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Original Article

Seroprevalence of peste des petits ruminants in sheep and goats managed under pastoral and agro-pastoral systems

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Abstract

Introduction: Peste des petits ruminants (PPR) is an infectious disease that imposes substantial economic burdens on small ruminants (SR) production. For Tanzania to develop efficient management and eradication plans, it is essential to comprehend the seroprevalence of PPR designated for global elimination by 2030.

Methodology: This study investigated the prevalence of PPR in animals kept under pastoral and agropastoral communities in Tanzania. A total of 1,128 blood samples from SR were collected and analyzed for PPR-specific antibodies using the HPPR-b ELISA technique. Multivariate logistic regression was used to analyze the risk factors

Results: The overall seroprevalence was 10%. Higher seropositivity was observed in the Kiteto, Longido, and Simanjiro districts of the northern zone and the Mbarali district of the southern highlands, with the seroprevalence decreasing trend from the northern to southern zones. Multivariate logistic regression analysis for risk factors identified significant differences in seroprevalence across disease surveillance zones, with odds ratios (OR) ranging from 2 to 3.

Conclusions: Agropastoral production systems exhibited lower PPR seroprevalence compared to pastoral systems. The increasing seropositivity in the Mbarali district suggests a southward spread of PPR, increasing a threat to Tanzania's southern regions and neighboring countries. The disease's dissemination is closely linked to livestock trading infrastructure, highlighting the need for periodic seromonitoring. Control efforts should prioritize highly affected northern zones and implement strict regulations on animal movement to protect less-affected southern areas.

Key words: Seroprevalence; agropastoral; pastoral; surveillance zones; peste des petits ruminants.

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Introduction

Peste des petits ruminants (PPR), a highly lethal economic disease, can afflict both domestic and wild small ruminants [1]. It is endemic in Tanzania as well as in Asia, the Middle East, and Africa [2]. Nearly two-thirds of all sheep and goats in the world are at risk of PPR infection [3]. Fever, ocular and nasal discharges, stomatitis, and copious diarrhea are the typical clinical symptoms of PPR [4]. Animals infected with the PPR virus (PPRV) discharge massive amounts of the virus through their saliva, feces, nasal and ocular secretions. PPRV's high fragility when outside the host explains its susceptibility to heat and sunshine [5]. The disease is mostly transmitted by fomites, tainted food and water, and animal-to-animal contact via the respiratory mucosal pathway [6]. Livestock movements play a key role in the spread of PPR due to the contagiousness nature of the virus [7]. The growth of SR trade has a significant contribution to SR mobility compared to other factors like grazing land and social and cultural activities [8]. PPR economic losses are mostly brought about by mortality rates that are higher than 90% in the naive population and management costs for associated morbidities that can reach 100% [9]. Due to mortality, output loss, and control expenses, it is estimated that PPR results in an annual global economic loss of between US$1.2 and 1.7 billion [10]. With a control benefit-cost ratio of 33.8 and an internal rate of return (IRR) of 199%, the net benefit of the global eradication of PPR is estimated to be US$74.2 billion [11]. PPRV management is easier than other viral diseases like foot and mouth disease, which has seven serotypes, due to its antigenically stable single serotype and lifetime immune response following vaccination [5]. With this in mind, the Food and Agriculture Organization (FAO) and the World Organization for Animal Health (WOAH) have set 2030 as the goal for the global elimination of PPR [12].

Pastoral communities can be found in northern Tanzania (Figure 1) and are historically dominated by Maasai ethnicity, with less populated groups such as the Barabaig ethnicity [13,14]. While agropastoral communities, which may be found in numerous regions of Tanzania, depend on both agriculture and livestock husbandry as compared with pastoral groups depend only on animal production. Climate change, inadequate resources, and loss of control over epidemics have led to a shift from pastoralism to agropastoralism [15]. Both agropastoral and pastoral societies adopt mitigation strategies, such as livestock diversification, to address these challenges. However, the shift to small ruminants has led to changes in livestock disease epidemics, making investigations and control crucial for their livelihoods [10].

