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Review

Prospects of control and eradication of capripox from the Indian subcontinent: A perspective

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ABSTRACT

Sheeppox and goatpox, two endemic capripox infections in India, pose a significant economic threat to small ruminant productivity in the subcontinent. Vaccination of all susceptible sheep and goats is the feasible and sustainable means of control. Availability of effective live attenuated vaccines that are inherently thermostable and development of improved diagnostics provide the opportunities to initiate effective control measures for capripox. All animals older than 4 months can be vaccinated with the current homologous vaccines using a single vaccination by intradermal or subcutaneous routes. The success of the control program needs to be monitored by active surveillance particularly for the presence of virus, as sero-monitoring does not enable the differentiation of infection and vaccination. And also the seroconversion following capripox vaccination is not detectable enough by the available tools. Sustained control efforts call for socio-economic and political stability, adequate infrastructure and logistic support to store and transport vaccines for reaching out vaccines to the remote end users. Availability of veterinary services, improved extension services for increased awareness among farmers, contribute significantly to the control campaigns. Poor vaccination coverage and in-adequate infrastructure in major parts of the country are some of the major elements that come in the way of effective implementation of building herd immunity through immunization.

Contents

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1. Introduction

Members of the genus *Capripoxvirus* (Poxviridae) are Office Internationale des Epizooties (OIE) notifiable diseases (oie.int) reflecting their economic significance. The capripox diseases of goatpox and sheeppox and are prevalent in Africa above the equator, Asia, the Middle East, and occasional outbreaks occur in regions of Europe surrounding the Middle East. In contrast, lumpy skin disease is endemic in Africa and outbreaks have occurred in the Middle East surrounding Egypt (Babiuk et al., 2008). In India, an outbreak of capripox was reported as early as 1936 (Anon, 1936–37). Ever since numerous outbreaks have been reported across the country (Lall et al., 1947; Das et al., 1978; Bandyopadhyay et al., 1984; Saha et al., 1985; Joshi et al., 1999; Roy et al., 2008; Bhanuprakash et al., 2010; Venkatesan et al., 2010; Verma et al., 2010). The sheeppox and goatpox outbreaks in India during 2000–2008 are depicted in Fig. 1. In India, both sheeppox and goatpox occur often and cause high annual losses due to their enzootic nature. Vaccination is in use for several years particularly for sheeppox to reduce the disease endemicity. Live goatpox vaccine is introduced only recently to contain the disease incidence in goats. Vaccination is the only practical countermeasure against capripoxvirus infections in the country.

2. Capripoxviruses

2.1. Classification and characteristics of the capripoxviruses

Sheeppox and goatpox are caused by sheeppox virus (SPPV) and goatpox virus (GTPV), respectively; and both viruses belong to the genus *Capripoxvirus*, the subfamily *Chordopoxvirinae* in the *Poxviridae* family. The remaining member of *Capripoxvirus* is lumpy skin disease virus (LSDV) which does not exist in India. All these viruses are closely related and indistinguishable from each other serologically and they share over 96% sequence homology among themselves (Tulman et al., 2002).

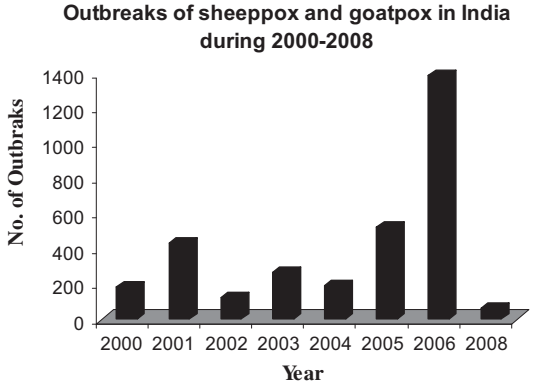

Fig. 1. Outbreaks sheeppox and goatpox in India during 2000–2008. (Source: dahd.nic.in).

