An epidemiological study of sheep pox infection in Karnataka state, India

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Summary

Analysis of retrospective quantitative sheep pox epidemiological data from the Government Animal Husbandry Department, Karnataka, India, covering 24 years revealed significant information on sheep pox. The state has a dense sheep population including some valuable breeds. Data revealed the endemicity of the disease: there were a considerable number of outbreaks and attacks, high mortality and case fatality rates and low immunisation coverage. None of the years studied were free from infection. Temporally, the disease was most prevalent between November and May. Spatially, the disease was recorded in 19 out of 27 districts; in some of these districts sheep pox was highly endemic, in some it was endemic at low levels and in the remaining districts outbreaks occurred sporadically. Environmental factors influenced disease occurrence. Vaccine production met only one tenth of the requirement, and its peak utilisation was in the dry season.

Keywords

Annual trends – Correlation – Environmental factors – Epidemiology – India – Karnataka – Sheep pox – Spatial pattern – Temporal distribution – Vaccine production – Vaccine utilisation.

Introduction

Sheep pox is a highly contagious and devastating viral disease of sheep, which occurs in Asia and Africa; it has either not been reported or been eradicated from developed countries (19). The virus belongs to the genus *Capripox* of the sub-family Chordopoxvirinae of the Poxviridae family (8). The virus is transmitted by the aerosol route, close contact and mechanically biting flies (4).

Sheep pox is one of the major pox viral diseases of domestic animals with considerable morbidity and a mortality of between 10% and 50%. The sheep is the primary host. All age groups are affected, but death occurs mainly in young lambs, followed by yearlings and adults. Severe economic losses result from the high mortality, abortions and mastitis, skin condemnation and loss of wool and mutton, and from consequent restriction of the export of meat, wool and skin (16). The disease appears on the World Organisation for Animal Health (OIE) list of notifiable diseases.

Sheep pox is endemic in India, and several outbreaks have been reported regularly from almost all states, including Karnataka, which is one of the major sheep rearing states in the country. Karnataka has a sheep population of more than 7.5 million, mainly reared by small and marginal farmers; sheep are an important source of family income

and are known as the 'moving banks' of shepherds. However, this income is often reduced by various infectious diseases, including sheep pox (6).

Information on epidemiology is meagre in Karnataka. Hence, a thorough study of the different aspects of sheep pox infection was necessary to understand the disease dynamics, mortality, prevalence, incidence, spatial and temporal distribution and other ecological (biometeorological) factors responsible for the maintenance of infection in nature and to formulate appropriate preventive measures to eradicate this infection.

Materials and methods

Epidemiological data

The epidemiological data on sheep pox infection in various parts of Karnataka were collected from the data transmitted to the Office of the Deputy Director for Disease Surveillance and Monitoring at the Department of Animal Husbandry and Veterinary Services in Bangalore.

Annual and monthly data

The quantitative data on sheep pox outbreaks, cases, deaths and vaccinations were collected for the period 1976 to 2000 from the Office of the Deputy Director for Disease Surveillance and Monitoring. Similarly, monthly data for individual districts were available from April 1996 to March 2000.

Data on vaccine production and utilisation

The data on total production and utilisation of the inactivated sheep pox vaccine in all districts of Karnataka for each month were collected from the Institute of Animal Health and Veterinary Biologicals (IAHVB), Bangalore, for 1991 to 2000.

Data on sheep population

A census of the sheep population is conducted once every six years by the Department of Animal Husbandry and Veterinary Services, Karnataka. The data were collected for the censuses of 1972, 1977, 1983, 1990 and 1997.

Data on the number of villages, climatic factors, physiography and soil types of Karnataka

The data pertaining to the number of villages, the climatic factors and the geography of Karnataka were obtained from the Project-Directorate of Animal Disease Monitoring and Surveillance (PD-ADMAS), IAHVB, Bangalore, Karnataka.

Analysis

Standard methods (3, 8, 22) and the statistical package for social survey (SPSS) for Windows, marketed by SPSS Inc., in Chicago and available at the PD-ADMAS in Bangalore, were used to analyse the epidemiological data.

