, Middle East, and Asia (Balamurugan *et al.* 2014, Balamurugan *et al.* 2021). PPR is considered to be the most significant economic threat to the development of sustainable sheep and goat production across the developing world (Ahaduzzaman 2020). The global economic burden of PPR amounts to USD 1.5 to 2.0 billion per year hence, a Global Control and Eradication Strategy (GCES) was planned to control and eradicate PPR by 2030 (FAO 2015).

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In India, PPR is ranked first among various infectious diseases that affect sheep and goats (Balamurugan *et al.* 2021). The disease was first reported in India in 1987 in the southern state of Tamil Nadu and later spread to other states (Singh *et al.* 2009). The estimated loss in India due to PPR was INR 16,116 million during 2015-16 (Govindaraj 2016). In India, three vaccine strains (Sungri 96, Arasur 87 and Coimbatore 97) are available, of which PPR vaccine (Sungri 96 strain) developed by ICAR-IVRI has undergone extensive field trials (Singh *et al.* 2009, Singh 2011) and that provides immunity for 3 to 6 years (Saravanan *et al.* 2010) was used since 2002 during focussed vaccination and in the PPR Control Programme (PPR-CP) implemented in some states since 2011. Except for the southern states, all other states in India including Madhya Pradesh (MP) had practiced only focussed vaccination under Assistance to States for Control of Animal Diseases (ASCAD) funding from the Government of India (GoI). During 2014-15, the GoI extended PPR-CP to the entire country, but there was a delay in implementation in many Indian states including the MP state.

The studies on the socio-economic impact of PPR and the effectiveness of vaccination programme implemented in India is scant except the studies on PPR Mass Vaccination Campaign (PPR-MVC) implemented in Chhattisgarh, and vaccination impact in Karnataka (Govindaraj *et al.* 2019, Govindaraj *et al.* 2023) using post-interventional study design. The present study independently investigated the financial viability of PPR-CP implemented in MP using reported secondary data and cross-sectional survey data using pre-post interventional design (pre-intervention (survey-I) and post-intervention (survey-II)) under actual vaccination coverage (scenario-I) and as per PPR-CP strategy (scenario-II).

MATERIALS AND METHODS

Study area, sampling procedure, sample size and data collection: The present study was undertaken in MP, India. The total livestock population in MP state is 40.6 million (20th livestock census 2019), of which, 28 per cent of the population comprised of sheep and goats (11.3 million), with 97 per cent goats. A cross-sectional survey among sheep and goat rearing households in three risk districts, viz. Betul (high PPR risk), Sagar (medium PPR risk), and Bhopal (low PPR risk) of MP was undertaken to assess the impact of the vaccination intervention before (survey-I: 2015-16) and three year after (survey-II: 2018-19) the implementation of PPR-CP using a multistage random sampling procedure. The districts were grouped into three risk groups based on the number of PPR outbreaks, PPR attack/1000 population, frequency of outbreaks in the preceding three years and sheep and goats population density. The estimated total sample size for the primary survey was 408 flocks (Cochran 1963), and the data was collected from 410 flocks before PPR-CP implementation (survey-I) using the pre-tested schedules. During survey-II, 340 flocks were surveyed as some farmers had sold their sheep and goats; a few had migrated to other places, and some were not available to interact. The primary data on socio-economic parameters, sheep and goats inventory, production parameters, mortality and morbidity, vaccination status, direct and indirect cost associated with PPR were collected from farmer. The PPR incidence in the flocks were triangulated with the field veterinarian, and also by testing a few serum samples collected from the outbreak reported flocks for the identification of exposure to PPRV infection by employing PPR competitive ELISA (Singh *et al.* 2004).