2.2. Host range and transmission

Both SPPV and GTPV are generally considered host-specific but some strains are infective to heterologous hosts also. The molecular basis of host specificity is intriguing although some genes are recently implicated to confer host preference (Tulman et al., 2002). It is observed that most African strains share more or less equal host pathogenicity for either sheep or goats, while almost all Indian strains are host specific affecting homologous hosts (Bhowmik et al., 1986; Dubey et al., 1987; Mullick, 1988; Bhanuprakash et al., 2006b) under natural/experimental conditions. There is at least one confirmed report of simultaneous infection of sheep and goats in Kenya showing pock-like lesions in both sheep and goats, wherein the causative agent was found to be a naturally attenuated virus, designated as "Kenya Sheep and Goat (KSG) virus (Davies, 1976). Human infections with capripoxvirus do not occur and capripoxviruses are not pathogenic to humans (Anon, 1996).

Virus transmission can occur through aerosols generated from infected animals or through direct abraded skin/mucosal contact or indirectly through mechanical transmission by vectors (OIE, 2004; Kitching and Mellor, 1986). There is no evidence for the existence of animals persistently infected either with GTPV or SPPV; that means there is no carrier state. However in the experimentally infected animals, viral shedding has been found to occur albeit at low levels up to 6 weeks on virus inoculation (Bowden et al., 2008). Vertical transmission of the virus occurs in some infected animals (our unpublished data).

2.3. Features of disease in sheep and goats

The clinical signs in sheep and goat include mild to severe clinical disease development of erythematous macules, vesicles, papules, pustules and scab on the skin. The lesions may also develop on the mucous membrane and on internal organs, causing respiratory signs, diarrhea, depression, emaciation, abortion and sometimes death (Fig. 2). Sheeppox and goat pox occur throughout the regions in which sheep and goats are reared (ICAR, 1998), adversely affecting small ruminant productivity. Morbidity and mortality rates may be as high as 100% in naïve animals. Young and exotic animals are, respectively, more susceptible than adult and indigenous breeds (Bhanuprakash et al., 2006b). As per the latest census, India has an estimated 140.05 million goats and 78.7 million sheep (dahd.nic.in).

3. Economic impact of capripoxvirus diseases in India

Enzootic capripox is responsible for tangible (direct) and intangible (indirect) economic losses to the small ruminant productivity. Direct losses though mortality is less but morbidity and the disease after-effects on the wool and leather quality and meat productivity are considerable. Goats and sheep with a combined population of over 218 million contribute significantly to the Indian meat and leather industries. The productivity losses due to sheeppox and goatpox endemic areas include reduced milk yield, reduced weight gain, increased abortion rates, damage to wool and hide, and increased susceptibility to pneumonia and fly strike,

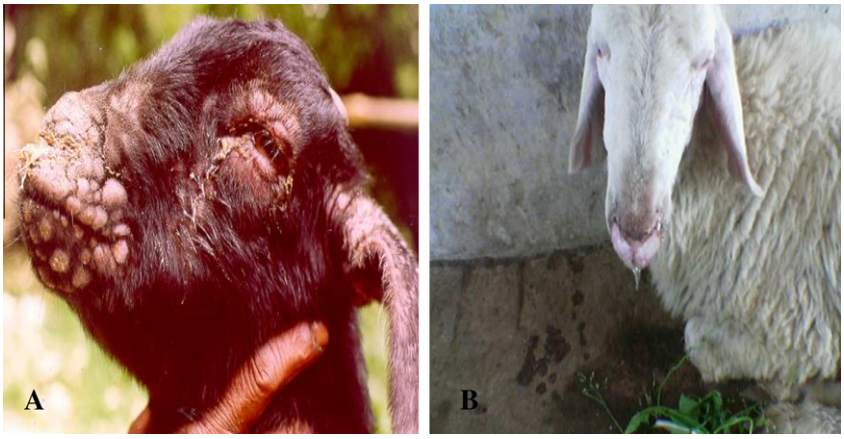

Fig. 2. (A) Goats with severe clinical lesions following natural outbreak of goatpox in a goat farm. Malignant form of capripox affecting skin, eyes and respiratory system is responsible for higher mortality as a result of secondary infections; (B) sheep with clinical lesions following natural outbreak of sheeppox in a sheep farm.

while also being direct cause of mortality (Yeruham et al., 2007). In addition, the presence of sheeppox and goatpox prevent the free trade of animals and animal products from endemic regions, thereby inflicting indirect economic loss to the country, which is hard to estimate by substantial. As per a report, the losses due to capripox in Maharashtra (India) state alone are estimated over INR 105 million (US$2.3million) with an average morbidity and mortality of 63.5% and 49.5%, respectively, and it took nearly six years for a flock to recover from outbreak (Garner et al., 2000). By extrapolation of this data, total estimated annual loss at the national level amounts to be INR 1250 million (US$ 27.47 million) (Bhanot et al., 2009). A proportion of infected animals will survive the infection and survived animals will become immune for life long.