Formulae

$$\text{Average sheep population of Karnataka} = \frac{\text{total sheep population over all the censuses (between 1976 and 2000)}}{\text{number of censuses}}$$

$$\text{Incidence rate} = \frac{\text{number of cases per annum}}{\text{average population of sheep during that particular year}} \times 10^5$$

$$\text{Mortality rate} = \frac{\text{number of deaths}}{\text{average population of sheep during that particular year}} \times 10^5$$

$$\text{Case fatality rate} = \frac{\text{number of deaths}}{\text{number of cases}} \times 100$$

$$\text{Vaccination rate} = \frac{\text{total number of vaccinations}}{\text{number of years} \times \text{average sheep population}} \times 100$$

Correlation

The correlations between various epidemiological factors and environmental factors were calculated using SPSS® 10.00 for Windows.

Results

Cumulative profiles

The retrospective quantitative data for the past 24 years in Karnataka included the information that there were:

- five livestock censuses
- 29,366 villages
- an average of 221 sheep per village
- an average annual sheep population of 6.44 million
- a total of 1,548 outbreaks
- 22,890 cases
- 4,262 deaths

– immunisation coverage of 3.45 million sheep
– three to four outbreaks per 10,000 km^2
– 22 outbreaks per 10,000 villages
– an incidence rate of 28.84 per annum per 10,000 sheep
– a case fatality rate of 18.62%
– a vaccination (inactivated) coverage of only 2.22%.

Annual trends

Outbreaks occurred in all years, with the highest number occurring in 1989, followed by 1978 and 1979; there was only one outbreak in 1985. The highest incidence rate was observed in 1989, followed by 1997, 1978, 1994 and 1999; the lowest incidence rate occurred in 1985. Similarly, the highest mortality rate occurred in 1989, followed by 1999, 2000 and 1978; the lowest mortality rate was observed in 1985. The highest vaccination percentage was achieved in 1998, followed by 1999, 1989 and 1997; the lowest vaccination percentage was in 1988 (Table I).

Temporal distribution

Data for various parameters were collated by month for the period April 1996 to March 2000. During this period, the disease occurred in all months of the year, but the highest number of outbreaks, the second highest incidence and the greatest mortality and vaccination coverage occurred in March; the fewest outbreaks and the lowest incidence, mortality and vaccination coverage occurred in August. The average case fatality rate was highest in January, followed by May and December, as shown in Table II.

Spatial distribution

Analysis of the spatial pattern indicated that the disease occurred in 19 of the 27 districts. The highest number of outbreaks was reported from Tumkur (n = 58), followed by Raichur (n = 43), Bagalkote (n = 31), and Mandya (n = 24) districts. Outbreaks were not reported in Bangalore (Urban), Belgaum, Bidar, Chamrajnagar, Dakshina Kannada, Kodagu, Udupi and Uttara Kannada districts. The lowest number of outbreaks occurred in Bangalore (Rural), Bijapur, Chickmagalur, Dharwar, Gadag, Hassan,

Table I
Annual statistics of sheep pox in Karnataka (1976-2000)

Year	Number of outbreaks	Incidence rate per 10^5 sheep	Mortality rate per 10^5 sheep	Case fatality rate (%)	Vaccination rate (%)
1976	8	3.56	2.28	64.07	2.08
1977	85	5.84	5.83	99.74	1.66
1978	166	33.58	6.89	20.51	1.91
1979	135	4.25	2.28	53.62	2.19
1980	46	3.07	1.16	37.69	1.38
1982	31	4.82	2.04	42.49	0.61
1983	13	10.86	2.04	18.87	0.61
1984	6	0.97	0.31	31.25	0.57
1985	1	0.08	0.02	20.00	0.72
1986	17	1.46	0.40	27.37	0.76
1987	14	13.33	1.88	14.10	0.46
1988	3	0.83	0.03	3.70	0.31
1989	634	99.09	9.92	10.02	4.02
1990	23	9.37	0.86	9.21	3.32
1991	4	0.97	0.49	50.79	1.29
1992	10	0.67	0.30	45.45	2.60
1993	10	3.45	0.08	2.23	2.40
1994	25	33.25	3.91	11.77	1.73
1995	18	1.45	0.91	62.77	3.04
1996	26	10.77	1.13	11.73	2.66
1997	27	41.90	2.13	5.08	3.90
1998	45	11.63	3.24	27.51	6.49
1999	89	32.08	9.05	28.19	4.86
2000	62	25.41	8.49	33.41	3.64

Table II
Seasonality of sheep pox in Karnataka (April 1996 to March 2000)

