Development of a practical framework for sustainable surveillance and control of ticks and tick-borne diseases in Africa

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Received: 29-03-2020, Accepted: 22-07-2020, Published online: 19-09-2020

doi: www.doi.org/10.14202/vetworld.2020.1910-1921 How to cite this article: Nchu F, Nyangiwe N, Muhanguzi D, Nzalawahe J, Nagagi YP, Msalya G, Joseph NA, Kimaro EG, Mollel M, Temba V, Harouna DV (2020) Development of a practical framework for sustainable surveillance and control of ticks and tick-borne diseases in Africa, Veterinary World, 13(9): 1910-1921.

Abstract

A workshop on ticks and tick-borne diseases (T&TBDs) was held on June 25 and 26, 2019, at the Tropical Pesticides Research Institute, Division of Livestock and Human Diseases Vector Control, Arusha, Tanzania. The objectives of the workshop were to discuss the current situation and to formulate actionable strategies to improve surveillance and control of T&TBDs in Africa. The workshop was funded by the National Research Foundation and the Cape Peninsula University of Technology and attended by livestock health providers, farmers, and researchers from East, West, and Southern African countries. During the workshop, experts presented recent surveillance data focused on T&TBDs; participants discussed research opportunities and community engagement. The primary outcome of the workshop was the creation of a new research consortium known as The African Consortium for T&TBDs. The consortium is intended to function as a community for researchers, students, farmers, policymakers, extension workers, and community members who are interested in the advancement of T&TBD control. The consortium will engage in research activities that focus on comprehensive surveillance of T&TBDs, developing tick acaricide resistance, alternative tick control programs, and policy development and education. These areas were identified as top priorities to be developed to improve T&TBD control on the continent.

Keywords: Africa, consortium, ticks, tick-borne diseases.

Introduction

Ticks are second only to mosquitoes as vectors of human and animal pathogens [1]. Tick infestations can have devastating effects on human health as well as on livestock and hence the livelihoods of livestock farmers [2]. Indisputably, the burden of tick and tick-borne diseases (T&TBDs) on the economies and livelihoods of all those involved in the livestock industry in Africa remains significant [3,4]. Several reasons have been put forward to explain the consistent and unremitting increase in the incidence of T&TBDs. These include poor veterinary and healthcare services, inadequate monitoring and surveillance programs targeting T&TBDs, deforestation and human encroachment on wildlife habitats, tick resistance to acaricides, and climate change. These factors have also been identified to be among the most likely drivers of emerging zoonotic diseases [5].

Efforts to curb T&TBDs are intensifying worldwide. Monitoring and surveillance programs are among the most reliable tools for the sustainable management of T&TBDs. When used appropriately, they can provide targeted control interventions, enable timely detection of high-risk areas and emerging acaricide resistance, reduce the misuse of acaricides, document the movement of ticks on translocated livestock, facilitate the development of effective policies, and provide long-term and far-reaching datasets that predict future disease outbreaks and risk assessment. Despite
the well-known benefits associated with effective tick surveillance and monitoring, success stories focused on these practices in Africa are very few. Active or even passive country-wide T&TBDs surveillance programs have not been conducted in any African countries over the last few decades. Furthermore, there are no inter-territorial T&TBD sampling protocols that facilitate data comparison and risk assessment. Many tick surveys still rely on morpho-taxonomic keys that are both cumbersome and inaccurate, especially when used to identify damaged, engorged, and sub-adult stages of ticks from species that are difficult to distinguish from one another on a purely morphologic basis [6]. Given these challenges, we organized a T&TBDs workshop at the Tropical Pesticides Research Institute in Arusha, Tanzania. We intended to discuss high-impact research approaches and programs that might ultimately serve to tackle some of the pervasive challenges that ultimately hinder the effective T&TBD management in East, West, and Southern African countries. As such, the objectives of the workshop were to discuss the current situation concerning surveillance of T&TBDs in selected African countries, to formulate actionable strategies within an adaptive framework, and to improve the monitoring and control of T&TBDs in East, West, and Southern African countries.