4. Tools for disease management

The key components of disease control program that are required to initiate the control and eradication of sheeppox and goatpox are discussed here. Skin papules, lung lesions or lymph nodes are the material for virus isolation and antigen detection, which can be collected as biopsy or post-mortem. These samples are to be collected within the first week of occurrence of clinical signs or prior neutralizing antibody development. However, samples for nucleic acid detection can be collected in the presence of neutralizing antibody. For isolation of virus from blood, buffy coat is to be collected in an anticoagulant during viremic stage, and before or within 4 days of generalization. For histopathological studies, tissue from surrounding area is preferred and the samples should be placed in 10% formalin. Blood samples may be kept at 4 °C for up to 2 days and should not be frozen or kept at ambient temperatures. Tissues and dry scabs for virus isolation, antigen and genome detection should be kept at 4 °C, on ice or at −20 °C. If the samples are to be carried out for long distance without refrigeration, then 10% glycerol should be incorporated in the medium. The samples should be of sufficient size and the transport medium does not penetrate the central part of the biopsy. The central portion of the scab/tissue should be used for virus isolation/detection (OIE, 2010). At present there are no universal diagnostic tests available commercially since this represents an important gap.

4.1. Diagnostic tests

4.1.1. Antigen detection

Various diagnostic assays developed for detection of capripox virus (CaPV) antigen are based on polyclonal antibodies. Such assays are of limited value because of cross-reactivity with other poxviruses. Most of the diagnostics used earlier were based on detection of soluble antigens of capripox scab samples. Immunocapture ELISA was earlier used for detection of antigens in the scab suspensions (Rao et al., 1997). However, this assay had been used in combination with counterimmunoelectrophoresis, which is a less sensitive method. One of the drawbacks of these tests was high background reactivity requiring, optimization with each lot of antigen preparation. Recombinant antigen trapping ELISA has been developed that has advantage of significantly reduced background reactivity as the protein is expressed in *Escherichia coli* (Carn, 1995).

4.1.2. Antibody detection

One of the major problems encountered in the pox diagnosis is poor seroconversion, an inherent feature of poxvirus immunity. Particularly in the vaccinated animals, antibody levels are often below detectable levels. Following vaccination with the Kenyan vaccine, sheep and goats do not have detectable antibody responses by virus neutralization as well as inactivated whole virus ELISA (Babiuk et al., 2009). Also the vaccines used in India lead to low level of seroconversion by virus neutralization and whole virus ELISA. Several methods have been developed to detect poxvirus induced antibodies and efforts have been made to improve assay sensitivity and specificity. Indirect ELISA has been developed that relies on purification of viral antigen by ultra centrifugation method using density gradients. The sensitivity of the assay depends on the purity of the antigen. Avidin–Biotin (AB) and indirect ELISA assays have been developed in the past to detect antibodies in the infected animals (Rao et al., 1999; Bhanuprakash et al., 2006a). To improve assay specificity, ELISA assays have been constructed using the major antigen P32 which is specific for capripoxvirus and does not cross-react with sera from Orf virus or vaccinia virus infected animals (Heine et al., 1999). Background reactivity has been significantly reduced by developing recombinant antigens using *E. coli* (Heine et al., 1999) or the yeast (Bhanot et al., 2009) expression systems. Furthermore, Bowden et al. (2009) tested an array of open reading frames of GTPV expressed in *E. coli* for their diagnostic potential in ELISA (Bowden et al., 2009). Although, these antigens enable differential diagnosis of capripox from other diseases such as Orf, they did not provide clear results in the sera from vaccinated animals. The latter remains the major hurdle in the use of antibody-based detection methods.