Month	Number of outbreaks	Average incidence rate per 10^5 sheep	Average mortality rate per 10^5 sheep	Average case fatality rate (%)	Average vaccination rate (%)
January	32	2.68	1.73	64.04	0.61
February	25	1.05	0.30	28.57	0.57
March	43	7.21	1.86	25.76	0.80
April	28	3.78	0.37	9.79	0.54
May	23	1.68	0.79	46.22	0.31
June	7	0.22	0.03	12.28	0.29
July	4	0.16	0.05	28.57	0.26
August	3	0.03	0.004	11.11	0.19
September	6	0.62	0.24	38.75	0.22
October	15	8.86	0.01	0.13	0.36
November	23	1.89	0.19	10.40	0.45
December	23	0.49	0.20	40.62	0.58

Koppal and Mysore districts. Raichur district experienced the highest incidence rate (8.04 cases per 10^5 sheep per year), followed by Bellary (5.75 cases per 10^5 sheep per year), Bijapur (3.16 cases per 10^5 sheep per year) and Mandya (3.14 cases per 10^5 sheep per year). The mortality and case fatality rates ranged from 0 to 1.98 per 10^5 sheep per year and 0% to 82.55%, respectively. The vaccination (inactivated) coverage was very low in all districts, being highest in Tumkur (0.78%) (Table III).

Influence of macro-ecosystems

Before the reorganisation of districts in 1999, the state had 20 districts; there are now 27 districts. The arid ecosystem includes Bijapur, Bagalkote, Bellary, Raichur and Koppal districts; the semi-arid ecosystem includes the districts of Bidar, Gulbarga, Dharwar, Gadag, Haveri, Shimoga, Chitradurga, Davangere, Chickmagalur, Kolar, Hassan, Mysore, Chamrajnagar, Belgaum, Bangalore (Urban), Bangalore (Rural), Tumkur and Mandya; the coastal ecosystem includes the districts of Uttara Kannada, Dakshina Kannada, Udupi and Kodagu. The study of the influence of different ecosystems on sheep pox attacks indicated that the highest annual incidence rate (19.43 per 10^5 sheep) occurred in the arid ecosystem, followed by the semi-arid ecosystem (9.25 per 10^5 sheep); the coastal ecosystem had almost no cases (Table IV). Thus, sheep pox can be classified as hyperendemic in the arid ecosystem, endemic in the semi-arid ecosystem and low or sporadic in the coastal ecosystem.

Influence of physiography

The macro-physiography of the state has been divided into three areas, namely the Western Ghats, the Eastern Ghats and the Deccan Plateau. The Western Ghats includes the districts Uttara Kannada, Dakshina Kannada, Udupi and Kodagu. The Eastern Ghats includes Shimoga, Chitradurga, Davangere, Chickmagalur, Tumkur, Hassan, Mandya, Bangalore (Urban), Bangalore (Rural), Kolar, Mysore and Chamrajnagar. The Deccan Plateau includes the districts Bidar, Gulbarga, Bijapur, Bagalkote, Raichur, Koppal, Belgaum, Dharwar, Haveri, Gadag and Bellary. During the period under study, the highest average annual incidence rate (21.58 per 10^5 sheep) and average annual mortality rate (4.50 per 10^5 sheep) occurred in the Deccan Plateau; in the Eastern Ghats the incidence and mortality rates were 7.10 per 10^5 sheep and 1.26 per 10^5 sheep, respectively. No outbreaks of sheep pox were reported in the districts of the Western Ghats (Table IV).

Influence of different soils

The soils of Karnataka are classified into four types: red loamy; red and laterite; shallow and medium deep black; and red and black. The red and laterite soil is found in four districts (Uttara Kannada, Dakshina Kannada, Udupi and Kodagu). Gulbarga, Bidar, Belgaum, Haveri, Gadag and Dharwar districts are rich in shallow and medium deep black soils, whereas Bijapur, Bagalkote, Raichur, Koppal and Bellary are enriched with red and black soils. The study of soil type in relation to sheep pox infection showed a higher incidence rate (19.43 per 10^5 sheep) in the districts enriched with red and black soils than in the districts with red loamy soil and shallow and medium deep black soils, where the incidence rates were 7.10 per 10^5 sheep and 2.15 per 10^5 sheep, respectively. No outbreaks, incidence or mortality were reported from the districts possessing red and laterite soils (Table IV).

