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Review

The deadly drink: Nipah virus transmission through date palm sap, cultural practices and the evolution of behavioral interventions in Bangladesh over two decades

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ABSTRACT

Nipah virus (NiV) has emerged as a significant public health threat, with recurring outbreaks in Bangladesh often linked to the consumption of raw date palm sap contaminated by fruit bats (*Pteropus* species). Over the past two decades, substantial efforts have been made to understand the cultural context of sap consumption, promoting behavior change and developing interventions to prevent NiV spillover. Despite these efforts, achieving sustainable change in sap consumption practices remains challenging due to deep-seated cultural practices, community perceptions of sap consumption, habitual behaviors, limited awareness of health risks and economic barriers. To prevent sap-borne transmission, future efforts should focus on affordable, community-led solutions while protecting local livelihoods. Promoting behavior change through trusted community education and safe harvesting practices must be supported by involving local health workers and community members in planning and evaluation. Long-term preparedness also requires investment in diagnostics, treatments and vaccines through inclusive, collaborative intersectoral research and one health approach.

Contents

Abbreviations: NiV, Nipah virus; DPS, Date palm sap; BDT, Bangladeshi taka; PPE, Personal protective equipment; IPC, Infection prevention and control; CDC, Communicable disease control; DGHS, Directorate general of health services; IEDCR, Institute of Epidemiology, Disease Control and Research

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Background

The consumption of raw date palm sap (DPS), a centuries-old and culturally cherished practice in Bangladesh, has been repeatedly linked to outbreaks of Nipah virus (NiV) infection, a highly fatal zoonotic disease [1–6]. Infected fruit bats, the natural reservoir of the virus, contaminate the sap collection sites with their saliva, urine or faeces while feeding on the exposed sap [7–9]. Multiple studies have established a causal link between this mode of consumption and the spillover of NiV from bats to humans [7,10,11]. Experimental studies have demonstrated that NiV can remain stable in artificial palm sap at 22°C for at least seven days, suggesting that the virus can survive long enough to be transmitted through consumption of contaminated sap [12]. Infected individuals can transmit the virus to others, often within households or healthcare settings, leading to human-to-human transmission [1,4,8,13–15,43].

In Bangladesh, NiV outbreaks occur in a predictable seasonal pattern, typically from December to April, coinciding with the peak DPS harvesting season [1,16]. Despite widespread recognition of this risk, raw sap remains a valued seasonal delicacy and a deeply rooted cultural tradition, particularly in rural areas where awareness of zoonotic disease spillover risks is limited [6,7]. Over the past two decades, this practice has persisted, reflecting complex social norms, low perceived personal risk and the limited reach or effectiveness of behavior change interventions.

Efforts to prevent Nipah transmission through raw DPS consumption have evolved over time, ranging from technical solutions such as physical barriers on sap-collection pots to broader community engagement strategies. However, challenges remain. Cultural resistance, socio-economic factors and the symbolic significance of sap consumption have limited the uptake and sustainability of these interventions [2]. Understanding how these practices have changed or resisted the change over time is critical to developing effective, acceptable and sustainable public health strategies.

In this review, we analyzed the economic and cultural context of raw DPS consumption in Bangladesh and its role in NiV transmission. This review uniquely synthesizes two decades of evolving behavioral interventions and tries to explore how public health responses have evolved in response to persistent spillover events. Drawing on the literature, we propose context-specific, culturally sensitive strategies to reduce transmission risk, including more meaningful engagement with community leaders, incorporation of lived experiences, and sustained investment in behavioral interventions tailored to local realities. Our aim is to inform future prevention efforts and contribute to a more holistic approach to zoonotic disease control in South Asia.

The culture of raw DPS harvesting and consumption

DPS, locally known as *khejur-er rosh*, is an age-old traditional beverage in rural Bangladesh. Harvested during the winter, the sap is a culturally cherished seasonal delicacy often consumed fresh, before fermentation [17]. Although DPS is tapped year-round for various uses, sap consumption is highly seasonal. It is only consumed fresh and raw in the early morning during the winter months, from November to April, known as the 'sap season' [8,18].

Tappers (locally known as *gachhi*) climb the trees to carve channels in the bark and attach pots (usually made of clay) to collect the sap that flows overnight. This practice has symbolic and economic importance for communities, marking the seasonal cycle and providing a source of income for tappers as well as tree owners. Individuals who harvest sap at home are more likely to consume it due to its easy accessibility and low or no cost. The cost of date juice is very low, 10–20 BDT (0.1–0.2 USD) per glass. Household members primarily consume raw DPS, followed by using it to make molasses and often share the raw DPS with neighbours and relatives [19]. DPS possesses a pleasant, distinctively sweet taste and is a widely cherished and easily available seasonal delicacy during winter. The clandestine collection of raw date juice for fun at midnight is like a thrilling adventure and an act of excitement for rural youth.