**Monitoring and Surveillance of T&TBDs in Africa**

Extensive and comprehensive T&TBD surveillances can shed light on the seasonal, temporal, and spatial variability of ticks and tick-borne hemoparasites. Surveillance approaches that are often applied when sampling ticks include both active and passive tick surveillance. Active tick surveillance involves dragging, flagging, semichochemical-based trapping, and live animal capture. Passive tick surveillance, which is generally less costly, relies on farmers and volunteers who submit ticks for identification and pathogen screening [7]. Combined use of both surveillance approaches may be more effective in providing information on tick abundance in a given habitat. Recently, Fryxell and Vogt [8] demonstrated that collaborative tick surveillance programs involving academia and government partnerships might be improved to generate useful data, including pathogen detection, revisiting sites of detection, and hence providing continuous updates of tick encounters. In Africa, long-term and broad-based T&TBD surveillance programs are rare. Furthermore, a handful of T&TBDs surveillance programs, both past and present, have generated only limited data that are relevant at the national and regional levels; this may be because most surveys are restricted to particular geographic areas and/or brief periods of time. However, scientific evidence suggests that long-term passive tick surveillance is a meaningful and credible approach that might be used to explore the ecology of both common and rare tick species [7]. Although community members in both the United States and the United Kingdom provide significant contributions toward this effort by participating in passive tick surveillance, passive sampling, and community involvement in Africa is rare. However, most researchers believed that community-based tick sampling in Africa is feasible and can be achieved. Small-scale livestock farmers in Africa often live in poor rural areas. The farmers in these communities communally graze their livestock and have strong cultural and social bonds; they may be highly motivated partners in an appropriately designed T&TBD surveillance and control project.

**Highlights of the Gaps in T&TBDs Surveillance and Control Programs in Africa: Individual Country Reports**

Tick population dynamics have revealed critical shifts in the compositions of tick communities; there are many reports of cases in which exotic tick species invade new territories and replace some specific of indigenous ticks. This has largely been due to the translocation of exotic ticks from their native lands to new habitats through imported livestock. These observations, together with other factors, including inadequate veterinary and healthcare services and T&TBD monitoring and surveillance, land use changes such as deforestation and human encroachment on wildlife habitats, tick resistance to acaricides, and climate change, all result in rapid expansion of the tick population and hence TBDs [9-11]. To cope up with the challenge of monitoring and managing T&TBDs associated with livestock and human health, this workshop was organized to review existing T&TBDs surveillance and control programs and to identify gaps in these programs in selected East, West, and Southern African territories, including Uganda, Tanzania, Nigeria, and South Africa. The participants from these countries discussed individual country reports focused on the current state of T&TBDs. Based on the reports from the individual countries, it became apparent that there were few in-depth and comprehensive studies of T&TBDs surveillance in these African countries. Consequently, invasive tick species and zoonotic diseases are spreading rapidly across the continent.

**Uganda**

Cross-sectional and focal tick surveys have revealed that *Rhipicephalus* spp. are the most abundant tick species in Uganda [12-14] (Table-1). The few focal studies that have been conducted indicate that tick density varies greatly between different agroecological zones in Uganda, with the highest tick density recorded in the Lake Kyoga and Lake Victoria Crescent districts. However, there have been no tick surveys across 11 agroecological zones and during both the wet and dry seasons. Similar to what we learned regarding tick surveys, tick-borne hemoparasites (TBPs) surveys have all been cross-sectional and focal. These studies have identified *Theileria parva*, *Anaplasma marginale*, *Ehrlichia ruminantium*,...
Table-1: Predominant species of ticks and tick-borne pathogens surveyed in various locations in South Africa, Nigeria, Tanzania and Uganda.