PPR vaccination programme: The state had practiced focussed vaccination against PPR from 2006-07 to 2015-16 and implemented PPR-CP since 2016-17 with a plan to cover 100% target sheep and goat population of >4 months age during the first year followed by 30% bi-annual vaccination for two years to cover the naïve population. Under PPR-CP, as per plan, vaccination was initiated during March 2017 and continued for 30 days. Around 1,502 vaccination teams were formed to cover the entire sheep and goat population in 51 districts. The vaccination

was also carried out in animal markets and check posts in each of the districts. Although the PPR-CP plan stipulates 100% vaccination in the first year followed by 30% bi-annual vaccination, the state could not stick to the plan due to financial and other administrative constraints resulting in 80% coverage during the first year (2016-17) followed by 31% and 4% coverage in the next two years (2017-18 and 2018-19).

Estimation of incidence risk, case fatality rate, and impact parameters: The primary metrics of mortality, morbidity and impact parameters, viz. incidence risk, Case Fatality Rate (CFR), mortality loss, loss due to body weight reduction, distress sale loss, treatment cost, and the opportunity cost of labour were estimated as per the methodology reported by Govindaraj *et al.* (2019). During the survey, the actual weights of sheep and goats of different age and sex groups were recorded in the healthy flocks and a conservative reduction of 10% in the mean weight was assumed (though a 15% reduction in weight was reported (Limon *et al.* 2020) to calculate the weight loss in the PPR affected flocks as pre- and post-outbreak weights in the affected flocks were not available.

Incidence projection: The estimated PPR incidence was available for survey-I (2015-16) and survey-II (2018-19) and hence for 2016-17 and 2017-18, the incidence was calculated based on linear interpolation of incidences between survey-I and II.

Incremental Benefit-Cost Analysis (IBCA): The Incremental Benefit Cost Ratio (IBCR) calculated to assess the financial viability of PPR-CP implemented in MP is,

$$IBCR = \frac{IB_v}{IC_v}$$

Where, IBC , Incremental benefit-cost ratio; IB_v , Total incremental benefits/disease avoidance benefits for a specific vaccination scenario (INR); IC_v , Total incremental cost of vaccination for a specific vaccination scenario (INR).

Incremental benefits stream: The incremental benefits of vaccination in different years were calculated based on the difference in PPR incidence under with and without vaccination scenario, the projected risk population in the respective year, and the disease cost components.

$$IB_v = \sum_{i=1}^n [(\Delta I_i * P_i) \{ (Mp_i * MI_i) + (Rp_i * R_{wi} * W_i) + (Dp_i * DI_i) + Tc_i + Oc_i \}] * VE_i$$

Where, IB_v , Total incremental benefits or disease avoidance benefits (₹); ΔI_i , Incremental PPR incidence in i^{th} year (%); P_i , Projected population in i^{th} year (No.); Mp_i , Mortality rate of animals in i^{th} year (%); MI_i , Average per animal mortality loss for in i^{th} year (₹); Rp_i , Recovered animals rate in i^{th} year (%); R_{wi} , Body weight reduction per animal in i^{th} year (kg); W_i , Live weight price/kg in i^{th} year (₹); Dp_i , Distress sale rate in i^{th} year (%); DI_i , Average distress sale loss/animal in i^{th} year (₹); Tc_i , Average treatment cost/animal in i^{th} year (₹); Oc_i , Average opportunity cost of labour/animal in i^{th} year (INR); VE_i , Vaccination effectiveness in the i^{th} year (80%); n , number of years ($i=1,2,\dots,n$).