Table III
Spatial distribution of sheep pox infection in Karnataka (April 1996 to March 2000)

District	Number of outbreaks	Incidence rate per 10^5 sheep per year	Mortality rate per 10^5 sheep per year	Annual average case fatality rate (%)	Annual average vaccination rate (%)
Bagalkote	31	2.33	0.97	41.98	0.64
Bangalore (Rural)	3	0.03	0	0	0.05
Bangalore (Urban)	0	0	0	0	0.06
Belgaum	0	0	0	0	0.20
Bellary	8	5.75	0.13	2.40	0.27
Bidar	0	0	0	0	0.007
Bijapur	4	3.16	0	0	0.40
Chamrajnagar	0	0	0	0	0.0002
Chickmagalur	3	0.07	0	0	0.004
Chitradurga	6	0.45	0.27	60.16	0.34
Dakshina Kannada	0	0	0	0	0
Davangere	7	0.21	0	0	0.14
Dharwar	3	0.18	0.07	54.28	0.143
Gadag	2	1.14	0.94	82.55	0.211
Gulbarga	8	0.38	0.12	31	0.10
Hassan	2	0.04	0.004	0.34	0.05
Haveri	6	0.47	0.19	39.51	0.04
Kodagu	0	0	0	0	0.001
Kolar	12	1.11	0.23	20.76	0.72
Koppal	4	0.13	0.06	48.57	0.08
Mandya	24	3.14	1.31	4.17	0.24
Mysore	2	0.04	0.007	16.67	0.02
Raichur	43	8.04	1.98	24.66	0.59
Shimoga	6	0.32	0.10	32.14	0.06
Tumkur	58	1.65	0.50	30.46	0.78
Udupi	0	0	0	0	0
Uttara Kannada	0	0	0	0	0

Influence of amount of rainfall

The average annual rainfall in the state ranges from 562 mm to 4,119 mm. Accordingly, the districts are divided into four groups. Group I (562 mm-600 mm) includes Bijapur, Bagalkote, Raichur, Koppal, Bellary, Chitradurga, Davangere and Tumkur. Gulbarga, Belgaum, Dharwar, Gadag, Haveri, Kolar, Mandya, Mysore and Chamrajnagar belong to Group II (601 mm-750 mm). Group III (751 mm-850 mm) comprises Bidar, Hassan and Bangalore (Urban and Rural) districts; and Group IV (851 mm-4,119 mm) consists of Uttara Kannada, Dakshina Kannada, Udupi, Kodagu, Shimoga and Chickmagalur districts. When the prevalence of sheep pox was compared in districts with different average annual rainfalls, it was observed that the highest number of outbreaks (n = 39), incidence rate (21.08 per 10^5 sheep) and mortality rate (3.94 per 10^5 sheep) were recorded in Group II districts, followed by Group I and Group III; the lowest figures were seen in the Group IV areas (Table IV).

Influence of relative humidity

Comparison of relative humidity and occurrence of sheep pox revealed that the largest number of outbreaks (n = 19) occurred in the range of 50% to 60% humidity, whereas the highest incidence rate (11.48 per 10^5 sheep) was reported in the range of 81% to 90% humidity; no sheep pox was reported in areas where the relative humidity is high (91%-98%) (Table IV).

Influence of temperature

The study found that sheep pox infection was not reported in areas where the maximum temperature ranged from 23.9°C to 25°C, whereas the highest number of outbreaks (n = 17), incidence rate (10.16 per 10^5 sheep) and mortality rate were reported in areas where the temperature ranged from 27.6°C to 30°C, 30.1°C to 32.5°C and 27.6°C to 30°C, respectively. The lowest

Table IV
Cumulative sheep pox profiles in different macro-ecosystems and geographical regions and under different climatic conditions (April 1996 to March 2000)

Region	Average number of outbreaks per year*	Incidence rate per 10^5 sheep per year	Mortality rate per 10^5 sheep per year
Macro-ecosystem			
Arid	23	19.43	3.17
Semi-arid	36	9.25	2.59
Coastal	0	0	0
Macro-physiography			
Western Ghats	0	0	0
Eastern Ghats	31	7.10	1.26
Deccan Plateau	27	21.58	4.50
Temperature (°C)			
23.9-25	0	0	0
25.1-27.5	3	1.37	0.08
27.6-30	17	3.59	1.83
30.1-32.5	12	10.16	0.52
32.6-35	10	3.52	0.59
35.1-37.5	12	7.14	1.79
37.6-40.4	5	2.91	0.94
Soil types			
Red loamy	31	7.10	1.25
Red and laterite	0	0	0
Shallow and medium deep black	5	2.15	1.33
Red and black	21	19.43	3.16
Rainfall (mm)			
562-600	11	6.08	1.32
601-750	39	21.08	3.94
751-850	6	1.07	0.39
851-4,119	3	0.45	0.10
Humidity (%)			
50-60	19	11.03	3.05
61-70	13	3.46	1.95
71-80	12	2.71	0.29
81-90	14	11.48	0.46
91-98	0	0	0

*Numbers of outbreaks are rounded to the nearest integer

number of outbreaks, incidence rate and mortality rate were reported in areas with a temperature range of 25.1°C to 27.5°C for the period under study (Table IV).