DPS holds cultural and religious significance among Muslims as date palm is considered as a religiously significant tree. In recent days, even the city dwellers, including the residents of major cities like Dhaka, flock to various spots to enjoy the fresh sap. Raw DPS is even sold through online platforms and thus it reaches throughout the country. People eagerly take part in this festive indulgence of tasting fresh date juice [20]. However, considering the consumption, there are varying factors that significantly influence the likelihood of sap consumption [21].

Sap consumption and NiV spillover

The first recorded outbreak of NiV infection occurred in Malaysia in 1998, where the virus spread from pigs to humans, primarily affecting pig farmers [22,23]. In Bangladesh, the first human cases were reported in 2001 and since then annual outbreak has been reported nearly every year [5,24,25]. However, it was not until the 2008 outbreak in Tangail that the role of raw DPS in NiV spillover was clearly identified. Since then, multiple lines of epidemiological and ecological evidence have confirmed that the consumption of raw, unboiled DPS is a key route of transmission from fruit bats to

Table 1
Evidence of Sap consumption as a risk factor for Nipah virus transmission, Bangladesh, 2001–2024.

Reference	Cases	Controls	Risk/odds /adjusted odds ratio (RR/OR/aOR)	95 % Confidence Interval (CI)	P value	Findings
Gurley et al. [2]	60	73	6.39	1.61–25.40	0.008	Per each 10 % increase in households reporting that someone consumed raw DPS during the harvest season.
Hegde et al. [28]	157	632	4.91	3.2–7.7	0.000	Cases were 4.9 times more likely to consume raw DPS.
Chakraborty et al. [4]	40	155	9.6	4.0–22.9	< 0.001	NiV cases had higher odds of drinking DPS within 30 days prior the onset of illness compared to the controls.
Sazzad et al. [10]	15	58	7.9	1.6–40	0.012	NiV case-patients were more likely than controls to have consumed raw DPS during the month before the case-patient's illness
Rahman et al. [26]	10	40	25	3.3–∞	< 0.001	Drinking raw DPS 2–12 days before illness onset was the only risk factor most strongly associated with the illness
Montgomery et al. [29]	12	36	4.1	0.47–197	0.328	Although not statistically significant, greater proportion of case-patients reported drinking raw DPS
Luby et al. [3]	11	33	7.9	1.6–38	0.01	Drinking raw DPS was significantly associated with illness.
Gurley et al. [14]	34	204	4.3	1.0–17.1	0.049	Having had a household member harvest DPS was associated with an increased risk for infection

Note: NiV- Nipah Virus; **DPS**- Date palm sap

humans in Bangladesh (Table 1) [1,11,24,25]. Both the consumption of fresh raw sap and the consumption of '*tari*' (sap that has undergone natural fermentation until it becomes alcoholic) are linked to spillover of NiV (Fig. 1) [21,26,27].

Pteropus bats, the natural reservoir of NiV, are attracted to the sweet sap collected in open pots placed high on palm trees [30]. While feeding, they can contaminate the sap with their saliva, urine and faeces, allowing the virus to pass to humans who consume the fresh sap [3,13,16–18]. This transmission route has been consistently supported by case–control studies. For example, during the 2008 outbreak in Manikganj and Rajbari, drinking raw DPS was found as the only significant risk factor for infection, with an adjusted odds ratio of 25 (95 % CI: 3.3–∞; $p < 0.001$) [26]. Similarly, another study found that 64 % of case-patients had consumed raw DPS compared to 18 % of controls (OR = 7.9; $p = 0.01$) [1].

Since 2001, nearly all outbreaks in Bangladesh have occurred during the winter sap-harvesting season and most cases have been epidemiologically linked to raw DPS consumption in rural areas [1,3,21]. Spillover risk increases during colder winters, when bats feed more frequently on sap and sap consumption rises [25]. A recent report showed that between 2006 and 2021, 50 % of cases (162/322) reportedly consumed raw DPS [16]. Despite high mortality rates associated with NiV ranging from 40 % to 75 % outbreaks continue to recur, indicating that sap contamination remains a persistent and unresolved problem [3,5].

The role of anthropologists has been central in uncovering these links. Using participatory and culturally grounded approaches, they worked alongside epidemiologists and community members to understand local practices and identify sap consumption as a recurring risk factor. Their work emphasized the importance of context in shaping effective public health messaging and intervention strategies. Unlike many other zoonotic diseases, NiV also spreads from person to person through close contact with infected individuals, particularly via respiratory secretions and bodily fluids [1,10,11,14,15,19,29]. In Bangladesh, family caregivers often provide hands-on care to sick relatives, increasing the risk of secondary transmission [31]. This leads to transmission chains extending within households and across communities [10,14,15].