Incremental cost stream: To estimate the total incremental vaccination cost in different years, the incremental vaccination coverage compared to base year (2015-16), sheep and goat population in the respective year and the vaccine and vaccination cost was considered. Sheep and goats <4 months old were not vaccinated under PPR-CP (Balamurugan *et al.* 2016) and data for this age group was not available and hence 10% of the projected population was considered as <4 months old. Accordingly, for calculating the incremental vaccination cost per year, the 90% of the projected population for each year was multiplied with the vaccination cost (vaccine cost-₹ 1.8/dose) and vaccination cost-₹ 18.2/dose)) as reported earlier (Govindaraj *et al.* 2019). The total incremental vaccination cost for the respective year n was calculated as,

$$IC_v = \sum_{i=1}^n (\Delta V_i * P_i * Vc_i)$$

Where, IC_v , Total Incremental cost of vaccination (INR); ΔV_i , Incremental vaccination coverage i^{th} year (%); P_i , Population at risk to be vaccinated i^{th} year (number); Vc_i , Cost of vaccination (vaccine and vaccination) per animal (₹); n , Number of years ($i=1,2, \dots, n$).

For comparison, all the benefit and cost estimates were converted to 2018-19 constant prices based on consumer price index prevailed in the respective year.

Vaccination scenarios: The incremental benefits and costs of vaccination were assessed under two vaccination scenarios (Scenario-I, actual vaccination coverage after PPR-CP implementation; Scenario-II, vaccinating 100% risk population during the first year followed by 30% bi-annual vaccination during two subsequent years as per the PPR-CP plan).

Statistical analysis: Two sample z-test of proportion was used to compare PPR incidence and mortality risk before and after PPR-CP implementation using the online web service <https://www.socscistatistics.com/tests/ztest/default.aspx>.

RESULTS AND DISCUSSION

Reported PPR vaccination coverage, and diagnosed and death cases in MP: The reported secondary data on vaccination against PPR in MP revealed that the vaccination coverage increased from 0.5% (2010-11) to 29% (2015-16) during the focussed vaccination period, whereas, it reached 80% after PPR-CP implementation (during 2016-17) (Fig. 1). PPR vaccination was carried out only in regions with previous reports of outbreak during focussed vaccination period hence the vaccination coverage was less in the state till PPR-CP implementation. Over the years, in consonance with increased vaccination coverage, the reported number of cases (841 during 2010-11) had declined and no cases were reported consecutively for two years (2017-19) after PPR-CP.

The results of the primary surveys undertaken during the survey-I and II are described further.

Socio-economic profile: The socio-economic profile of the sample households revealed that majority of them is

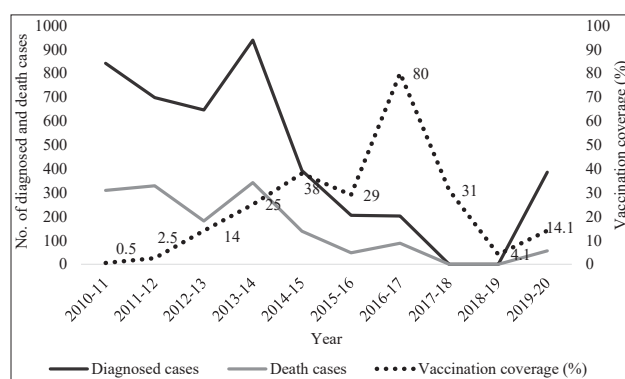


Fig. 1. Reported PPR cases and deaths and vaccination coverage from 2010-11 to 2019-20 in Madhya Pradesh.

landless and less educated. The average number of sheep and goats reared was 27 per flock during survey-I and declined to 22 per flock during survey-II. Majority (72%) of the sample farmers' nominal income during 2015-16 were less than ₹ 50000 whereas, during 2018-19, it was between ₹ 50000 to 100000. The other socio-economic details of the sample farmers are presented in Table 1.

PPR affected flocks and animals: The details of PPR affected flocks and disease incidence in sheep and goats among the surveyed flocks during survey-I and II in the study districts is presented in Fig. 2 and Fig. 3, respectively. Among the study districts, before PPR-CP implementation, the highest proportion of PPR affected flocks was in Bhopal (46.7%), followed by Betul (23%) and Sagar (22.5%) and after PPR-CP implementation, PPR affected flocks declined considerably in all the survey districts (Fig. 2). Similarly, the number of PPR affected animals also declined considerably after three years of PPR-CP implementation and the details are presented in Fig. 3.