Correlation

The bivariate correlation studies revealed that sheep pox occurrence was significantly influenced ($P \leqslant 0.01/0.05$) by various aspects of the regional geography and climate (Table V).

Trends in vaccine production and utilisation

The total production and utilisation of the inactivated sheep pox vaccine were compared across different years, months and districts. The annual production data showed that the highest number of doses (0.8 million) were produced in 2000, whereas in 1992 only 0.12 million doses were produced. The monthly utilisation statistics showed that the vaccine was utilised during all months of the year, with the most doses (0.55 million) being utilised in January, followed by March (0.43 million doses) and

Table V
Correlations

Factors compared	Number of outbreaks per unit area	Number of outbreaks per unit population	Incidence rate	Mortality rate	Vaccination rate
Number of outbreaks per unit area	1	0.539 [b]	0.034	– 0.082	0.095 [b]
Number of outbreaks per unit population	0.539 [b]	1	0.294 [b]	– 0.032	0.112 [b]
Incidence rate	0.034	0.294 [b]	1	1	– 0.029
Mortality rate	– 0.082	– 0.032	1	1	0.052
Vaccination rate	0.095 [b]	0.112 [b]	– 0.029	0.052	1
Average sheep population of state	0.146 [b]	0.018	– 0.193 [a]	0.026	0.03
Average sheep population of village	0.146 [b]	0.026	– 0.15	0.137	0.055
Macro-ecosystem	– 0.118 [b]	– 0.064 [a]	– 0.035	– 0.101	– 0.05
Macro-physiography	0.058 [a]	0.024	0.039	0.155	0.054
Soil type	0.068 [a]	0.024	0.039	0.14	0.078 [b]
Regional climate	– 0.041	– 0.03	0.035	0.101	0.015
Normal rainfall	– 0.108 [b]	– 0.033	0.111	– 0.199 [a]	– 0.045
Morning wet bulb temperature	– 0.059 [a]	– 0.071 [a]	0.071	– 0.072	– 0.07 [b]
Morning dew point temperature	– 0.105 [b]	– 0.078 [b]	0.108	– 0.172	0.11 [b]
Morning relative humidity	– 0.153 [b]	– 0.046	0.089	– 0.234 [a]	– 0.11 [b]
Morning vapour pressure	– 0.106 [b]	– 0.078 [b]	0.105	– 0.167	– 0.10 [b]
Morning rainfall	– 0.073 [a]	– 0.044	0.149	– 0.137	– 0.06 [a]
Evening dry bulb temperature	0.11 [b]	0.029	– 0.024	0.173	– 0.055
Evening wet bulb temperature	– 0.082 [b]	– 0.04	0.047	– 0.099	– 0.048
Evening dew point temperature	– 0.141 [b]	– 0.054	0.072	– 0.26 [b]	– 0.08 [b]
Evening relative humidity	– 0.155 [b]	– 0.057	0.07	– 0.268 [b]	– 0.09 [b]
Evening vapour pressure	– 0.145 [b]	– 0.059 [a]	0.073	– 0.261 [b]	– 0.08 [b]
Morning maximum temperature	0.092 [b]	0.032	0.001	0.142	0.059 [a]
Morning minimum temperature	0.016	– 0.069 [a]	– 0.013	0.099	– 0.02
Wind speed	0.021	– 0.029	– 0.26 [b]	0.109	0.003

a) Correlation is significant at 0.01 level (two-tailed)
b) Correlation is significant at 0.05 level (two-tailed)

December and February (0.425 million doses each). The fewest doses (0.2 million) were utilised in August. The statistics for cumulative use by district revealed that Kolar, Raichur, Koppal, Tumkur, Bijapur, Bagalkote, Chitradurga, Davangere, Bellary, Dharwar, Gadag, Haveri and Gulbarga are the highest consumers of sheep pox vaccine. Chickmagalur, Bidar, Dakshina Kannada, Chamrajnagar and Kodagu districts used only a negligible amount of vaccine.

Discussion

Sheep pox is one of the endemic diseases of sheep in India, and its prevalence causes heavy economic losses. The disease is widespread in Karnataka, and the extent of its spread, the seasonal pattern and the climatic and environmental factors influencing its occurrence are not clearly understood.