The cultural practices of consumption of raw DPS are more or less similar throughout Bangladesh. However, the availability of date palm trees and sap harvesting practice is not the same throughout the country. During the earlier outbreaks, the Nipah belt, that is the central and northwestern regions of Bangladesh, showed higher number of cases and deaths. However, during recent years, non-Nipah belt areas have been almost equally affected, probably due to the online advertising and selling, resulting in widespread availability of the raw DPS [32].

Given its well-documented epidemiology, seasonal predictability and repeated outbreaks, Bangladesh represents a critical setting for both continued public health intervention and potential therapeutic trials for NiV [5]. Understanding and addressing the cultural dimensions of sap consumption is central to reducing spillover and breaking the chain of transmission.

Knowledge gaps in sap-borne transmission

Despite persistent evidence of sap-borne NiV transmission, raw sap consumption remains widespread, particularly in rural communities, where risk perception is low and awareness of NiV remains limited [6]. Even though sap consumption was limited in rural areas, this has changed in recent times where there is an increasing trend of DPS consumption among the urban population. Studies show that when sap is available, people often continue drinking it regardless of their awareness of potential health risks, reflecting a gap between knowledge and behavior [6]. Individuals with household access to date palm trees are significantly more likely to

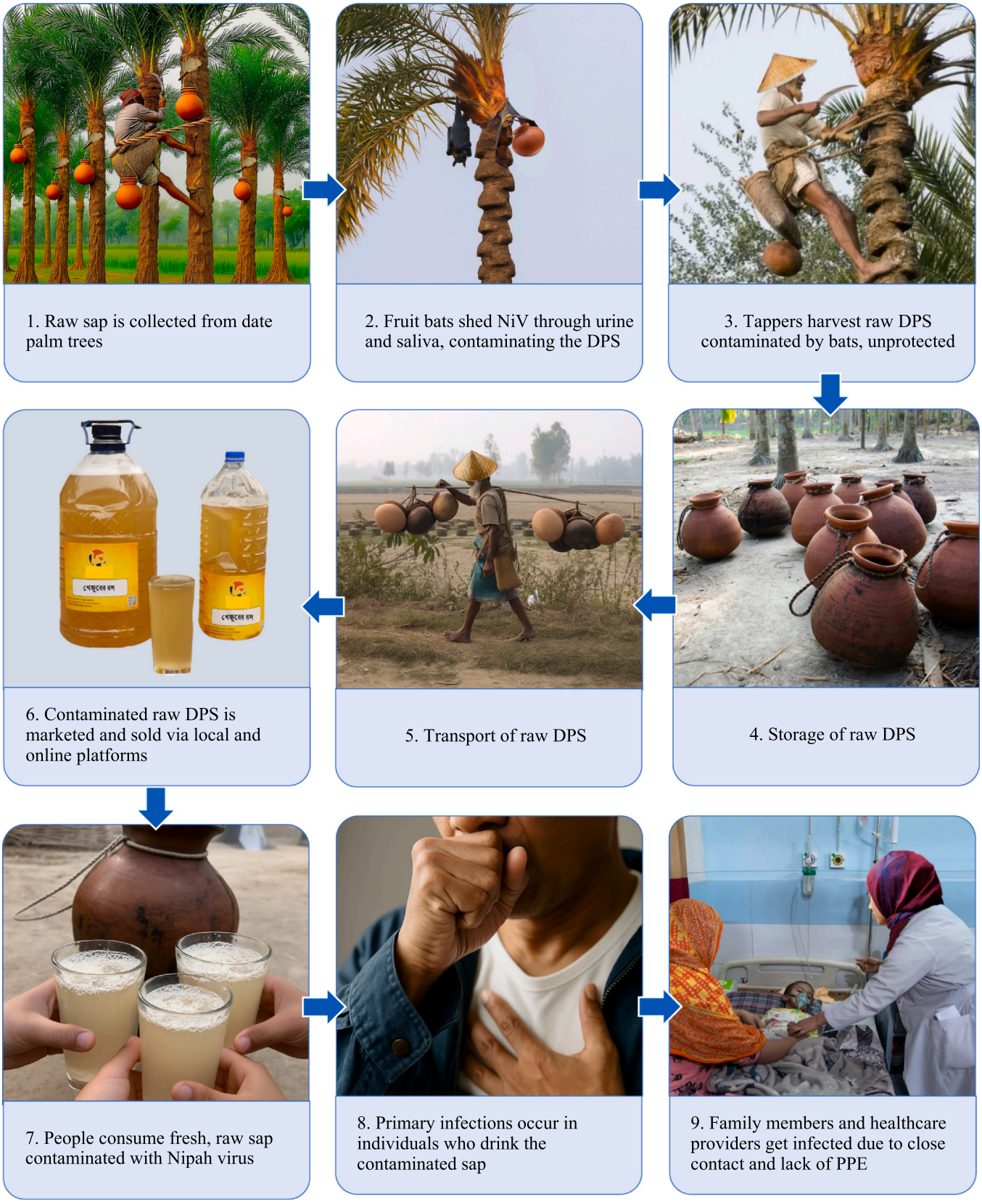

Fig. 1. Pathway of Nipah virus transmission in Bangladesh.

consume sap (79 % vs. 65 %, $p < 0.001$), indicating that availability strongly influences behavior [6].