For the purpose of disease surveillance, Tanzania has been divided into 7 surveillance zones, which are the Northern, Southern, Eastern, Central, Lake, Southern Highlands, and Western zones [1]. The southern half of Tanzania's introduction of PPR to other nations is being slowed down by the high concentration of pastoral communities in the northern part and the lower concentration in the southern part of Tanzania [16]. PPR vaccinations were provided in Tanzania at various times and places [1], therefore, our study won't be affected by vaccination because it was carried out in the area under investigation decades ago. There has been no substantial research on PPR seroprevalence in relation to livestock trade infrastructure distribution in Tanzanian pastoral and agro-pastoral communities, resulting in a scarcity of knowledge on its prevalence. The purpose of this study is to determine the current PPR seroprevalence as well as the impact of livestock mobility on PPR spread in sheep and goats.

Methodology

Study Area

A cross-sectional study was conducted in 17 districts of Tanzania to determine the prevalence of PPR (Figure 2). Using a purposive sampling approach, risk factors for disease spread were considered in selecting our study area. Risk factors considered in this study include geographical location, husbandry system, animal population (Table 1), and composition, species, season, vaccination, and source of the animal [17]. Apart from risk factors, information from the Director of Veterinary Services (DVS) on the zones with recent outbreaks of PPR was considered during sample collection. Five surveillance zones, namely the southern, southern highland, northern, lake, and central zones, were selected from seven surveillance zones established for animal disease control in Tanzania [1].

Ethical Statement

Specimens were collected as part of routine disease investigations, in compliance with the Animal Welfare Act of 2008 (CAP.154) [18]. DVS authorizes the

Figure 1. Map of Tanzania showing the distribution of pastoral and agropastoral societies.

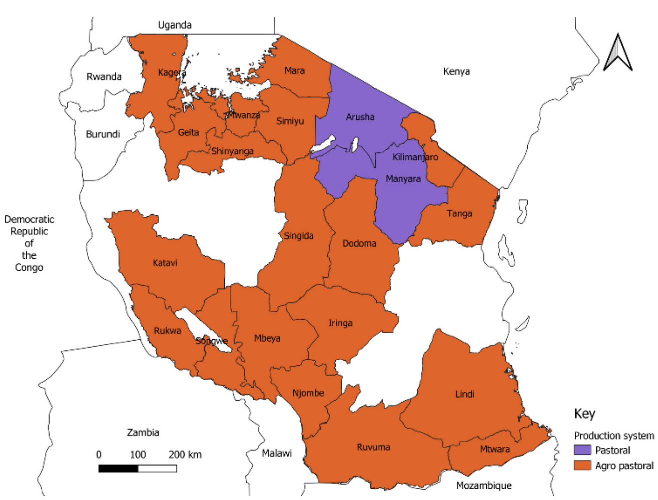


Figure 2. Map of Tanzania showing our study area surveyed for PPR.

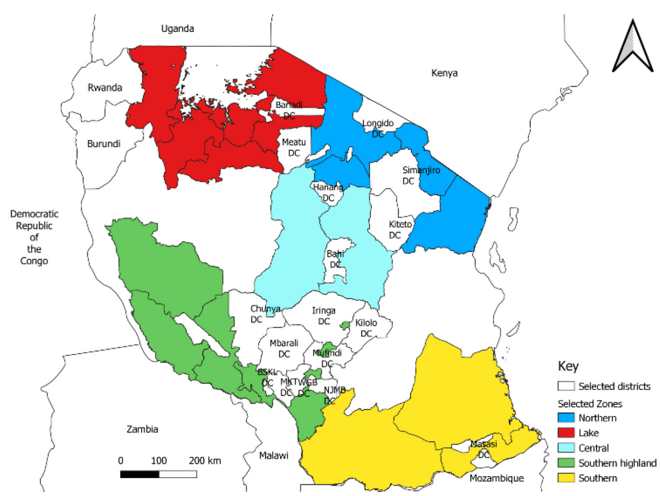


Table 1. Sheep and goat populations in the study area based on the National Agricultural Census report.