| Predominant tick species/Tick-borne pathogens/diseases | Hosts or vegetation | Area surveyed | Year       | References |
|-------------------------------------------------------|---------------------|---------------|------------|------------|
| Predominant tick species in South Africa              |                     |               |            |            |
| Amblyomma hebraeum                                    | Cattle, Goats       | Eastern Cape Province (north-eastern regions) | 2009; 2011 | [34,35]    |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         |                     |               |            |            |
| Rhipicephalus decoratus                               |                     |               |            |            |
| Rhipicephalus follis                                  |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, Goats, Sheep| Northwest Province (North—eastern, Central and Western regions) | 2011     | [43]       |
| Hyalomma rufipes                                      |                     |               |            |            |
| Amblyomma hebraeum                                    |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Hyalomma rufipes                                      |                     |               |            |            |
| Rhipicephalus zambesiensis                            | Donkeys, Horses     | Gauteng Province (Pretoria) | 2017     | [45]       |
| Amblyomma hebraeum                                    |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, Vegetation  | Limpopo Province (Soutpansberg and Thabazimbi district) | 2004; 2013 | [37,44]    |
| Hyalomma rufipes                                      |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, donkeys, horses, dogs | Northern Cape Province (Northern-eastern regions) | 2017; 2010 | [32,44,46] |
| Hyalomma truncatum                                    |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Hyalomma truncatum                                    |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus simul                                   | Cattle, goats, horses| Mpumalanga     | 2002; 2015; | [45,47,48] |
| Rhipicephalus zambeiensis                              |                     |               |            |            |
| Amblyomma hebraeum                                    |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, Goats, sheep| KwaZulu Natal (Umsinga) | 2015     | [39]       |
| Hyalomma truncatum                                    |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Xodes rubicundus                                      |                     |               |            |            |
| Amblyomma hebraeum                                    |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Sigmodon hispidus                                      |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, Goats, sheep| Free State Province (north-west, south-west and south of the province) | 2015     | [31]       |
| Hyalomma truncatum                                    |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus evertsi mimeticus                       |                     |               |            |            |
| Rhipicephalus gertrudiae                              |                     |               |            |            |
| Rhipicephalus microplus                               |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus simul                                   |                     |               |            |            |
| Rhipicephalus zambeiensis                              |                     |               |            |            |
| Amblyomma hebraeum                                    |                     |               |            |            |
| Rhipicephalus decoloratus                             |                     |               |            |            |
| Rhipicephalus appendiculatus                          |                     |               |            |            |
| Rhipicephalus evertsi evertsi                         | Cattle, Sheep, Eland, Gemsbok, White rhinoceroses, Cats, Donkeys, Horses | Western Cape | 2017     | [31]       |
| Babesia bigemina                                       | Cattle, Sheep and goat, Tick | Eastern Free State of South Africa | 1998-2000 | [38,49]    |
| Babesia spp., Theileria spp., Anaplasm marginale, Rickettsia spp., Ehrlichia ruminantium and Coxiella burnetti | Cattle, Sheep and goat, Tick | Eastern Free State of South Africa | 1998-2000 | [38,49]    |