Understanding the sociocultural drivers of sap consumption is essential. Research suggests that seasonal variation, particularly colder winter days when sap is sweeter, contributes to increased consumption and may explain inter-annual differences in spillover events [6,18]. Anthropologists, working alongside epidemiologists, veterinarians, and public health experts, have co-

Table 2
Findings of Nipah virus intervention studies, Bangladesh 2001–2025.

Publication	Intervention	Key findings
Nahar et al. [34]	Pilot study to assess the acceptability of two indigenous methods to prevent bats from accessing the sap, bamboo skirts and lime (calcium carbonate) among sap harvesters.	Bamboo skirts are considered a practical, affordable and effective barrier against bats, while expressing skepticism about lime's effectiveness due to sap washed away by the sap flow. Further research is needed to confirm the skirt's effectiveness in preventing bat access and to assess its acceptance for regular use.
Parveen et al. [19]	Pilot study (behavioral intervention) examined participants' beliefs, care-seeking practices, and responses to prevention messages about NiV through an interactive approach to demonstrate how NiV is transmitted from bats to humans via raw DPS and person-to-person contact.	Participants demonstrated understanding of NiV transmission and committed to refraining from consuming raw DPS.
Khan SU et al. [35]	Bamboo, sesban (*dhoincha)*, jute stick and polythene skirts interventions (four types of intervention) that may impede NiV transmission from bats to humans through DPS.	Bamboo, *dhoincha*, jute stick and polythene skirts covering the sap-producing areas of palm trees were effective interventions in preventing bat-sap contact.
Nahar et al. [36]	Pilot behavioral change interventions targeting tappers (*gachhis)* and to evaluate if the interventions encouraged them to make and use skirts.	The intervention did not show high levels of continuous skirt use, but showed that many harvesters were prepared to adopt this strategy during the season with the highest risk.

Note: NiV- Nipah Virus; **DPS**- Date palm sap

developed interventions to reduce contamination risk [6,7]. These efforts reflect a syndemic approach, combining ecological, cultural and behavioral insights to reduce transmission risks [33]. Experts have also identified practices that may amplify spillover potential, such as mixing sap from multiple pots or feeding contaminated sap to domestic animals, both of which raise the possibility of secondary transmission, as seen in the Malaysian outbreak involving pigs [22,23].

Despite these advances, several questions remain. Nipah spillover events are sporadic, despite widespread bat presence and sap consumption. It is still unclear why only some exposures lead to human infection. Factors such as bat infection dynamics, human susceptibility, and environmental conditions may influence spillover risk but are not fully understood. Additionally, asymptomatic or mild human cases may go undetected, obscuring the true frequency of spillovers. Further research is needed to clarify these uncertainties and to better integrate multidisciplinary efforts into a coordinated prevention strategy.

Past interventions to prevent NiV transmission via DPS

Over the past two decades, a range of interventions spanning behavioral, community and structural approaches have been implemented in Bangladesh to reduce NiV transmission associated with raw DPS consumption (Table 2). These efforts have aimed to interrupt the bat-to-human transmission route by altering sap collection practices, enhancing public awareness and encouraging safer behaviors in high-risk communities.

Community awareness, education and behavioral change communication

Public health campaigns led by the government and research partners have focused on educating communities about the risk of consuming raw DPS and its association with NiV infection. Messaging has emphasized transmission routes and simple protective behaviors, such as boiling sap before consumption. While these efforts have raised awareness in some regions, their reach and long-term impact remain limited, especially in rural areas where cultural traditions and low perceived risk persist. Interactive behavior change interventions have used storytelling, visual demonstrations, and community dialogue to convey the risks of NiV and promote preventive practices [17]. While these approaches show promise, there is a lack of standardized communication materials developed with direct involvement of communities that have experienced past outbreaks. Moreover, few studies have evaluated the long-term uptake or sustained impact of these messages [19].

Physical barriers (bamboo skirts and other pot covers)

One of the most studied interventions involves the use of bamboo skirts or *banna* to physically block bats from accessing sap collection pots. These skirts have proven effective in reducing bat access to sap [9,34,35,37]. However, adoption by sap harvesters has been inconsistent due to labor demands, reduced sap yield, and economic constraints. Other physical barriers tested include nets, lime coating, and skirts made from local materials like sesban (***Sesbania bispinosa***, locally known as *dhoincha*), jute, and polythene [17,27].