PPR incidence, mortality, and CFR: The age- and sex-wise mortality and morbidity distribution of PPR in sheep and goats during survey-I and II are summarized in

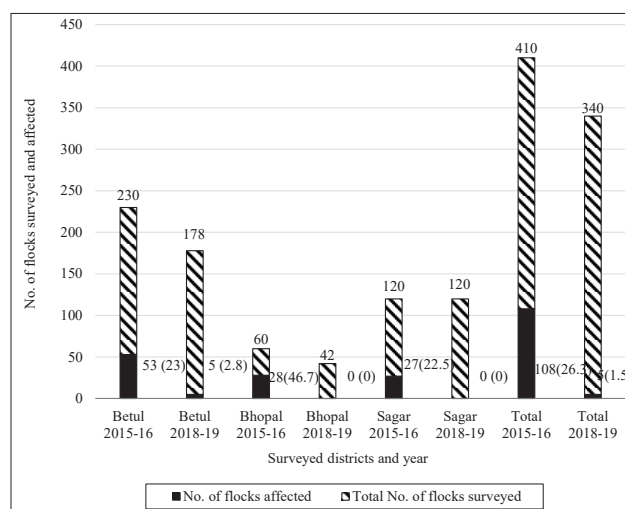


Fig. 2. Number of sheep and goat flocks surveyed and PPR affected (figures in parentheses are percentages) during before PPR-CP (2015-16) and post PPR-CP (2018-19) implementation in the surveyed districts in Madhya Pradesh.

Table 1. General characteristics of sample farmers in Madhya Pradesh during 2015-16 and 2018-19

Particular	Unit	2015-16 (Survey-I)	2018-19 (Survey-II)
No. of farmers surveyed	No.	410	340
Median age of the farmers (range)	years	46 (21-75)	49 (18-80)
<i>Education (%)</i>			
Illiterate	No.	170 (41.5)	153 (45.0)
Primary	No.	113 (27.6)	99 (29.1)
High school	No.	114 (27.8)	84 (24.7)
College and above	No.	13 (3.1)	4 (1.2)
Median family size (range)	No.	6 (1-16)	6 (1-19)
<i>Land holdings (%)</i>			
Landless	No.	232 (56.6)	167 (49.1)
Small (<5 acre)	No.	143 (34.9)	161 (47.4)
Medium (5 to 10 acre)	No.	28 (6.8)	10 (2.9)
Large (>10 acre)	No.	7 (1.7)	2 (0.6)
<i>Income levels (₹)</i>			
< 50000	No.	296 (72.2)	134 (39.41)
50001-100000	No.	98 (23.9)	203 (59.71)
100001-200000	No.	13 (3.2)	3 (0.88)
> 200001	No.	3 (0.7)	0 (0)
Total no. of sheep and goats in the sample farms	No.	11213	6847
Average no. of sheep and goats/farm	No.	27	22
Total no. of sheep and goats sold/year	No.	1087	1191
Average no. of sheep and goats sold/farm/year	No.	3	4

Figures in parentheses indicate percentage to the total.

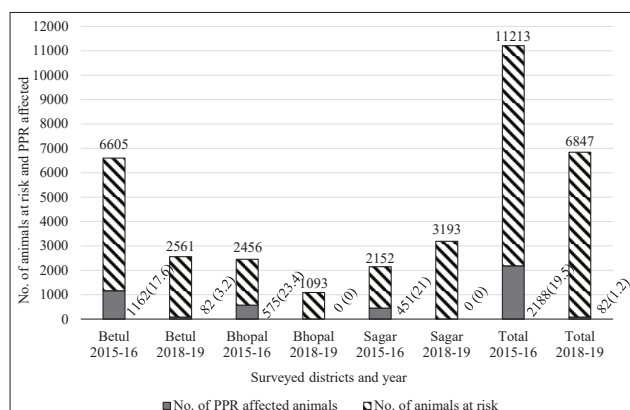


Fig. 3. Number of animals at risk, PPR affected, and incidence (figures in parentheses are percentages) during before PPR-CP (2015-16) and after PPR-CP (2018-19) implementation in the surveyed districts in Madhya Pradesh.