Tick-borne pathogens/diseases in South Africa

(Contd...)
| Predominant tick species/Tick-borne pathogens/diseases | Hosts or vegetation | Area surveyed | Year | References |
|------------------------------------------------------|---------------------|---------------|------|------------|
| Theileria spp., Anaplasma ovis and Ehrlichia ruminantium | sheep and goat | Free State and KwaZulu-Natal provinces, South Africa | 2018 | [41] |
| Anaplasma marginale | | | | |
| Theileria spp. | | | | |
| Theileria separate Anaplasma bovis | | | | |
| Rickettsia africana | Human | Swedish tourists who visited South Africa | 2004; 2015-2016 | [42,51] |
| Rickettsia mongolotimonae | Human | Near Ellisras, Limpopo Northern Province | 2002 | [52] |
| Ehrlichia chaffeensis, Ehrlichia canis, Ehrlichia muris, Ehrlichia spp. UFMG-EV and Ehrlichia spp. UFMT | Ticks on domesticated cattle, sheep and goats and horses | Chris Hani District Municipality, Eastern Cape Province | 2016 | [53] |
| Babesia bovis, Babesia bigemina and Anaplasma marginale | Cattle | Magwiji, Ukahlamba district, and Cala, Chris Hani district communal rangelands of the Eastern Cape Province | 2007-2008 | [54] |
| Predominant tick species in Nigeria | | | | |
| Rhipicephalus spp. | Cattle | Vom, Plateau State | 1986 | [25] |
| Rhipicephalus spp. | Cattle | Mokwa, Niger State | 1986 | [25] |
| Hyalomma spp. | Dog | Makurdi, Benue State | 2007 | [55] |
| Amblyomma spp. | | | | |
| Rhipicephalus spp. | | | | |
| Amblyomma spp. | | | | |
| Rhipicephalus sanguineus | Dog | Makurdi Benue State | 2008 | [56] |
| Amblyomma variegatum | Cattle | Plateau State | 2017 | [27] |
| Rhipicephalus sanguineus | Dog | Jos Plateau State | 2018 | [57] |
| Rhipicephalus decoloratus Haemaphysalis leachii | | | | |
| Rhipicephalus decoloratus Amblyomma variegatum | Cattle | Lafia Nasarawa State | 2019 | [58] |
| Hyalomma rufipes | Cattle | Runka, Katsina State | 1974 | [59] |
| Amblyomma variegatum Rhipicephalus decoloratus | | | | |
| Amblyomma variegatum Rhipicephalus decoloratus | | | | |
| Rhipecephalus simus | Cattle | Zaria, Kaduna State | 2019 | [28] |
| Rhipicephalus sanguineus Rhipicephalus decoloratus Amblyomma variegatum Rhipicephalus microplus | | | | |
| Amblyomma spp | Cattle | Mambila, Taraba State | 1986 | [25] |
| Amblyomma variegatum | Cattle | Yobe and Borno State | 2011 | [63] |
| Hyalomma spp. | | | | |
| Rhipicephalus spp. | | | | |
| Dermacentor spp. | | | | |
| Rhipicephalus spp. | | | | |
| Amblyomma variegatum Rhipicephalus sanguineus sensu lato Rhipicephalus decoloratus Hyalomma truncatum | | | | |

(Contd...)
### Table-1: (Continued).