Cumulative profiles

Analysis of retrospective quantitative data for sheep pox for the past 24 years revealed a considerable number of outbreaks in Karnataka throughout the period under study, implying that sheep pox is endemic in the state. Plausible reasons for these outbreaks include low vaccination coverage compared to the sheep population, migration, environmental conditions and vaccination failure. The host factors responsible could include age, sex, breed and physiological, nutritional and immunological status (2, 9, 13, 14, 15, 17, 20). The possible agent factors include strain, virulence and pathogenicity. A combination of host, agent and environmental factors could have precipitated the disease (22). Other possible factors include a lack of efficient feedback from the field level regarding outbreaks, negligence on behalf of the individual farmers and a preference for ovination (Nagaraj, personal communication) over vaccination in rural areas because it is cheap and easy and there is a false notion that it protects sheep against infection.

The high case fatality rate indicates the severity of the disease. Case fatality rates for sheep pox ranging from 52.47% to 57.9% have been reported from the states of Rajasthan and Gujarat in different breeds (Bikaneri, Mandya, mutton and wool types) (13, 14, 20).

The vaccination coverage was only 2.22%. This shows that most of the sheep population was left unprotected against sheep pox. This could be one of the major factors contributing to disease outbreaks. The Directorate of Animal Husbandry and Veterinary Services has reported a similar trend in vaccination coverage in the state (6). The same problems with vaccination against sheep pox exist in other Indian states. Sheep may be left without protection or a minority of sheep may be vaccinated or ovination may be practiced.

Annual trends

The study of annual trends of sheep pox in Karnataka showed that the most outbreaks occurred in 1989 and the fewest occurred in 1985. Not a single year of the period studied was free from outbreaks, and, although some vaccination was carried out, the disease is still endemic. The high incidence in 1989 might be due to several factors, such as efficient reporting of outbreaks, a higher number of susceptible sheep, the host and agent factors mentioned earlier, ovination in lieu of vaccination in rural areas and various environmental factors. A reversal in one or more of these factors might have contributed to the low incidence in 1985.

The highest vaccination rate (6.49%) occurred in 1998 and the lowest rate (0.31%) occurred in 1988; this was due to the demand and supply of vaccines. The low vaccination coverage in 1988 might have been responsible for the increase in outbreaks in 1989. Various workers have reported similar findings in different parts of India (5, 7, 10, 12, 13, 14, 15, 18, 20, 21).

Temporal distribution

When the monthly data was analysed, it was found that the peak number of outbreaks occurred during the month of March, followed by January, April, February, May, November and December. However, outbreaks were recorded during all months of the year. During the month of August, the fewest outbreaks were recorded. This shows that the disease peaks between November and May, because of adverse climatic conditions. During this season, sheep are exposed to adverse temperatures, which cause the release of stressors that could suppress the immune system, predisposing the sheep to infection. Other probable causes include migration during the summer months in search of fodder (7, 11) and possibly ovination practiced by shepherds at the field level as a prophylactic measure. Migration and ovination aid the spread of virulent forms of the virus. Various workers (5, 7, 10, 13, 14, 15, 17, 18) have reported similar observations in India. Sheep pox outbreaks have also been reported in Oman and Yemen (11), in Mauritania (9) and in Algeria (1). These reports indicate that sheep pox occurs between October and July, depending upon the prevailing climatic conditions and the breeds of sheep native to that place. So it can be concluded that the disease is most prevalent between November and May.

Spatial pattern

The high number of outbreaks in Tumkur, Raichur, Bagalkote, Mandya and Kolar districts might be due to high sheep density, climatic conditions, ovination, insufficient vaccination coverage, efficient reporting of outbreaks, movement of animals due to drought, or agent factors. A low number of outbreaks were reported in Gadag and Mysore. No outbreaks or only sporadic outbreaks were reported in Bangalore (Urban), Belgaum, Bidar, Chamrajnagar, Dakshina Kannada, Kodagu, Udupi and Uttara Kannada; this might be due to the prevalence of factors that adversely affect the survival of the sheep pox virus. The disease was reported in 19 out of the 27 districts of the state. One of the most significant ecological features of sheep pox infection in Karnataka was that areas with a high incidence of sheep pox had low rainfall and high temperatures and the flora consisted mostly of bushes and thorny plants such as *Acacia* species. Owing to a scarcity of fodder, sheep in these areas nibble *Acacia* leaves, which damage the skin on the face, lips and other exposed areas, making it easier for sheep pox to pass from infected sheep to susceptible sheep.