Zone	Region	Goat	Sheep	Total
Central	Dodoma	1,663,483	44,725	1,708,208
Northern	Manyara	2,380,072	937,541	3,317,613
Northern	Arusha	1,597,787	1,576,091	3,173,878
Lake	Simiyu	960,310	800,022	1,760,332
Southern	Mtwara	435,633	13,599	449,232
Southern highland	Iringa	461,381	173,394	634,775
Southern highland	Mbeya	479,957	75,599	555,556
Southern highland	Njombe	168,909	24,680	193,589

Source: The United Republic of Tanzania (URT) Ministry of Agriculture (2021) The United Republic of Tanzania National Sample Census of Agriculture 2019/20 key findings report.

collection of specimens from the outbreaks through his approval letter (Ref. No. DB.16/324/01/12) of April 15, 2021. The samples were sent to Sokoine University of Agriculture (Morogoro, Tanzania) for serological diagnosis of PPR antibodies, benefiting the Tanzanian government's implementation of animal disease law and strengthening PPR control strategy.

Sampling procedure

To assess the seroprevalence of PPR in small ruminants in the research area, a cross-sectional, three-stage sampling technique (region, district, and ward) was employed to investigate the seroprevalence of PPR in small ruminants in our study area. Purposive sampling was employed to evaluate the influence of multiple risk factors on PPR spread. The sampling focused on livestock keepers at higher risk of PPR exposure. With a huge study area and a large animal population, the strategy will increase the efficiency of the investigation as only relevant samples will be collected. This approach accounted for geographic, social, economic, and migratory factors influencing PPR spread [19]. Our study unit was purposefully chosen at each stage based on geographical location, husbandry system, demographic characteristics, and vaccination status. With the limitation of establishing a sample frame, the sample size for the detection of disease was used to estimate the required number of animals to be sampled per village. Due to the absence of a sample frame, disease detection sampling guidelines were applied to estimate the number of animals sampled per village [20]. A 95% sensitivity of finding at least one positive animal in a finite population and an expected prevalence of 10% were assumed, with a sample size of at least 30 units [20]. There was no set quantity for each ward's animal sample. It fluctuated according to flock sizes, ease of transportation, and accessibility of logistical services [19]. Five disease surveillance zones were selected because regions with a high number of small ruminant populations or other zones with a small ruminant population were included for comparative advantage in our study. Geographical location to include the cross-border effect (northern zone) and the centrality effect (central zone) for effective PPR dissemination were considered in zone selection. A huge number of districts (17) were selected to explore the effect of livestock movement on the country-wide spread of PPR. Due to convenience and the fact that the southern highlands have historically had few PPR outbreaks and a low SR population, a sizable sample size was gathered from the zone during surveillance. As a result, DVS was interested in verifying the PPR status in the relevant field. A team of one veterinarian and two livestock field officers collected specimens between August 21, 2021, and October 13, 2021. Poor representativeness made it difficult to define a sampling frame in purposeful sampling because only selection criteria were taken into account in the sampling area; either way, bias will not be prevented because other areas that don't fit the predetermined criteria will be accidentally overlooked; and it is challenging to precisely define the boundaries of sampling areas because selection criteria may change as the research progresses [20]. During specimen collection, information on potential risk factors such as location and husbandry practices was recorded in the Kobo Collect software.