| Predominant tick species/Tick-borne pathogens/diseases | Hosts or vegetation | Area surveyed | Year | References |
|--------------------------------------------------------|---------------------|---------------|------|------------|
| **Rhipicephalus spp.**                                | Cattle              | Ogun State    | 2013 | [26]       |
| **Rhipicephalus sanguineus**                          | Dog                 | Ogun, State   | 2018 | [66]       |
| **Haemaphysalis leachi**                               |                     |               |      |            |
| **Amblyomma variegatum**                               |                     |               |      |            |
| **Tick-borne pathogens/diseases in Nigeria**           |                     |               |      |            |
| *Theileria velifera*                                   | Cattle              | Vom, Plateau State | 1986 | [25]       |
| *Theileria mutans*                                     | Cattle              | Mokwa, Niger State | 1986 | [25]       |
| *Anaplasma marginale*                                  | Cattle              |               |      |            |
| *Babesia canis*                                        | Dog                 | Makurdi, Benue State | 2007 | [55]       |
| *Hepatozoon canis*                                     | Dog and Tick (DNA)  | Plateau State | 2012 | [30]       |
| *Ehrlichia canis*                                      |                     |               |      |            |
| *Rickettsia spp.*                                      |                     |               |      |            |
| *Babesia rossi*                                        |                     |               |      |            |
| *Anaplasma platys*                                     |                     |               |      |            |
| *Babesia bigemina*                                     |                     |               |      |            |
| *Babesia divergens*                                    |                     |               |      |            |
| *Anaplasma marginale*                                  |                     |               |      |            |
| *Rickettsia africae*                                   |                     |               |      |            |
| *Theileria mutans*                                     | Cattle              | Plateau State | 2016 | [67]       |
| *Theileria velifera*                                   | Cattle              |               |      |            |
| *Theileria taurotragi*                                 | Cattle              |               |      |            |
| *Anaplasma marginale*                                  | Cattle              |               |      |            |
| *Ehrlichia ruminantium*                                | Cattle              |               |      |            |
| *Anaplasma spp. Babesia spp.*                          | Goat and Sheep      | Makurdi, Benue State | 2018 | [68]       |
| *Babesia bovis*                                        | Cattle              | Gidan Jaja, Katsina State | 1986 | [25]       |
| *Anaplasma marginale*                                  | Cattle              |               |      |            |
| *Babesia canis*                                        | Dog                 | Zaria, Kaduna State | 2013 | [69]       |
| *Babesia perronatoi*                                   | Pig                 | Zaria, Kaduna State | 2014 | [70]       |
| *Anaplasma phagocytophilum*                            | Cattle              | Zaria, Kaduna State | 2019 | [28]       |
| *Anaplasma ovis*                                       | Sheep and Goat      | Maiduwuri, Borno State | 2017 | [71]       |
| *Babesia ovis*                                         | Sheep and Goat      |               |      |            |
| *Theileria mutans*                                     | Cattle              | Fashola, Oyo State | 1987 | [25]       |
| *Theileria velifera*                                   | Cattle              |               |      |            |
| *Theileria mutans*                                     | Cattle              | Akunnu, Ondo State | 1987 | [25]       |
| *Rickettsia spp.*                                      | Cattle              | Ibadan, Oyo State | 2012 | [72]       |
| *Coxiella burnetii*                                    |                     |               |      |            |
| *Anaplasma spp. Ehrlichia spp.*                        |                     |               |      |            |
| *Babesia spp. Anaplasma and Babesia*                   | Cattle              | Ogun State    | 2013 | [26]       |
| **Predominant tick species in Tanzania**                |                     |               |      |            |
| *Rhipicephalus appendiculatus and Amblyomma variegatum*| Cattle              | Shinyanga, Southern Highlands, Tabora, Arusha and Dar es Salaam | 1973-1976 | [21]       |
| *Rhipicephalus appendiculatus, Rhipicephalus evertsi, Rhipicephalus kochi and Haemaphysalis leachii* | Cattle, Goats, Sheep and Rodents | Lower Kihansi (Iringa and Morogoro) | 2000 | [73]       |
| *Rhipicephalus appendiculatus, Amblyomma spp. (A. variegatum, A. gemma and Amblyomma lepidum) and Rhipicephalus spp. (R. decoloratus and R. microplus)* | Cattle | Lake zone (Mwanza, Kagera, Mara and Shinyanga) Southern Highlands (Iringa and Mbeya) Southern zone (Mlwara, Ruvuma and Rukwa) Western zone (Kidoma and Tabora) Central zone (Dodoma and Singida) | 1998-2001 | [22]       |
| *Rhipicephalus appendiculatus, Rhipicephalus evertsi, Amblyomma variegatum, Hyalomma spp. and Rhipicephalus decoloratus* | Cattle | Ngorongoro district | 2004 | [74]       |

(Contd...)
Table-1: (Continued).

| Predominant tick species/Tick-borne pathogens/diseases | Hosts or vegetation | Area surveyed | Year | References |
|-------------------------------------------------------|---------------------|---------------|------|------------|
| Amblyomma gemma, Amblyomma variegatum, Rhipicephalus microplus, Rhipicephalus evertsi and Rhipicephalus appendiculatus | Cattle | Iringa and Maswa | 2012 | [75] |
| Amblyomma variegatum, Rhipicephalus microplus, Rhipicephalus evertsi and Rhipicephalus appendiculatus | Cattle | Rufiji district | 2009, 2011 and 2012 | [24] |
| Amblyomma variegatum and R. appendiculatus | Cattle | Mara region | 2015 | [76] |
| Amblyomma lepidum, A. variegatum, Rhipicephalus microplus, Hyalomma rufipes and Rhipicephalus appendiculatus | Cattle | Singida region | 2015 | [76] |
| Hyalomma rufipes, Rhipicephalus evertsi and Rhipicephalus microplus | Cattle | Mbeya region | 2015 | [76] |
| **Tick-borne pathogens/diseases in Tanzania** | | | | |
| Theileria spp., Anaplasma spp. and Babesia spp. (37.1%) | Cattle | Same district | 2013-2014 | [77] |
| Anaplasma spp., Ehrlichia spp., Babesia spp., Theileria spp. and Rickettsia spp. | Tick | Maswa and Iringa | 2012 | [75] |
| Theileria spp., Babesia bigemina, Anaplasma marginale, Ehrlichia ruminantium and Babesia bovis | Cattle | Pemba Island | 2017 | [41] |
| Anaplasma marginale | Ticks | Ngorongoro crater | 2001 - 2005 | [78] |
| Babesia bovis, Babesia equi, Theileria buffeli, and Theileria parva | Ticks | Ngorongoro crater | 2001 - 2005 | [79] |
| **Predominant tick species in Uganda** | Cattle | In isolated districts of south-western, south-eastern Uganda and north-western regions of Uganda | 2008-2020 | [13,80-84] |
| Rhipicephalus spp. (R. appendiculatus, R. evertsi evertsi, R. microplus, R. decoloratus, R. africana, R. pulchellus, R. simus, R. sanguineus, R. turanicus and R. muhsamae) and Amblyomma spp. (A. lepidum, A. variegatum, A. cohaerens, Amblyomma gemma, and A. paulopunctatum) | Cattle | In isolated districts of south-western, south-eastern Uganda and north-western and central regions of Uganda | 2004-2020 | [81,85-89] |