Influence of macro-ecosystems

When sheep pox infection was compared in different ecosystems, it was found that the highest incidence rate occurred in arid areas, followed by semi-arid areas; there were no outbreaks in the coastal areas. The reasons for the high rate in arid areas might be high temperature, low humidity, high density of sheep, migration of sheep, ovination, low rainfall, partial vaccination coverage and illiteracy of the shepherds. The low incidence in coastal areas might be due to heavy rainfall, low temperature, good vegetation, high humidity, a smaller sheep population, a high literacy rate, very little migration or ovination and better vaccination coverage of the flock. In coastal areas, probably owing to heavy rainfall and high humidity, the scab material may not be carried in the air for long distances, so the infection cannot be spread as readily as in other ecosystems where sheep pox is more prevalent. When the scab material settles in wet soils, it may naturally

disintegrate, denaturing the virus so that it does not pose a threat to susceptible animals. There is no published report available that correlates the macro-ecosystem with the occurrence of sheep pox infection.

Influence of physiography

When the physiographic influence on sheep pox infection was studied, it was found that the Deccan Plateau had significantly higher incidence and mortality rates than the Eastern Ghats. The Deccan Plateau is probably more prone to adverse temperature and dry weather than are the Eastern Ghats and the Western Ghats. There was almost no sheep pox in the Western Ghats. Again, no reports are available in the literature on this particular issue.

Influence of soil type

The study revealed that the highest incidence rates occurred on red and black soils, followed by red loamy soils and black soils. The reasons for this may be that areas with red and black soils receive low rainfall and have high temperatures. Hence, fodder production is low, making the shepherds migrate, which places the sheep under much stress and makes them more prone to infections, including sheep pox. Similarly, high temperatures lead to a high incidence of sheep pox and other infections. Also, the density of sheep in these areas is high. Soil associated factors might play an important role in the high incidence rates in areas rich in red loamy soils and black soils. No sheep pox was reported in areas having red and laterite soils, which may be because these areas have high rainfall, low temperature, high vegetation and tree cover, plenty of fodder, high humidity, less migration and a lower sheep density.

Influence of amount of rainfall

When the sheep pox infections for the period under study were compared, it was found that the incidence was higher in areas with low rainfall, followed by areas with moderate rainfall and areas with moderate to high levels of rainfall. The fewest incidences of sheep pox were seen in the 'Malnad' area (Uttara Kannada, Dakshina Kannada, Udupi, Kodagu, Chickmagalur and Shimoga), which received the highest rainfall in the state. The main effect of increasing rainfall is to increase the heat loss from an animal, and thus the intensity of cold stress, at a given air temperature; rainfall also affects the normal process of digestion (23). Hence, it could be that sheep pox was more prevalent in areas receiving low to moderate levels of rainfall owing to adverse climatic conditions, a high density of sheep and migration. The low incidence of sheep pox in the 'Malnad' area might be due to high levels of rainfall, a low density of sheep and less migration. Rainfall might influence the infection indirectly.

Influence of relative humidity

The incidence rate of sheep pox was highest in the humidity range 81%-90%, followed by the ranges 50%-60%, 61%-70% and 71%-80%. Mortality was highest in areas with 50%-60% humidity, followed by areas with humidity ranges of 61%-70%, 81%-90% and 71%-80%. There was no sheep pox reported in areas with 91%-98% humidity. This finding indicates that the relative humidity of the environment has a significant influence on sheep pox occurrence. In areas with higher relative humidity infectious material might absorb more moisture from the atmosphere and settle (23), whereas in areas with low relative humidity a higher incidence rate is reported.

Influence of temperature

Comparison of epidemiological data for sheep pox in areas with different temperature ranges revealed that the highest number of outbreaks and the highest incidence rate occurred in areas with mean temperature ranges of 27.6°C-30°C and 30.1°C-32.5°C, respectively; there was almost no sheep pox in areas with a lower temperature (23.9°C-25°C). This indicates that high temperature probably increases the stress on the sheep and alters their metabolic rate (23), which, in turn, increases the severity of infection.

During a search of the literature with respect to sheep pox infection in India, it was observed that no epidemiological study has been undertaken to investigate the influence of several environmental factors on the occurrence of sheep pox. The possible relationship between sheep pox infection and environmental factors in Algeria has been studied (1). However, this work is probably the first to examine the effect of several environmental factors on the occurrence of sheep pox infection in Karnataka.