Promotion of boiled sap

Boiling sap before consumption inactivates the virus and has been promoted as a safe alternative [38]. Yet, widespread adoption remains low, primarily due to the perceived loss of taste, altered texture, and deviation from traditional preferences. As a result, boiled sap is not widely accepted as a substitute for the fresh product [38].

Government initiatives and policy measures

To mitigate NiV infection and transmission, the government of Bangladesh has adopted a multi-faceted approach that includes surveillance, prevention, and public awareness. Since 2006, the Institute of Epidemiology, Disease Control and Research (IEDCR), under the Ministry of Health and Family Welfare, has collaborated with icddr,b to conduct hospital-based encephalitis surveillance in Nipah-affected areas [37]. In 2011, the government officially recommended against consuming raw DPS during the Nipah season due to the associated risks. IEDCR and the Communicable Disease Control (CDC) program under the Directorate General of Health Services (DGHS), Bangladesh, coordinate public awareness efforts each year through national television, print media, and public service announcements to educate the population about NiV transmission, particularly during the high-risk winter months [39].

While these initiatives represent important progress, they remain limited in scope and coverage. Understanding of NiV among the general population remains low, and many interventions are not scaled across all affected regions.

Limitations of past interventions and challenges in preventing NiV spillover

Although the past interventions and efforts by the government, along with other partners, were able to improve public awareness of

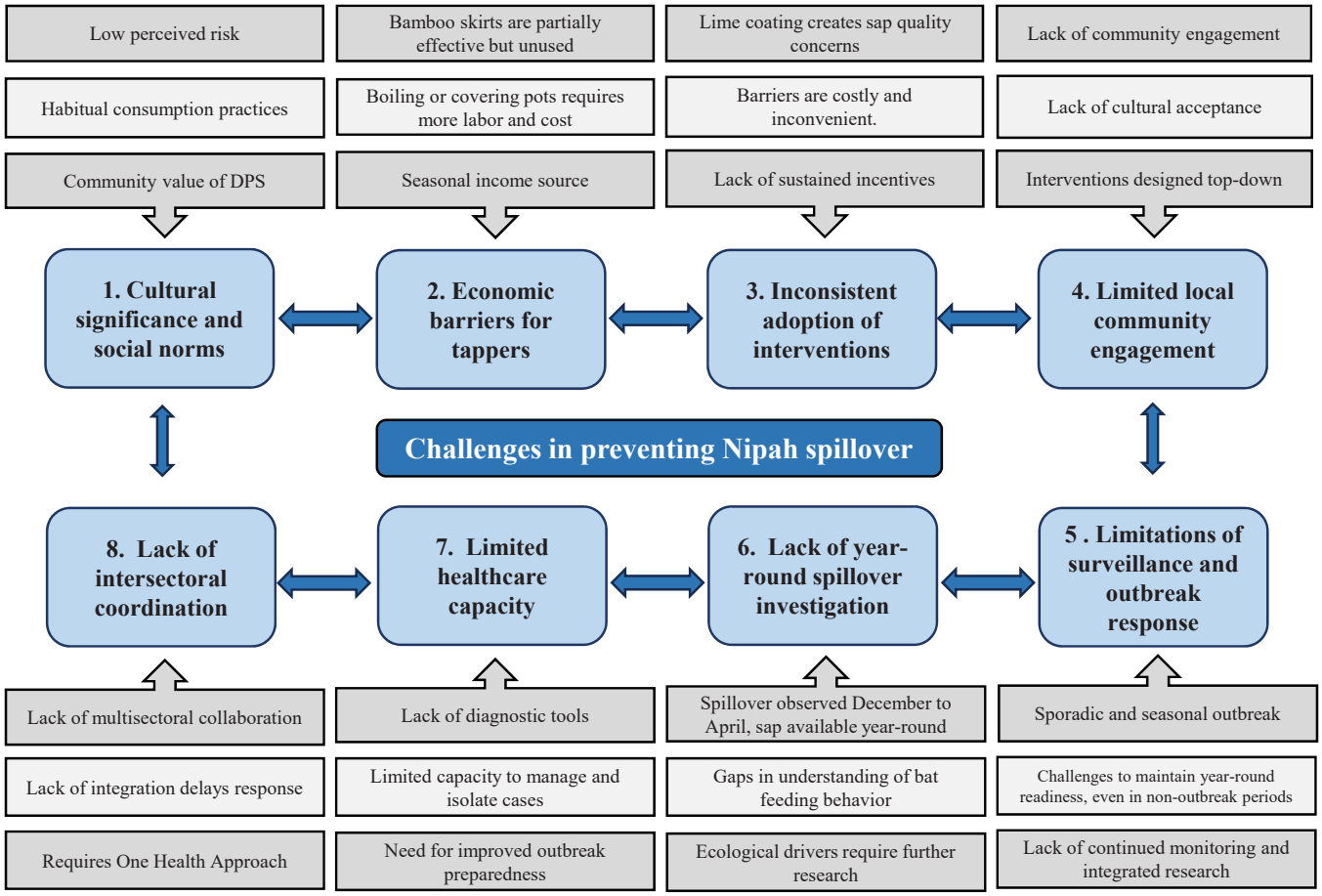

Fig. 2. Challenges in preventing Nipah virus spillover in Bangladesh.