**Babesia bovis**, and *B. bigemina* as among the most economically important of the circulating TBPs [14-18,19] (Table-1).

**Tanzania**

The most comprehensive survey of ticks in Tanzania was conducted in the 1950s and 1960s [20]. Since that time, two additional comprehensive studies revealed marked expansion of tick species, most notably *Rhipicephalus microplus* and *Rhipicephalus appendiculatus*, in areas previously not occupied by these species [21,22] (Table-1). Another study based on Geographical Information System (GIS) collected on an extensive field survey for *Rhipicephalus appendiculatus* and *R. pravus*, as well as for *Amblyomma* species in cattle rearing areas of Tanzania between July 1998 and March 2001, found that cattle density influenced the distribution of *A. variegatum* and, to a certain extent, of *A. lepidum*, but had no appreciable influence on the distribution of other ticks studied [23]. The *R. microplus* is nearly dominant in this new habitat and has completely displaced *Rhipicephalus decoloratus in* regions where they previously coexisted [22]. Furthermore, the previous studies reported widespread distribution of both *Amblyomma* (especially *Amblyomma variegatum*) and *Rhipicephalus* spp., with *R. appendiculatus* identified as the most abundant species in both the northern (Arusha and Manyara regions) and southern (districts of the Mtwara and Rukwa regions) agroecological zones [22]. The migration and re-settlement of livestock farmers who are searching for ample grazing lands for their animals have contributed to the spread of economically important tick species. A survey conducted in the new livestock farming region in Rufiji, on the coastal region of Tanzania, has revealed that various tick species are widely established in this area, with the highest distribution observed for *A.*
variegatum and R. microplus [24]. The widespread distribution of Amblyomma spp. and R. appendiculatus has contributed to the development of major economic threats to the livestock industry in this country, including heartwater, anaplasmosis, East Coast fever (ECF), and, to some extent, babesiosis (Table-1).

**Nigeria**

Nigeria is divided into six geopolitical regions, namely, North-Central (NC), North-West (NW), North-East (NE), South-West (SW), South-East (SE), and South-South (SS). T&TBDs surveillance was conducted somewhat more frequently in the Northern parts of the country in contrast to Southern Nigeria [25,26]. Most reports on T&TBD surveillance came from the states of Plateau (NC), Benue (NC), Kaduna (NW), and Borno (NE) and covered the years 1974-2019 [25,27,29]. The most comprehensive of these studies, which focused on T&TBD pathogens, was conducted over 30 years ago; this study relied on morphology, cytology, and serology as diagnostic tools [25]. The major tick populations encountered in Nigeria included A. variegatum, R. decoloratus, Rhipicephalus sanguineus, Rhipicephalus simus, and Hyalomma spp. [25,26] (Table-1). Notably, R. microplus was also recorded in a recent study in Zaria [28]. The genera of tick-borne pathogens of prominence include Babesia spp., Anaplasma spp., Theileria spp., Hepatozoon spp., and Ehrlichia spp. [25,30] (Table-1). Studies that include molecular surveillance of T&TBDs are quite rare in Nigeria [27]. A means for monitoring T&TBDs in the six geopolitical zones in Nigeria using modern molecular surveillance techniques is necessary. These studies would provide critical baseline information and may also serve to validate or invalidate earlier studies based on primarily morphological criteria. Furthermore, given the trans-boundary movement of animals, long-term monitoring of T&TBDs will facilitate the timely detection of ticks that are introduced into Nigeria from other countries and will permit timely control strategies to be put in place.