Correlation studies

The correlation studies indicated that, in addition to host and agent factors, environmental factors played an important role in the incidence and mortality rates of sheep pox (22).

Vaccine production and utilisation

The data indicate that there was a wide chasm between the number of doses of inactivated vaccine produced and the actual sheep population of the state. This limited production of vaccine might be due to the high quantity of virus required per dose in the vaccine, the lack of a better cell culture system for growing and propagating the virus, variation in the titre of the virus between different batches, lack of sufficient infrastructure and the cost involved.

The study of utilisation of sheep pox vaccine by district revealed that the most doses were utilised in districts where there were large populations of sheep with a high incidence of sheep pox; very little vaccine was utilised in districts where there were low sheep populations (6). Utilisation of vaccine is highest in the dry season, when more outbreaks of sheep pox occur. The lowest vaccine utilisation was in the rainy season, i.e. in August. The farmers get their flocks vaccinated during outbreaks, to protect the sheep, and hence there is a greater demand for the vaccine during the dry season.

Conclusions

To summarise, sheep pox occurs throughout the year but is most prevalent during the months of November to May, reaching a peak in March. Hence, the appropriate time to vaccinate flocks is at the beginning of September. Apart from a few districts in the coastal area, in much of Karnataka, especially Tumkur, Bagalkote, Raichur, Mandya and Kolar, sheep pox is highly endemic, as exhibited by the high numbers of outbreaks, incidence rate, mortality and loss of revenue. Hence, ring vaccination should be undertaken for a period of two to three years, to try to eradicate the disease. In addition to virus and host factors, environmental conditions should be considered when attempting to eradicate this disease with the appropriate attenuated vaccines.

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Une étude épidémiologique de l'infection par le virus de la clavelée dans l'État de Karnataka, Inde

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Résumé

L'analyse de données épidémiologiques quantitatives et rétrospectives sur la clavelée émanant du Government Animal Husbandry Department (département public de l'élevage), Karnataka, Inde, et couvrant 24 années, a révélé des informations intéressantes sur cette maladie. L'État de Karnataka a une population ovine assez dense qui comprend quelques races précieuses. Les données ont révélé le caractère endémique de la maladie : un nombre considérable de foyers et de contaminations, des taux de mortalité et de létalité élevés et un faible taux d'immunisation ont été constatés. Le Karnataka n'a été indemne d'infection pendant aucune des années étudiées. Sur le plan temporel, c'est entre novembre et mai que la prévalence était la plus forte. Sur le plan spatial, la maladie a été observée dans 19 districts sur 27 ; dans certains de ces districts, la clavelée était fortement endémique, dans d'autres elle était endémique à de faibles niveaux et dans les districts restants elle apparaissait de façon sporadique. Les facteurs environnementaux ont influé sur l'apparition de la maladie. La production de vaccins n'a couvert que 10 % des besoins et le pic de l'utilisation a eu lieu pendant la saison sèche.

Mots clés

Clavelée – Corrélation – Distribution temporelle – Épidémiologie – Facteurs environnementaux – Inde – Karnataka – Production de vaccins – Tendance annuelle – Utilisation de vaccins.

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Estudio epidemiológico de la viruela ovina en el estado de Karnataka (India)

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Resumen

El análisis de datos epidemiológicos cuantitativos sobre la viruela ovina en los últimos 24 años en el estado de Karnataka (India), procedentes del Departamento de Producción Animal del gobierno estatal, desveló interesante información sobre la enfermedad. El estado alberga una densa población ovina, con algunas razas de gran valor. Los datos pusieron de manifiesto la endemicidad de la viruela ovina: además de un número considerable de brotes y crisis, se registraron tasas elevadas de mortalidad y letalidad y una escasa cobertura de inmunización. En ninguno de los años estudiados dejó de observarse la infección. Ésta resultó más prevalente entre noviembre y mayo. En cuanto a su distribución espacial, se describieron casos en 19 de los 27 distritos: en algunos de ellos la viruela ovina era muy endémica, en otros presentaba un nivel bajo de endemicidad y en los restantes sólo había brotes esporádicamente. Se observó también que los factores ambientales influían en la presencia de la enfermedad. La producción de vacunas satisfacía sólo una décima parte de las necesidades, y su nivel máximo de utilización coincidía con la estación seca.

Palabras clave

Correlación – Distribución espacial – Distribución temporal – Epidemiología – Factor ambiental – India – Karnataka – Producción de vacunas – Tendencia anual – Utilización de vacunas – Viruela ovina.

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