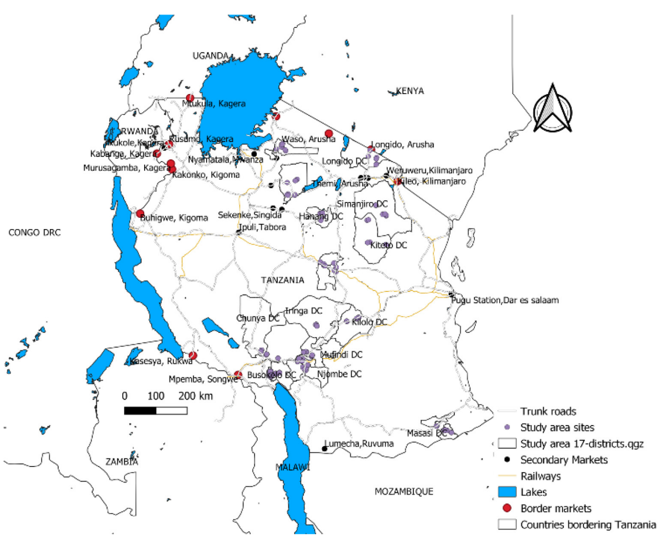
Serum collection and testing

Blood samples were collected with sterile, disposable plain vacutainer tubes and needles, and they were identified with special codes that corresponded to the species, sampling ward, and specimen serial number. Vacutainer tubes containing blood were kept at room temperature to allow serum formation. Serum specimens were harvested 12 hours after collection and immediately transferred to a liquid nitrogen tank before being transported to SUA-Laboratory for analysis. HPPR-b-ELISA was used to detect antibodies against the PPR virus. The HPPRb-ELISA method incorporated vaccination history to distinguish vaccinated from unvaccinated populations [21]. Quality assurance procedures were followed throughout sample collection and laboratory analysis to guarantee the accuracy of the results. Disposable sample collection tools and cold chain facilities, such as a liquid nitrogen tank, were utilized during sample collection. The SUA laboratory, which practices laboratory quality assurance as demonstrated by the use of disposable lab supplies, reliable cold chain facilities (ultra freezers), the use of validated diagnostic kits, and participation in PPR interlaboratory proficiency tests, is where laboratory assays were carried out. The results were compiled and analyzed in Microsoft Office Excel. The ELISA kit did not differentiate between vaccinated and non-vaccinated animals but could have been used with a marker vaccine that differentiates between natural infections and vaccinated animals [22].

Mapping of Livestock trade infrastructure

GPS data collected during sampling and online searches were used to map livestock market accessibility. GPS data collected from sampling sites and those collected from online searches were arranged and saved in comma-separated value (CSV) format. Respective maps were drawn using the Quantum Geographic Information System (QGIS) 3.16 software and exported as Portable Network Graphics Files for subsequent use [23]. Maps drawn include the regional distribution of pastoral and agropastoral communities in Tanzania, where Masai ethnicity can be found in Longido, Kiteto, and Simanjiro districts, while Barabaig ethnicity is located in Hanang district (Figure 1). A second map of Tanzania was drawn to show our study area surveyed for PPR (Figure 2), while a third map was drawn to show the spatial accessibility of our study sites to livestock markets (secondary and border markets) (Figure 3).

Figure 3. Map of Tanzania showing the density of roads, railways, livestock markets, and study sites.



Data management and analysis

Spatial data were processed using QGIS 3.16, regression analysis was performed in R, and data processing was conducted in Microsoft Excel [23,24]. Descriptive statistics were summarized, and individual-level seropositivity calculated. Individual-level seropositivity was calculated at different stages by using the survey command in R, with the ward being the primary sampling unit. Our study utilized a generalized linear model to examine the correlation between exposure variables and PPR antibody seropositivity, calculating the degree of association using the odds ratio [25].

Results

Out of 1,128 serum samples collected from 17 districts across five surveillance zones, an overall seroprevalence of 10% (117/1,128) was observed. Univariate and multivariate analyses of zones, regions, and districts are presented in Tables 2 and 3. The mapping of the spatial accessibility infrastructure network to livestock markets and study area proximity has been shown in Figure 3.

Mapping seropositivity distribution and livestock trade infrastructure

Figure 2 highlights secondary cattle markets and spatial accessibility in Tanzania. The northern zone exhibited high accessibility due to its dense network of roads, railways, and markets, whereas the southern zone showed limited infrastructure (Figure 3).

Univariate analysis of risk factors

Fifteen of the 31 examined factors showed a significant correlation ($p < 0.05$) with PPR seropositivity (Table 2). These variables were divided into districts, regions, and zones. Notable findings were observed in the Lake Zone and Mtwara Region, despite the limited sample size. In five surveillance zones, goats and sheep were shown to have PPR antibodies, with only minor variations as shown in Table 2.

Multivariable risk factor analysis regarding exposure to PPR

Multivariable logistic regression analysis (Table 3) identified geographical location as the primary risk factor for PPR seropositivity. The Northern Zone demonstrated an odds ratio (OR) of 3 (95% CI), while the Manyara Region exhibited an OR of 0.5 (95% CI). Post-estimation statistics, including the Hosmer-Lemeshow goodness-of-fit test, indicated the model's alignment with observed data (R^2: 0.61; adjusted R^2:

Table 2. Univariable analysis of exposure variables and PPR prevalence in sheep and goats.