4.1.3. Nucleic acid detection

Several assays are available for detection of virus nucleic acid as reviewed previously (Rao and Bandyopadhyay, 2000;

Bhanuprakash et al., 2006b). New methods based on PCR have been developed over the years in India and other parts of the world, for specific diagnosis of infection by capripox virus species (SPPV and GTPV) that may be useful for disease epidemiology (Ireland and Binepal, 1998; Heine et al., 1999; Hosamani et al., 2004a; Fulzele et al., 2006). The single-tube duplex PCR developed by Fulzele et al. (2006) could be very useful in analyzing samples originating from herds where both sheep and goats are affected. Quantitative PCR have also been developed in several laboratories (Balinsky et al., 2008; Bowden et al., 2008; Kallesh et al., 2009; Balamurugan et al., 2009; Lamien et al., 2011a). This technique is increasingly used as a routine diagnostic method in animal diseases in India and other countries for diagnosis of different pox virus infections.

4.1.4. Differential diagnosis

Differentiation from similar diseases (bluetongue, *peste des petitis ruminants,* Orf, photosensitization, insect bites, parasitic pneumonia, streptothricosis, mange) (Bhanuprakash et al., 2006b) and other viruses from the same family are essential for surveillance and disease diagnosis. This can be achieved by identifying the disease specific clinical signs/symptoms and; virus/agent specific conventional and molecular techniques. Capripoxviruses have morphological, physical and chemical properties akin to vaccinia virus. However, conventional virological or biochemical or serological methods are not useful for differentiation of member species of capripoxvirus. Nevertheless, a spectrum will emerge in which some strains of capripoxviruses have clear host preferences; while, others will be less defined and naturally infect the host with which they come across that identification based on host specificity will be hard since strains with a broad host range. Latest developments in molecular biology have lead to the design of techniques, which are capable of differentiating members of capripoxviruses. These techniques are difficult to apply at field level but they can very well be done at district veterinary polyclinic in the event of launch of national programs on sheeppox and goatpox control and eradication. Some of the notable techniques are RNA polymerase subunit (RPO30) (Lamien et al., 2011b) and ORF026 (Orlova et al., 2006) gene based PCRs, P32 (Hosamani et al., 2004a) and attachment (Fulzele, 2006) gene specific PCR-RFLP and attachment ["A"] and fusion ["F"] genes specific-multiplex PCR (Fulzele, 2006), G-protein coupled receptor binding gene based real time PCR (Lamien et al., 2011a) and genome sequencing (Tulman et al., 2002).

4.2. Capripox vaccines

Control of capripox diseases is vital to augment small ruminant productivity in the Indian subcontinent. In India, socio-economic factors preclude the use of slaughter policy for disease control while the movement controls are difficult to monitor. Therefore, vaccination is considered as the economical and sustainable means of disease control. Considering the disadvantages with inactivated vaccines such as short duration of immunity and high antigenic mass required for vaccination of vast livestock population, live vaccine is the best choice as a long-term solution towards control of capripox infections (Bhanuprakash et al., 2006b). Live attenuated vaccines have been routinely used world over for immunization of small ruminants. Unlike in Africa, no single attenuated strain (Kitching et al., 1987) is developed in India to tackle pox in both sheep and goats. Sheeppox vaccine has long been used for control of sheeppox in sheep, while vaccine for goatpox has recently been developed and is currently under field validation. This live vaccine has been found to confer partial protection in sheep for sheeppox under experimental conditions (our unpublished data).

Control through vaccination may be carried out in campaign style to contain the disease in a defined area. Vaccination of all susceptible sheep and goats shall be targeted and the success of the program to be monitored by active surveillance particularly for the presence of virus. Sero-monitoring is hard to assess as the status of differentiation of infection and vaccination is currently not possible. All the susceptible animals including kids and lambs aged more than 4 months can be vaccinated by single vaccine using intradermal or subcutaneous routes. Vaccination of pregnant animals may be contraindicated as a thumb rule, from the safety point of view. There are some interesting observations on both these vaccines which are discussed here.

4.2.1. Goatpox

An attenuated live goatpox vaccine has been developed by the Indian Veterinary Research Institute (IVRI) and the vaccine is currently undergoing extensive field validation in different parts of the country after successful in-house trials. Laboratory studies have shown that the vaccine provides complete protection against high dose of challenge goatpox virus (GTPV) (Hosamani et al., 2004b, 2006). It causes no adverse reaction as doses as high as 10^5 $TCID_{50}$, while it confers protection even at low dose of 10 $TCID_{50}$ in goats. The vaccine is administered by intradermal route, on the abaxial surface of the tail in the adults and kids aged more than 4 months. The vaccine produces mild hyperemia at the site of inoculation by day 5–6 post vaccination. The vaccine is safe at OIE recommended field dose, i.e., $10^{2.5}$ $TCID_{50}$. However the vaccine is not recommended for use in pregnant animals as a precaution of safety. The vaccine provides protection for 52 months, as tested so far (our unpublished data). However, the vaccine is likely to provide life-long immunity as is true with other pox vaccines. Further, the turn-over rate of sheep and goat is about 3–4 years – except breeding rams and bucks, as one-third of animals are replaced every year.