sap-borne NiV transmission, meaningful and sustained behavior change has been minimal. Due to socio-cultural and economic setbacks, limitations and inconsistency of adopted interventions, lack of community engagement, limited surveillance, response and healthcare facility and intersectoral coordination, sap-related transmission persists and hinders the overall effectiveness of national outbreak prevention and control efforts (Fig. 2).

Sociocultural drivers of risk

Despite sustained public health efforts, the consumption of raw DPS remains widespread in Bangladesh and may even be increasing. The growing availability of raw sap through online marketing and transport to urban areas has expanded access beyond traditional rural consumers. Observational reports from Dhaka suggest that raw sap is sold openly during the winter months and consumed by a wide range of people [40]. Once a rural tradition, now seen in the urban areas as well [20]. A study from 2013–2014 found that 15 % of respondents reported consuming DPS during January and February, with the highest levels of consumption [21]. Cultural attachment to raw sap continues to pose a major barrier to behavior change. Although awareness campaigns have communicated the risks of NiV transmission via contaminated sap, many individuals still view the practice as safe or culturally important. Even when risk awareness is raised, social habits and community preferences often override public health messages. This gap between knowledge and behavior reflects low perceived personal risk and occasional skepticism toward public health messages [13]. Behavior change initiatives—such as the "only safe sap" campaign and the promotion of effective physical barriers around sap collection pots—have had limited uptake, particularly where economic or practical concerns are prioritized over health warnings [9].

Economic setbacks

For many tappers, sap collection is a critical seasonal income source. Despite some evidence supporting the use of bamboo skirts and other physical barriers, the protective interventions or boiling sap at 70 degrees Celsius are often seen as labor-intensive, costly, or a threat to earnings[38]. Lack of co-designing solutions with tappers, low-cost tools, material support, or small financial incentives create unwillingness to undertake this extra workload. Moreover, very few or no initiatives have explored alternative income sources for sap collectors to reduce economic reliance on raw sap production.

Inconsistency and limitations of adopted interventions

A large-scale study analyzing data from over 10,000 households in 1001 communities have documented variations in sap consumption and risk awareness across regions [21]. While some households have reduced consumption in response to messaging or visible interventions like bamboo skirts, others continue traditional practices. Tappers often perceive these interventions as burdensome, particularly when they affect sap yield or involve extra effort and cost without corresponding financial incentives or benefits, leading to inconsistency in adopting the intervention.

Despite evidence of reduced bat-sap contact, the government faced several challenges in adopting and scaling up physical barrier interventions for the safe collection of DPS. A primary limitation was the inability of the government, as well as the consumers, to verify

whether the sap had been collected using protective barriers, creating a dilemma for policymakers between promoting a 'No Sap' approach versus advocating for 'Safe Sap'.

Even though, the bamboo skirts or *banna* reduced bat visits to the DPS collecting pots, hence reducing some risk of contamination by preventing bat-sap contact, it cannot eliminate the risk [7]. However, its use and advertisements by the promoters and sellers create a false sense of security among the sap collectors, sellers and consumers, in turn increasing the raw DPS consumption among the general population.

Consequently, the adoption of preventive measures has often been short-lived, hindered by economic realities, prevailing social norms and inadequate follow-up mechanisms. Despite a growing body of evidence and multiple pilot interventions, achieving sustained behavioral change remains a challenge. Furthermore, inadequate funding and competing national priorities are significant obstacles to the government's ability to scale up these interventions effectively.

Lack of community engagement and ownership

One of the critical reasons for the limited uptake and adoption of past interventions was the limited involvement of communities in designing the interventions. Even though some of the interventions (such as *banna*) involved the sap harvesters, the engagement was not adequate to sustain the intervention in the long run. Lack of community engagement may lead to reduced risk perception or the establishment of a belief that the threat of NiV is overstated due to the sporadic nature of the disease. Many programs fail to reflect local religio-cultural perspectives or socioeconomic realities, which limits their acceptance [41].