Variables	Levels	Number examined	Positive	Seropositivity (%)	*p*
Surveillance zone	Lake zone	50	2	4	0.04483
	Northern zone	106	43	41	0.47763
	Southern highland	866	63	7	0.96161
	Southern zone	63	1	2	–
	Central zone	43	8	19	–
Region	Mtwara	63	1	2	0.04213
	Dodoma	45	8	19	0.10325
	Arusha	26	14	54	–
	Simiyu	53	2	4	0.04652
	Manyara	77	29	38	0.18177
	Mbeya	297	58	20	0.053
	Njombe	282	0	0.0	0.01606
	Iringa	287	5	2	0.01643
Districts	Bahi	43	8	19	–
	Bariadi	25	0	0	0.995705
	Busokelo	96	2	2	0.003577
	Chunya	95	1	1	0.004471
	Hanang	25	0	0	0.995705
	Iringa	96	0	0	0.999141
	Kilolo	96	4	4	0.00994
	Kiteto	27	17	63	0.000331
	Longido	26	14	54	0.003329
	Makete	95	0	0	0.991627
	Masasi	63	1	2	0.014231
	Mbarali	106	55	52	0.00039
	Meatu	28	2	7	0.190492
	Mufindi	95	1	1	0.004471
	Njombe	93	0	0	0.991716
	Simanjiro	25	12	48	0.012713
	Wang'ing'ombe	94	0	0	0.991671
Species	Goat	882	91	10	–
	Sheep	246	26	11	0.909

$p > 0.05$ were significant; – value show the out-of-range p value.

0.30; $p = 0.167$). The district was not included in the multivariable analysis due to collinearity.

Discussion

Serological surveillance combined with monitoring livestock movement is an effective strategy for managing PPR in small ruminant populations. PPR surveillance in endemic environments is often carried out by antibody detection, which selects for both natural infection and vaccination in the results. Immunization-induced antibodies indicate the degree of protection, whereas spontaneous infection-related antibodies explain the extent of PPR spread. The requirement for an unavailable DIVA-compliant vaccination in the management of PPR disease stems from the ability to distinguish between the two sets of findings above utilizing the differentiation of infected from vaccinated animals (DIVA) vaccine [26,27]. Figure 3 highlights the association between increased small ruminant trade activity and the density of highways, railroads, and livestock markets. Livestock movement as a major PPR risk factor is driven by small ruminant trade, which is prominent in the northern, central, and lake zones where high seroprevalences were detected [28]. A study in

Table 3. Multivariable analysis of exposure variables and PPR seropositivity in sheep and goats.

Variables	Levels	Number of specimens	Positive (%)	OR	CI (97.5)	*p*
Surveillance Zone	Lake zone	50	2 (4%)	0.18229167	–	0.04483
	Northern zone	106	43 (41%)	2.98611111	2.72	0.47763
	Southern highland	886	63 (7%)	0.34324408	-0.75	0.96161
	Central	43	8 (19%)	–	–	–
	Southern zone	63	1 (2%)	0.07056453	–	–
Region	Arusha	26	14 (54%)	–	–	–
	Dodoma	43	8 (19%)	0.19592	–	0.06234
	Iringa	287	5 (2%)	0.01520	–	0.01262
	Manyara	77	29 (38%)	0.51786	–	0.07991
	Mbeya	297	58 (20%)	0.20801	–	0.53252
	Mtwara	63	1 (2%)	0.01382	–	0.01711
	Njombe	282	0 (0%)	0.00000	–	0.00753
	Simiyu	53	2 (4%)	0.03361	–	0.02708

No: number of tested specimens; CI: confidence interval; OR: odd ratio; $p < 0.05$ were significant – value shows the out-of-range p value and OD ratio.