Supplementary Table 1. The animal level PPR incidence in sheep and goats was 19.5% during survey-I, and 1.2% during survey-II. Similar results of higher incidence (17.5%) before mass vaccination implementation (Singh *et al.* 2014) and lower incidence (0.8%) after annual PPR-MVC implementation (Govindaraj *et al.* 2019) was reported. In sheep, age-wise comparison of incidence showed a significant difference in >one-year ($z=7.93$, $p<0.01$) whereas sex-wise comparison, revealed incidence differed significantly in males ($z=2.34$, $p<0.05$) and females ($z=5.73$, $p<0.01$) between the two surveys. In goats, the PPR incidence in all the age groups and in males ($z=18.562$, $p<0.01$) and females ($z=29.768$, $p<0.01$)

differed significantly between the two surveys. In goats, the significant difference in mortality risk, between survey-I and II was observed in all age groups (Table 2) whereas, in sheep, the difference was observed in <6 months ($z=1.714$, $p<0.10$) and 6-12 month ($z=1.900$, $p<0.10$). Further, The CFR was less during survey-I compared to survey-II (Supplementary Table 1).

Estimated loss per animal: The estimated mortality loss, bodyweight reduction loss, distress sale loss, treatment cost, and the opportunity cost of labour per animal are presented in Table 2. The mortality loss ranged from ₹ 694 to 5793 and ₹ 4491 to 8434; body weight reduction ranged from ₹ 510 to 1855 and ₹ 517 to 1045; distress sale ranged from ₹ 1657 to 3413 and ₹ 3950 to 6699; treatment cost ranged from ₹ 44 to 316 and ₹ 90 to 156 and opportunity cost of labour ranged between ₹ 34.3 to 265.3 and ₹ 46.2 to 700 per animal in sheep and goats during the survey I and II, respectively. The pooled results revealed that the mean mortality loss per animal during the survey I was ₹ 2488 whereas it was ₹ 6192 during survey II. Similarly, the mean distress loss was ₹ 2507 and ₹ 5800 during surveys I and II, respectively. The observed variation in loss per animal between various loss components during surveys I and II might be attributed to variation in PPR severity level, price difference between the species in the study period, and the results concur with the earlier reports (Govindaraj *et al.* 2019).

Projected loss: The projected loss in the state before vaccination was ₹ 3261 million (₹ 326 crore) and it declined by one seventh after PPR-CP, implies the significant and

Table 2. Estimated per animal loss (₹) due to PPR in sheep and goats in Madhya Pradesh at 2018-19 constant prices

Parameter	Sheep		Goats		Pooled	
	2015-16 Survey-I	2018-19 Survey-II	2015-16 Survey-I	2018-19 Survey-II	2015-16 Survey-I	2018-19 Survey-II
Mortality loss	2556.4 (679-5887)	6225.1 (3000-6884)	2386.3 (679-5660)	6174.7 (5999.7-10000)	2487.8 (693.7-5792.5)	6191.5 (4491-8434)
Body weight reduction loss	902.3 (708-1698)	762.3 (508-1250)	817.6 (298-1981)	631.4 (563-875)	875 (509.6-1855)	679.7 (517-1045)
Distress sale loss	2915.5 (2264-3396)	5000 (1500-6500)	2065.7 (1019-3396)	6199.9 (5999-6500)	2506.7 (1657-3413)	5800.2 (3950-6699)
Treatment cost	140 (44-316)	131.6 (90-156)	140 (44-316)	131.6 (90-156)	140 (44-316)	131.6 (90-156)
Opportunity cost of labour	100.1 (34.3-265.3)	115.5 (46.2-700)	100.1 (34.3-265.3)	115.1 (46.2-700)	100.1 (34.3-265.3)	115.1 (46.2-700)

Figures in parentheses represent CI at 95%.