The vaccine reactogenicity depends on the strain of the vaccine virus used, level of attenuation and the breed of animals immunized. Some breeds of goats have been shown to react severely to live goatpox vaccine (Abo-Shehada, 1990). Safety of the vaccine has been tested in different Indian breeds and some exotic crossbreds, but not in pure exotic breeds. Some strains of vaccine appear not completely attenuated to the natural hosts. This depends on viral virulence factors such as kelch-like and ankyrin repeat proteins (Tulman et al., 2002) and the idiosyncrasy of the animal. For example, Ranipet strain of sheepox vaccine virus used in India is considered to be more reactogenic especially for naïve population of sheep, as a proportion of vaccinated animals suffer from pyrexia following vaccination.

4.2.2. Sheeppox

Several sheeppox vaccine virus strains are available in India including Roumanian Fanar (RF strain), Jaipur and Ranipet strains. These strains are used for production and their subsequent field application. Ideally a single strain shall be used for mass immunization so that disease monitoring can be effectively implemented to check new and emerging viruses, if any. These vaccines are either primary or secondary cell culture based (lamb testes secondary cultures) with varying degree of reactogenicity in the immunized animals (Bhanuprakash et al., 2006b). Srinagar strain (Srinagar, 38/00) of SPPV from Jammu (India) has now been a new addition, developed as new vaccine strain currently under experimental field trials. Among all these vaccine strains, RF strain is generally considered to be the safest of all, in terms of its longest usage track record (Bhanuprakash et al., 2003). However, there are some concerns on the potency of the vaccine which has been much debated over. But no systemic studies were undertaken to verify or rule out this issue of the vaccine. Therefore there was growing interest on which of these is the best vaccine strain in Indian context. To address this issue, we undertook a study recently to compare the potency and

efficacy of different SPPV vaccine virus strains such as SPPV-RF (Rumanian Fanar), SPPV-Ranipet and SPPV-Srinagar. From this investigation it was revealed that the vaccine prepared using indigenous SPPV-Srinagar is found as efficacious as SPPV-Ranipet and also in-use commercial vaccine made form SPPV-RF, an Iraq strain as assessed by challenge experiments (our unpublished data). Earlier studies have inferred that the local strains are preferred for immunization purposes as they provide better protection than that of foreign strains. Although, a few attenuated strains of SPPV obtained from foreign countries were studied under Indian conditions, they were never thoroughly investigated. However, in limited trials, the exotic attenuated strains did not prove much effective (Das and Mallick, 1986; Singh et al., 1984; Matrencher et al., 1997). Likewise in this particular experiment, the challenge virus used was derived from the same Srinagar strain in the earlier passage, which probably gave a better degree of protection (our unpublished data). Therefore, such studies are not clear indicative of the extent of the antigenic coverage conferred by each of these vaccines to the prevalent field strains. It is expected that although most of these strains may have subtle variations at the antigenic level with minor antigenic drift they are expected to provide more or less similar degree of protective immunity.

4.2.3. Pox immunity and disease control

Pox virus/vaccines induce strong immunity that may last quite longer as compared to some pathogens through involvement of both cellular and humoral immune effectors (Panchanathan et al., 2008). Robust immune response following pox infection/vaccination can be best exemplified by the impact of smallpox vaccination used worldwide during the 70s. Cellular immunity is particularly remarkable in pox immunity, as memory cells are known to last for over 35 years following primary vaccination in humans (Green et al., 2011). And also, the anti-vaccinia antibodies were reported to be present till the age of 88 years (Taub et al., 2008). The current smallpox vaccine provides long-lasting CD4 help that may be critical for long-lived B-cell memory (Amara et al., 2004). Long-term protection has played a critical role in building strong herd immunity in smallpox which eventually contributed to its global eradication in 1979–1980.