Limited surveillance, health systems and response capacity

The sporadic nature of NiV outbreaks poses challenges for maintaining readiness. Many rural health facilities remain under-resourced, and the outbreaks are often detected late, especially due to a lack of robust surveillance, both sentinel and community-based. Outbreak response strategies, including patient isolation, quarantine and contact tracing, also face operational challenges due to delayed intervention and management [42]. Besides, the lack of healthcare worker training, diagnostic tools and protective equipment is also a critical challenge Bangladesh needs to overcome.

Ecological and environmental risk landscape

Spillovers are most frequently reported between December and April, yet sap availability and bat activity continue year-round [37]. There are gaps in understanding the ecological drivers, such as bat feeding behavior, viral shedding patterns, and climate influences. Spatial mapping and environmental risk assessment are critical to identify the hotspots. Long-term studies involving ecologists, virologists, social scientists, and communities can clarify seasonal risks and inform better prevention strategies.

Lack of intersectoral collaboration

NiV outbreaks have exposed a critical lack of integration across various sectors, including public health, veterinary, environmental health, and community. This incoordination caused a delay in an appropriate and comprehensive response during outbreaks. Establishing national cross-sectoral working groups through one health approach and shared data systems for surveillance is critical in order to strengthen coordination, improve information flow, and ensure aligned prevention and response strategies.

Strategic recommendations

Addressing the social, ecological and health system challenges identified in this review will require sustained investment, integrated approaches, and cross-sectoral collaboration. The following priorities outline a comprehensive way forward.

Culturally informed risk communication and community engagement

Awareness of NiV remains low in many affected regions despite multiple interventions. Community-led educational efforts, including community engagement, should prioritize culturally sensitive messaging, focusing on the risk of raw DPS consumption and basic IPC practices such as handwashing and avoiding direct contact with sick individuals. Caregivers, particularly in later stages of illness, should be informed of transmission risks in a respectful, locally appropriate manner, as close physical contact remains a key pathway for human-to-human NiV transmission. Promoting culturally appropriate community-based hygiene practices, such as handwashing with soap among family caregivers, traditional healers, and frontline health workers, can mitigate infection risks in both households and health facilities.

Media is an important stakeholder considering its role in shaping risk perceptions and health behavior. Targeted media campaigns during the sap harvesting season, tailored messages through the television, radio and social media in local languages can support risk awareness. Visual storytelling, testimonials from affected families and messages delivered by trusted local figures can enhance public understanding and motivate behavioral change. Besides, Government initiatives should not be limited to the peak transmission season. Regular, year-round awareness campaigns are essential to transform behavior over time. National and local authorities must work together to sustain risk communication and community engagement efforts.

Moreover, during outbreaks, coordinated messaging and temporary movement restrictions may help limit the spread of the virus. All public health guidance, such as avoiding raw sap, contact with symptomatic individuals, or high-risk behaviour, should be timely, clear, and adapted to local norms and behaviors.

Co-designed, acceptable and affordable interventions

Co-design and adaptation of protective practices, involving sap harvesters or tappers, community leaders and local influencers in designing and promoting community-driven, low-cost and sustainable interventions, increases ownership and adoption. New strategies to effectively shield sap pots from bats must be culturally acceptable, affordable, and easy to implement. Although most studies revealed economic constraints, one of the earlier pilot studies showed that cleaner sap, produced by using physical barriers, was sold at higher prices [36]. Future intervention messages should highlight the concept of better price among the tappers and promote the demand for safer sap among consumers from trees with interventions. This may motivate the harvesters to adopt these practices despite increased labour demand, slightly reduced yields and primary economic constraints [34]. Furthermore, raw sap collection is a seasonal income source for many. Offering financial incentives and low-cost protective materials promotes safer practices during the sap harvesting season.

The participation of economists and market leaders in designing and supporting alternative livelihoods can help reduce the economic barriers. Molasses production from DPS presents a viable alternative that eliminates the risk of Nipah virus transmission associated with raw consumption [34]. The government could incentivize this practice by financially supporting small-scale molasses processing units, providing training, and offering market linkages. Promoting

molasses as an alternative income source may encourage harvesters to gradually shift away from selling raw sap.

Revisiting and strengthening past interventions is another important way forward. Bamboo skirts, for example, has been widely promoted as an effective preventive measure, which was later proven to be not entirely accurate. This created a false sense of security, leading the harvesters and consumers to believe that the risk of NiV transmission has been completely eliminated, thereby increasing their consumption and making them more vulnerable. Future public health messages should carefully navigate this gap by clearly communicating the limitations to both tappers and consumers. Besides risk communication and awareness campaigns, mass media and social media can play a crucial role in this issue. Alongside, multidisciplinary teams should review and adapt prior interventions in light of past challenges and community feedback and come forward with newer interventions that entirely eliminate the risk of transmission. Understanding what worked and why some interventions failed to scale can inform more effective, context-specific future strategies.