**South Africa**

The geographical distribution of several tick species is currently changing in South Africa; ticks of the genera Amblyomma and Rhipicephalus have recently expanded their distributional ranges [31-33]. In many parts of the country, R. microplus is in the process of invading localities where the native tick R. decoloratus remains to be the prevalent species [32,34-37] (Table-1). A recent survey of TBDs in South Africa concentrated on the Eastern Cape, Free State, and the KwaZulu-Natal Provinces [38-41]. The predominant TBD pathogens identified among livestock in South Africa belong to the genera Babesia, Theileria, Anaplasma, and Ehrlichia (Table-1) [13,21-32,34,35,37-89]. Notably, land use, as well as habitat and climate change, may increase the frequency of interactions and sharing of tick-borne pathogens between humans, wildlife, and livestock [90,91]; these host-pathogen–environment interactions have not been explored in South Africa.

**Alternative Methods of Controlling Ticks**

At this workshop, three such methods were discussed; these include ethnoveterinary practices, anti-tick vaccines, and livestock breeding for T&TBDs resistance.

**Ethnoveterinary Practices in Africa**

Ethnoveterinary medicine and practices are widespread across Africa and are typically preferred by small-scale farmers in rural areas, as they are based on traditional knowledge that is transferred from generation to generation. Cultural practices associated with ethnoveterinary practices are not properly documented and are disappearing quickly. There are numerous documented anti-tick ethnoveterinary plants found in Southern, East, West, Central, and North Africa. In East Africa, of the 47 plant species have been documented as useful for tick control, only 14 (30%) have been scientifically validated. Similarly, in Southern Africa, only nine of 36 (25%) of the plants traditionally used to combat ticks have undergone scientific validation [92]. A similar situation exists in West Africa, where only three of the 13 (23%) of the plant species used to treat TBDs have been validated experimentally. As such, experiments aimed at validating the anti-tick activities of a variety of ethnoveterinary plants should be performed, and documentation of ethnoveterinary practices must be provided. Current research opportunities in ethnoveterinary medicine include the evaluation and validation of traditional claims, isolation of biologically active compounds from these plants, optimization of secondary metabolite production, development of herbal-based anti-tick products, and documentation and standardization of ethnoveterinary plant species.

**Anti-tick Vaccines**

Vaccination of livestock with immunologically active tick extracts might serve to generate antibodies in the vertebrate hosts; when ticks feed on animals with serum anti-tick antibodies, these may disrupt essential pathways, thereby reducing tick survival. There has been renewed interest in this rather old approach; current research suggests that this strategy might be beneficial for promoting tick control [93,94]. Renewed interest in this strategy has been triggered by the rising trend in acaricide resistance together with advancements in bioinformatics. Updates from Uganda indicated that the Molecular and Computational Biology Research group of Dr. Muhanguzi Dennis at the College of Veterinary Medicine, Animal Resources and Biosecurity are conducting both protein [84] and transcriptome/proteome studies in silico to identify
candidate peptides to be included in future anti-tick vaccine pipelines. The AfriCoTT consortium provides an important opportunity to extend this effort to include all participating countries and institutions to accelerate the entry of any peptides identified into in vitro and in vivo testing. Given the use of funds leveraged through this consortium, these efforts may be scaled up to include the identification of new targets for acaricide to expand their therapeutic range. This is especially important because some of the currently available acaricides have been overused, leading to the development of acaricide-resistant tick populations.