Table 3. Projected loss due to PPR in Madhya Pradesh at 2018-19 prices (₹ in million)

Particular	Sheep		Goats		Total	
	2015-16	2018-19	2015-16	2018-19	2015-16	2018-19
Mortality loss (A)	107.1 (29-156)	111.3 (39-331)	2531.3 (1312-3359)	233.1 (81-291)	2458.4 (1342-3515)	344.4 (120-622)
Body weight reduction loss (B)	11.9 (4.9-100)	1.4 (0.7-62)	231.7 (92-370)	0 (0-0)	243.6 (97-469)	1.4 (0.7-62)
Distress sale (C)	18.2 (6.3-144)	19.6 (2.1-71)	95.2 (9.8-225)	76.3 (16-199)	113.4 (16-370)	95.9 (18-270)
Treatment cost (D)	9.8 (4.9-89)	3.5 (0.7-39)	188.3 (99-450)	7.7 (4.2-104)	198.1 (104-539)	11.2 (4.9-143)
Opportunity cost of labour (E)	11.9 (3.5-98)	7 (3.5-81)	235.2 (104-494)	16.1 (5.6-176)	247.1 (107-593)	23.1 (9.1-258)
Total loss (A+B+C+D+E)	158.2 (48-587)	142.8 (46-586)	3102 (1617-4899)	333.2 (107-770)	3261 (1665-5486)	476 (153-1355)

Figures in parentheses represent range values.

positive impact of vaccination. The details of various components of loss projected are presented in Table 3.

Incremental benefit and cost ratio (IBCR): IBCR under scenario-I and II revealed a ratio of 69.75:1 and 39.4:1, respectively (Supplementary Table 2), whereas for the global eradication of PPR, Jones *et al.* 2016 reported 33.8:1 and 199 % of BCR and IRR, respectively. In India, BCR of 13.7:1; 34.65:1 and 37.78:1 under various scenarios for five-year vaccination cycle was reported (Govindaraj *et al.* 2019) and BCR of 12.0 for a five-year period using a dynamic herd model was estimated by Stem (1993). The estimated incremental benefits in the present study outweighed the incremental cost in both the vaccination scenarios, however, as per the vaccination plan being practiced now (scenario-I), the diagnosed cases and deaths were not reported only for two years following PPR-CP implementation and the PPR cases reoccurred during 2019-20 affecting 385 animals causing 56 deaths. The reoccurrence might be due to non-adoption of vaccination plan as stipulated in the PPR-CP, migration of infected animals from the contiguous states, high turnover ratio of sheep and goats results in naïve susceptible population for infection in a short span of time and sometimes concurrent

occurrence of other infections with PPR also aggravates the incidence (Kumar *et al.* 2022).

There exists an inverse relationship between PPR vaccination coverage and reported diagnosed cases and deaths. Further, the projected loss in the state declined by one-seventh after three years of PPR-CP implementation indicating the positive benefits of vaccination. The estimated incremental benefits outweighed the incremental cost in all vaccination scenarios, however, as per the vaccination plan being practiced now, the diagnosed cases and deaths due to PPR were not reported only for two years (2017-18 and 2018-19) following PPR-CP implementation, however, the cases reoccurred during 2019-20, as the state has not adopted the vaccination as stipulated in the PPR-CP. The diligent implementation of the vaccination strategy set out in the PPR-CP might have prevented the recurrence of outbreaks in the state. In conclusion, besides selecting the right vaccination strategy and its implementation in field conditions, animal movement management within and between the states and imposing compulsory vaccination certificates might reduce the PPR burden and aid in eradicating PPR by 2025 as envisaged by the Government of India, in line with the global strategy.

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