Limited experimental data is available on the duration of immunity on single vaccination with capripox vaccine. Previous studies have demonstrated protective ability up to 2–3 years following single immunization (Anandan et al., 1972; Achour et al., 2000). In our laboratory extended protective immunity studies have been undertaken to determine the duration of immunity following primary vaccination with goatpox vaccine in kids. Animals vaccinated at the age of six months were immune to challenge even for over 52 months of vaccination (our unpublished data). This data reveals that capripox virus infections can be effectively controlled by active mass immunization to build strong herd immunity. Single immunization is probably adequate to provide life-long (or at least commercial life span) of protection to small ruminant population. Other factors that assist in the control and disease eradication are the facts that there is no stage of viral persistence following exposure, and vaccinated or recovered animals are immune to exposure to virulent virus. Further, there is no shedding of virus as vaccination site remains closed and only "vaccine take" is observed at the vaccination site and no lesions form, if vaccinated aseptically.

5. Veterinary resources in India

India is a tropical country, with 28 states and seven union territories. The veterinary infrastructure is available both at federal and regional levels. A total of 8732, 18,830 and 25,195 of veterinary hospitals (polyclinics), veterinary dispensaries and veterinary aid centers/stockhome centers/mobile dispensaries, respectively, are available in the country (dand.nic.in). Apart from these, it has 53 veterinary colleges. In addition, it has 23 state biological units and more than 31 non governmental organizations (NGOs). The Animal Science Division of Indian Council of Agricultural Research (ICAR) and Krishi Vigyan Kendras (KVKs) is the central agency to plan, implement and execute control programs in consultation with the department of animal husbandry under the ministry of agriculture and animal husbandry. The central referral facility for disease diagnosis is the Centre for Animal Disease Research and Diagnostic (CADRAD). This acts as a pivot between the regional disease diagnostic laboratories (RDDLs) spread across the four zones i.e. north, south, west, and east. There is a need to maintain disease registry and disease data base to ensure effective reporting and coordination of outbreak occurrence and monitoring. The trained scientific, technical, supporting man power is an absolute necessity to make the control program successful. Adequate staff and trained personnel are available throughout the country (Singh et al., 2009). The entire facility can be effectively put into use in the coordinated efforts to control and eradication program for sheeppox and goatpox.

Cold-storage is not required for capripoxvirus live vaccines unlike the inactivated vaccines allowing cost effective distribution of live vaccines for capripoxvirus. One of the greatest advantages of the capripox vaccine is its high thermostability; unlike other RNA virus vaccine like peste des petits ruminant currently being used in small ruminants (Sarkar et al., 2003). If not the taluka (administrative subdivision of district), the districts head quarters are provided with cold storage facilities for storage of vaccines. Basic infrastructure requirements especially cold storage needs to be strengthened to provide better animal health services to the livestock. The advantage with capripox vaccine is that it can be transported even at ambient temperatures under tropical conditions without significant loss in the viable titer (data unpublished). Lyophilized vaccine can withstand 2–3 days of exposure to 37 °C under experimental conditions.

Surveillance is a key to tackle the disease control along side active immunization. At the district level, veterinarians and para-veterinarians are needed to be equipped for quicker disease diagnosis and reporting mechanisms. The officials need to collect the samples from different sources on regular basis such as veterinary hospitals, animal fares, and slaughter houses and most importantly the farmers who are the direct stake holders.

6. Strategies for disease control and eradication

6.1. Mass immunization is key to disease control

Mass immunization has been the empherical approach for control of many infectious diseases globally. This is the line adapted by World Health Organization (WHO) for the control of polio in humans. Some of the successful and eventful examples are smallpox and polio in humans and rinderpest in cattle. In India, there is a growing belief that there is perceptible reduction in the disease incidence (personal communication) of PPR ever since active vaccination is being carried out over the past few years. This experience further strengthens the case for mass vaccination campaigns for some of the selected diseases such as capripox leading to progressive disease control in the march towards, eventually, disease eradication.