Tanzania collected 1128 serum samples, showing a 10% seroprevalence compared to previous studies [1]. Factors contributing to lower seroprevalence include flock size variation, vaccination support, and enroute insecurity [29]. The northern zone exhibited a high seroprevalence of 41%, while the central and lake zones reported lower rates of 19% and 4%, respectively, consistent with previous findings [30]. The northern zone's high spatial accessibility has facilitated migratory livestock flows, contributing to its elevated seroprevalence. The southern highlands and southern zones recorded low seropositivity (7% and 2%, respectively), attributed to low small ruminant populations and limited livestock trade activities. In these zones, livestock migration is primarily for slaughter due to limited local livestock production. As seen in Figure 3, the large area in the southern zone has a limited number of trunk roads and secondary livestock markets, as represented by the Lumecha secondary market in Ruvuma. PPR outbreaks in new areas have been driven by settlement shifts due to the shrinkage of grazing land resulting from climate change and other social and economic factors. Mbeya region in southern highland historically experienced livestock migratory flow from the northern and lake zones, but letter-forced eviction from the region caused increased livestock migratory flow to the southern zone regions of Lindi and Mtwara [14]. Seroprevalence levels were closely associated with the distribution of livestock markets, railways, and road infrastructure (Figure 3). Infrastructure density in northern Tanzania, as reported in this study, was also reported by [28] to be associated with increased seroprevalence in the respective area.

While both sheep and goats are susceptible to PPR, naturally there are variations in susceptibility and mortality rates based on factors such as breed, age, and pre-exposure status. Additionally, management practices, vaccination status, and the presence of concurrent infections can influence the severity of the disease in both sheep and goats. The study found no statistically significant difference in seropositivity between sheep (11%) and goats (10%) ($p = 0.909$). The maximum entropy model, which can contribute to the spatial mapping of regional sheep and goat population distribution PPR hot spot identification discovered a non-significant influence on seroprevalence between sheep and goats [31]. Some researcher [32,33] found that goats have a higher seroprevalence than sheep, while others found the opposite [25]. Sample size and breed susceptibility contributing to result variability were the main conflicting findings in the previous research. Smaller sample sizes for sheep may skew seroprevalence comparisons. It will lead to a biased estimation of seroprevalence rates between the two species. As reported in many studies where more goats were sampled than sheep, the seroprevalence rates in goats appear to be higher simply due to the larger goat sample size. Consequently, this result interpretation challenge will complicate the development of targeted control and prevention strategies for PPR in both species. Arusha region had a high seroprevalence of 54%, followed by Manyara (38%), Mbeya (20%), and Mtwara, Iringa, and Njombe (0%–4%). Population variation, as shown in Table 1, is related to variations in contact rates between susceptible animal populations, which account for PPR risk variation in respective regions. Low animal populations may slow PPR spread to neighboring countries through southern borders [34,35].

Our study reveals that PPR seroprevalence in Tanzania is influenced by factors such as international borders and PPR incursion histories [36]. Districts like Kiteto (63%), Longido (54%), and Simanjiro (48%) have high PPR incidences and a high sheep and goat population, which is linked to their proximity to Kenya [37]. The seroprevalence distribution is correlated with the population distribution of agropastoral and pastoral communities, with the northern zone having a higher density of pastoral communities. Pastoralists and agropastoralists have been migrating from the northern, lake, and central zones to Mbarali district since 1972 [14,38], with 52% of seroprevalence in the district correlated with this integration. Geographical zone predisposition is evident in PPR occurrences in Tanzania. The findings underscore the need for enhanced surveillance systems.

Conclusions

PPR is spreading from Tanzania's northern to southern borders, and the northern border's rising seropositivity in the Mbarali district poses a serious threat to Tanzania's southern region and its surrounding countries. Infrastructure related to the livestock trade has an impact on PPR dissemination, and regular seromonitoring is essential for efficient control. A "PPR Progressive Control and Eradication Strategy" was established in Tanzania and other Southern African Development Community (SADC) countries to control PPR. The goals of the strategy are to: 1) stop PPR from being introduced and spreading further into the nation; 2) gradually control PPR in the affected zones; and 3) completely eradicate PPR from the infected countries by 2025 [39]. Restricting livestock migration to less PPR-prevalent southern regions while focusing control strategies on northern Tanzania is expected to benefit both Tanzania and neighboring Southern African countries.

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Authors' contributions

JM developed the research question, conducted the literature review, study design, laboratory work, data collection, analysis, and interpretation, and led the manuscript drafting and revision. GM, AC, and SK mentored JM throughout the research process, contributing to our study design, data interpretation, and manuscript review. SP mentored JM, assisted in study design, and reviewed the manuscript. DM, GM, and GO contributed to data collection, interpretation, and manuscript revisions. RS assisted with laboratory work and manuscript preparation. All authors read and approved the final manuscript.

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