Healthcare facilities, especially in resource-limited settings, require improved capacity to manage and contain NiV cases. Priorities include training health workers in IPC protocols, ensuring consistent access to personal protective equipment (PPE), establishing isolation areas, and reinforcing safe waste disposal practices.

Surveillance, outbreak preparedness, and one health coordination

Enhanced surveillance systems, including early warning and community-based reporting, are critical to detect cases and respond rapidly. Investments in surveillance infrastructure and local response capacity will reduce delays in containment and prevent wider transmission. Community-level reporting systems can support rapid response and reduce the lag between spillover and intervention, ultimately reducing disease severity and mortality.

The one health framework linking human, animal and environmental health is essential for effective NiV control. National-level working groups and integrated disease surveillance platforms can strengthen coordination and data sharing. Moreover, routine surveillance of known NiV reservoirs, such as bats and pigs, is needed to detect early warning signs of increased risk of virus circulation. Monitoring bat feeding behavior, movement patterns, and environmental factors during high-risk periods can inform targeted prevention efforts. Deploying rapid-response teams including epidemiologists, veterinarians, ecologists and social scientists during outbreaks can help uncover emerging risk factors, provide real-time context and guide appropriate local responses. These teams play a critical role in shaping adaptive, culturally sensitive prevention strategies.

Applied research and locally led innovation

Further research is needed to generate the evidence, including assessing the long-term effectiveness of behavioral interventions like protective barriers, boiling sap and communication strategies. This includes follow-up studies on earlier pilot interventions, measuring both behavioral outcomes and community acceptance. For understanding ecological and transmission dynamics, year-round research into bat behavior, sap contamination patterns, and ecological drivers of spillover is essential. Studies exploring viral shedding, human susceptibility, and seasonal patterns will strengthen outbreak forecasting and prevention.

It is required to initiate social and behavioral science research to understand how communities perceive risk, the trade-offs between health and tradition, and the social norms that drive sap consumption, which can guide more effective interventions. Exploring power dynamics, gender roles and cultural practices will also help identify hidden barriers to change.

Digital platforms expand access beyond traditional markets, and their emergence as a channel for selling raw DPS presents a significant emerging challenge and a relatively new aspect to the NiV spillover scenario through raw DPS consumption. While these platforms offer convenience and wider market access, they also bypass safety checks and create new risks for NiV transmission. Targeted awareness campaigns and extended monitoring and regulatory measures, such as seller registration, verification, and periodic safety inspections, could play vital roles in mitigating the risk. Research into the unregulated online sale of raw DPS is critical to understanding the evolving dynamics of its distribution and the associated public health risks of potential NiV transmission through contaminated sap.

However, in parallel with prevention, sustained investment in the development of Nipah-specific medical countermeasures is essential. Collaborative efforts involving governments, research institutions, and global health partners are needed to accelerate the development of vaccines, therapeutics, and diagnostic tools [44]. These efforts should prioritize equitable access, regional preparedness, and readiness to deploy tools in outbreak-prone areas**.** While addressing sap-related spillover is critical, broader strategies are essential to reduce the overall risk of NiV transmission and strengthen outbreak preparedness and response. These interventions focus on infection control, ecological surveillance, public health infrastructure, and medical countermeasure development.

Conclusion

Over the past two decades, progress has been made in our understanding of the repeated NiV spillover through raw DPS in Bangladesh. However, the persistence of culturally rooted consumption practices, economic reliance on sap harvesting and limited cross-sectoral collaboration continue to hinder the adoption of effective preventive strategies.

To reduce the risk of future spillover, there is a need for community-driven, low-cost, and culturally acceptable interventions that limit bat access to sap without undermining livelihoods. Promoting safe harvesting methods, sustained public awareness campaigns, and participatory education particularly through trusted community figures and local media will be essential for shifting behaviors in high-risk regions. Equally important is the inclusion of frontline clinicians, public health responders, and affected communities in the design and evaluation of both interventions and research agendas. Future strategies must prioritize context-specific solutions that integrate lived experiences, support local ownership, and ensure follow-up mechanisms for evaluating implementation. Finally, accelerating the development of diagnostics, therapeutics and vaccines through collaborative research and inclusive advisory panels will be critical for long-term preparedness. Protecting vulnerable populations from NiV requires sustained multisectoral commitment linking community insights with scientific innovation and coordinated public health action.

Ethical statement

Not applicable.

Author contributions

MZH conceived the original idea for the manuscript which was further developed by DY. DY, SH and MZH conducted the literature review, performed the analysis, and drafted the manuscript. DY and SH prepared the revision based on the feedback from MZH. MZH, MMH, SH and MR critically reviewed the scientific content,

contributed to revisions and finalized the manuscript. MZH provided supervision to the project. All authors reviewed and approved the final version of the manuscript.

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Declaration of Competing Interest

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