6.2. OIE pathway

In India, test and slaughter policy and restriction of animal movement is difficult to follow because of ethical, social, political

reasons. The best viable, feasible and economical method is mass vaccination program. The diseases are enzootic in the country. In order to control, eradicate and declare country free from sheeppox and goatpox, it is necessary to adopt the OIE pathway as followed for rinderpest eradication (Rweyemamu et al., 2006). This includes initial mass vaccination and serological surveillance for a period of two years and subsequent cessation of vaccination. These parameters enable the country declared as provisionally free from sheeppox and goatpox. To obtain complete eradication status of disease from country an application needs to be lodged at the OIE to officially declare as free from Capripox infection after period of three years of the initial declaration. During this two-year period, two successive annual rounds of serological surveys are considered necessary. Consequently, a total of 8–10 years is required, officially to declare a country free from sheeppox and goatpox (Rweyemamu et al., 2006).

6.3. Cost analysis of control program

The launching of control and eradication program for sheeppox and goatpox requires a substantial level of funding from the Government of India (Singh et al., 2009; Table 1). A provisional estimate for the program is US$2129.7 million, which includes the cost of vaccines, diagnostics, manpower (scientific, technical, and supporting), equipment, infrastructure and contingent expenses. Manpower can be provided by state veterinary departments, colleges and research institutes. Infrastructure created during the implementation of the National Project on Rinderpest Eradication (NPRE) could be utilized for the program after necessary up gradation (Singh et al., 2009; ivri.nic.in).

6.4. Public private partnership (PPP)

There are successful stories about public private partnership such as ongoing polio disease control and eradication program in India. There are a number of non governmental organizations (NGOs), which are involved in animal husbandry activities throughout the country. In the same way, many of the cooperatives are involved in sheep/goat breeding in certain states. The participation of NGOs and cooperatives is very important in the control and eradication program of sheeppox and goatpox. As the sheep and goat population is very high in the country, large quantity of vaccines is required to launch the campaign and therefore it is necessary to have liaison with private manufacturers. Further, a number of leading private vaccine manufacturers and NGOs readily accept the vaccine production technologies, in the event of launching the program.

6.5. Measures to disinfect the infected foods and premises

Infected materials including meat/mutton, food items, food, wool, skin and hide need to be properly disinfected by heat treatment chemical inactivation or by ionizing irradiation. Infected milk and suspected dairy products need to be destroyed. Infected bedding materials, feed stuff, excretory/secretary products including dung and urine, and clothing used by personnel working in animal houses need to be destroyed carefully.

6.6. Feasibility of control and eradication in India

India has potential to control and eradicate sheeppox and goatpox. Specific diagnostics, effective vaccines, adequate veterinary

Table 1
Cost estimation for control and eradication of sheeppox and goatpox from India.

Elements of eradication	Goats[a]		Sheep[a]		Estimated total cost (US$ millions)
	Year I (70% of population)	Year II (rest: 30% and 40% increase in population)[b]	Year I (70% of population)	Year II (rest: 30% and 40% increase in population)[b]	
(A) Vaccination @ 0.048 US$[e]/dose	4.705	4.705	2.644	2.644	14.7
(B) Diagnosis including serological monitoring					
(i) Indirect ELISA@2.74US$/sample					
(a) Seroconversion after vaccination	264.7		150.9		415.6
(b) First round of serological monitoring for disease free status[c]	264.7		150.9		415.6
(c) Second round of serological monitoring for disease free status[c]	264.7		150.9		415.6
(ii) Antigen detection based on CIE/PCR@1.25 US$[e]/sample					
(a) First round of antigen detection for infection-free status[d]	264.7		150.9		415.6
(b) Second round of antigen detection for infection-free status[d]	264.7		150.9		415.6
C. Cost of manpower(incentive)					
(i) Scientific/veterinary					10
(ii) Technical/para-veterinary staff					5
(iii) Supporting					2
D. Infrastructure[f]					5
E. Equipment[g]					5
F. Contingent expenses[h]					10
Total approximate estimated cost of control and eradication					2129.7

[a] Goat population in India: 140.05 million; sheep population in India: 78.7 million (dahd.nic.in).
[b] 40% rise of sheep and goat population annually.
[c] After 4th and 5th years of vaccination.
[d] After 6th and 7th years of vaccination.
[e] As per the existing rates.
[f] Minor repairs and renovation of laboratory premises.
[g] Equipment.
[h] Consumables, including needles, syringes, iceboxes, repair of vehicles and fuel charges; ELISA, enzyme linked immunosorbent assay; 1US$ = INR 45.5950 (date: 04.02.2011 at 10.16 AM); cost of 1 dose of vaccine = INR 2.20; cost of testing one sample of serum/antigen either for sheeppox or goatpox = INR 125/– (Singh et al., 2009; ivri.nic.in).