**Breeding Livestock for Tick Resistance**

Indigenous cattle on the African continent are believed to possess an inherent capacity to withstand diseases, heat stress, and food scarcity [95-98]. For example, West African N’Dama cattle are tolerant of trypanosomiasis [99]. In Kenya, the Small East African zebu were reported to be resistant to *R. appendiculatus* ticks [100], whereas in Tanzania, preliminary results have revealed that the Tanzania shorthorn zebu may be tolerant of ticks as well as to ECF [101,102]. However, the scientific basis of these findings has not been studied explicitly or described extensively in the scientific literature. Further studies that are focused on assessments of the level of tolerance observed in various breeds and populations of cattle in Africa are required. This will provide an avenue in which highly tolerant animals cross-bred to conserve this feature as well as to capitalize on their unique resistance/tolerance to TBDs. The consortium (AfriCoTT) can be a platform for researchers in the participating countries and for prospective members for sharing information regarding verification of the genetic potential of various breeds and animal populations that might be utilized in these programs.

**The Way Forward**

Approaches to integrated tick control that incorporate traditional cultural practices, education, and partnership within affected communities would certainly improve the efficacy of current tick management programs. As a group, the participants proposed a participatory approach that involves students, researchers, government agencies, and communities to enhance surveillance for T&TBDs, encourage multidisciplinary participatory research, and promote a means to share limited resources and knowledge. Multiple tick sampling approaches, including both passive and active approaches, might be the best toward achieving the goal of tick surveillance and control. Cultivated pastures were proposed as a means for improving security and minimizing the spread of ticks; however, some participants felt that their establishment and maintenance would be overly expensive. Participants identified that a platform where researchers could share ideas, expertise, and resources should be established. A practice community that is open to researchers, policymakers, communities, livestock businesses, pharmaceutical companies, and farmers was recommended by the meeting participants. Subsequently, the participants at the meeting conceived the consortium (AfriCoTT) whose mission would be to conduct survey and research on T&TBDs in Africa. The overarching goal of AfriCoTT is to improve the surveillance and management of T&TBDs in Africa through rigorous and high-impact research. The following thematic areas were developed, focused on the need to:

i. Establish national T&TBD survey programs initially in at least ten African countries;
ii. Develop national acaricide susceptibility profiles;
iii. Conduct ecological investigations on T&TBDs both regionally and nationally;
iv. Conduct research on innovative and culturally acceptable tick control options;
v. Implement social-based thematic areas that will have an impact on T&TBD management, including attitudes, practice, and cultures; and
vi. Influence policy development at both national and regional levels.

**Anticipated Impacts**

i. Development of five major interdisciplinary research themes.
ii. Publication and dissemination of research outputs.
iii. Collaboration with a wide range of partners at local, regional, and international levels.
iv. Training and mentoring of students.
v. Provision of a platform for sharing of ideas and for promoting collaborative work.
vi. Contribution to the efforts required for ongoing management of T&TBDs in Africa.

**Action Plan**

The work of the consortium will continue over 5 years. Activities are organized into three levels over 5 years.

**Level 1:** Initially, the consortium will focus on recruiting participants from each country. Participants will be tasked with developing research projects that focus on surveillance of T&TBDs and acaricide resistance. The participants will also develop and manage local T&TBD databases, recruit students, and volunteers in the communities, and collaborate with their counterparts in other African countries.

**Level 2:** Research projects will focus on surveys of ethnoveterinary plants and practices and also on other alternative tick control approaches, including animal breeding and immunization strategies. Surveillance data will be collected for use in ecological investigations of T&TBDs.

**Level 3:** Exploring the social and cultural aspects associated with T&TBD management will
be emphasized. Participants will be involved in developing policies and strategies for containment and surveillance of T&TBDs.

Authors’ Contributions

FN, NN, DM, JN, YPN, GM, NAJ, EGK, MM, VT, and DVH conceptualized and designed, drafted, revised, and finalized the report. All authors read and approved the final meeting report.

Acknowledgments

The authors would like to thank the National Research Foundation, South Africa, for funding this workshop through the Knowledge Interchange and Collaboration funding instrument awarded to Prof F. Nchu (Grant number 118357). Cape Peninsula University of Technology, South Africa, also provided financial support through the University Research Grant awarded to Prof F. Nchu (URF R161). We thank the Tropical Pesticides Research Institute for hosting the workshop. Furthermore, authors would like to extend our sincere gratitude to livestock extension workers, farmers and students, who attended the workshop.

Competing Interests

The authors declare that they have no competing interests.

Publisher’s Note

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