infrastructure, well trained scientific, technical and supporting staff and regulatory support enable the country to launch the program. Control and eradication of the disease can significantly contribute to foreign exchange through sale of animals and their byproducts. The other factors which favor the launch are economic impact of the diseases, easy detection of diseases/agents, non-existence of a carrier state, absence of reservoir hosts other than domestic sheep and goats, induction of solid immunity after vaccination (commercial life span), easy diagnosis of infected or exposed animals and relatively low annual turn over rate of animals in flocks, with a low level of introduction of new animals. In contrary, the factors which may impede the control program are long incubation period (5–14 days) of the diseases, prolonged stability (several months) of the virus on wool or hair of recovered animals or in the environment. Among other factors, unregulated introduction of livestock through importation or by illegal means of infected sheep and goats into India might be an impediment to successful eradication.

6.7. Enabling research areas

It is vital to develop and validate the latest PCR assays (Zheng et al., 2007; Le Goff et al., 2009; Lamien et al., 2011a) [real time PCR, loop mediated isothermal amplification of DNA (LAMP)], nanotechnology based fluoroimmunoassays (Yuan et al., 2009), ELISAs based on inactivated SPPV antigen (Babiuk et al., 2009), recombinant protein and monoclonal antibody based ELISAs to enable rapid capripoxvirus diagnosis and surveillance. These tools would strengthen the capacity to respond to outbreaks, monitor capripox viruses and to study epidemiology of diseases. In addition, it is required to develop tools to differentiate infection from vaccination (DIVA), which will be much needed during post eradication phase as the live virus is restricted to use during this phase. DIVA tools may be difficult to generate by deleting non-essential genes from the vaccine virus as the proteins expressed by these genes may not generate specific antibody responses. There is a possibility of generating a single vaccine that can protect both sheep and goats against sheeppox and goatpox and that the vaccine should be characterized by genetic sequencing and improved by knocking out the gene or genes involved in virulence. The duration of immunity generated by the vaccines should also be characterized. Attention should also be given to the factors, which are responsible for virulence of the virus such as kelch-like protein and ankyrin proteins (Tulman et al., 2002). Though, poxviruses are thermostable, it is required to have a complete data on thermostability of each pox vaccine. It is also of great concern to explore the extent of potential is the involvement of insects and flies in the mechanical transmission of capripoxviruses naturally. The report of sheeppox and goatpox in Bohor Reedbuck (wild ungulate, *Redunca redunca*) based on clinical signs and post mortem is a matter of concern (OIE, 2009).

7. Conclusions

Safer and efficacious vaccines combined with novel diagnostics are available for control of capripox diseases. Pox is very much a preventable disease which can be achievable though mass vaccination coverage. As is the case with smallpox vaccination that lead to disease eradication, mass vaccination was one of the primary goals of disease control. Anti-infective therapy is not cost effective, although many of the antivirals are active against poxvirus infections (De Clercq and Neyts, 2004; Bhanuprakash et al., 2008). However, there is a possibility of using sheeppox and goatpox as vaccine vectors (Soi et al., 2010; Chen et al., 2010; Chandran et al., 2010). Thus the most feasible strategy is the mass vaccination campaign and sanitation. Other control and eradication strategies for sheeppox and goatpox are not viable in the Indian context. Mass vaccination of the livestock is ambitious initiative to be undertaken and sponsored by the central governing body (Department of Animal Husbandry and Dairying, Ministry of Agriculture) to be supported by the state government in terms of infrastructure and manpower. Recently, Government of India has launched a control program for PPR and brucellosis which will run through XII Plan period (2012–2017) and beyond. Further, the FMD-Control Program (FMD-CP) – launched in XI Plan period (2007–2012) – has now been extended beyond 154 districts during the XII Plan. Further, any such national program needs strengthening of the infrastructure facilities, reporting system, prompt coordination of the local and central participants and adequate extension services. Developed nations have the required veterinary infrastructure, technology and financial resources required for disease control or eradication, whereas developing nations lacks one or many of these elements and thus suffer economic losses from endemic disease (Breeze, 2006).

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Further reading

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