Exploring the willingness to adopt pen-side diagnostic tests to improve antimicrobial medicine use amongst Tanzanian livestock farmers

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Abstract

This article deals with the challenge of addressing antimicrobial resistance in resource-poor countries. It explores the possibilities of using rapid diagnostic tests to improve animal health management and treatment, particularly in situations where laboratory veterinary infrastructure is limited. Using data from a survey undertaken in 2018, three composite variables, i.e. perceived usefulness, compatibility with existing practices, and ease of use, derived from the Model of Technological Acceptance and Diffusion Innovation Theory are used to analyse the perceived characteristics and values of rapid diagnostic test devices for farmers. Results suggest smallholder farmers' willingness to adopt and use the tests provided they are affordable, easy to use and suitable to their local conditions – a common referential being mobile phones. While such tests have the potential to improve how antibiotics are used in smallholder farms, they are more likely to instigate more general improvements in how treatment-decisions are made without necessarily reducing unnecessary antimicrobial use. The adoption may also imply a diminishing need for traditional veterinary services, thus making farmers more self-sufficient in animal health care. Farmers also seem to be more concerned by false negatives leading to sick animals missing vital treatment than by false positive where drugs will be administered to healthy animals. Overall promoting rapid diagnostic test technologies inevitably calls for new controls and regulations.

Keywords: Antimicrobial resistance; smallholder farmers; rapid diagnostic tests; technology adoption; veterinary services; antibiotics use, Tanzania

Introduction

As part of the global strategy to address the issue of antimicrobial resistance (AMR) in human healthcare and treatment, Tanzania, like many countries across the world, is seeking to respond to the broad recommendation of the World Health Organisation (WHO) that only those antibiotics prescribed by a licensed expert should be used in treating animals, and then only

after a positive diagnostic test to confirm the pathogen type that will determine antibiotic use (World Health Organisation, 2015). The WHO recommendation has important and far-reaching implications for a country such as Tanzania where, on the one hand, the livestock sector is dominated by poor smallholder farmers, who make up around 80% of all farmers (Ministry of Livestock and Fisheries Development, - hereafter MLF - 2015), with over half of them having either no access, or very limited access to animal health care (United Republic of Tanzania, 2017); and where, on the other hand, the vast majority of veterinary treatments are not supported by laboratory-based diagnosis (The Global Antibiotic Resistance Partnership - Tanzania, 2016).

The livestock sector in Tanzania is comprised of close to 23 million relatively low income farmers who keep between 1 and 10 animals in extensive rural areas (MLF, 2015, NBS, 2012). According to the 2012/2013 National Panel Survey, very few farmers in Tanzania have adopted improved farming practices or modern technologies. Only 38% of farmers vaccinate their animals against the common diseases, only 35% percent treat against internal parasites and only 36% use preventive measures against external parasites. For their part, extension and advisory services are poorly used (MLF, 2015; Covarrubias, 2012). Tanzania has a significant shortage of laboratories capable of running veterinary diagnostic tests. Moreover, it lacks a formalized national laboratory network with sufficient infrastructure (Global Antibiotic Resistance Partnership Tanzania, 2016). Despite the large number of livestock keepers, Tanzania has only one Biosafety Level 2 veterinary laboratory. In 2011, it was reported to have only 30 veterinary personnel suitably trained in relevant lab technology. In 2018, the ratio of graduate veterinarians to farms was 1 to every 3329 farms or 1 to every 1068 farms, if holders of the lower-level diploma or certificate in animal health are also included. In short, veterinary diagnostic capacity is seriously lacking in Tanzania in terms of both laboratory infrastructure

and human resource, while farmers' ability to demand and pay for lab services is severely limited.

Accompanying the increasing global concern over pathogen, resistance to antimicrobial drugs has been a growing number of international calls for innovation in diagnostic technologies and, more specifically, for the development and use of more rapid, portable diagnostic tests in both human and farm animal health care. Such tests, it is argued, would allow for more rapid detection and treatment of disease; could be carried out on at the point of care (for example, in the doctor's surgery or on the farm); and would allow for more targeted drug use. A widely recognised driver of antimicrobial resistance is the unnecessary use and over-use of antimicrobial medicines, wrongly or inappropriately prescribed in the absence of an accurate diagnosis for conditions that are not necessarily bacterial in origin. Various governments and scientific bodies have advocated this rapid pen-side or point-of-care diagnostic tests as a potentially significant contribution to addressing the issue of AMR both in human and veterinary medicine (Review on Antimicrobial Resistance, 2016; World Health Organisation, 2015; Wellcome Trust, 2016).

In veterinary medicine, rapid diagnostics offer many advantages (Persistence Market Research –hereafter PMR, 2019). They can be quick, providing the clinician or farmer with a result in a matter of minutes rather than days usually required to receive samples back from a laboratory. They are mostly designed to be easy to use in on-farm conditions, and are generally low cost when compared with laboratory tests. Moreover, they are said to offer the possibility of a verifiable result, allowing for an accurate treatment decision. As such, they are sometimes held in contrast to the presumptive and 'empirical' diagnostic practices of clinicians (Review on Antimicrobial Resistance, 2016). Although the adoption of rapid diagnostic test devices in

veterinary medicine has not been as intensive or as widespread as their earlier advocates would have wished, and that for a variety of reasons (Buller et al., 2020), rapid and point-of-care diagnostics are held to offer a possible solution to the relative lack of diagnostic and laboratory infrastructure in low and middle income countries (Academy of Medical Sciences, 2016) as well as a potential market opportunity for diagnostic developers.

In this paper, we consider the potential adoption and use of rapid on-farm diagnostic tests in Tanzania, a country where the availability and use of such tests is still very new and is largely unknown in many rural communities. In particular, following a survey undertaken in 2018, we explore the response of both smallholder livestock keepers and pastoralists to the possibilities and advantages of using rapid diagnostic tests to improve animal health management and treatment, particularly in a country and in situations where laboratory veterinary infrastructure is limited.

Exploring willingness to adopt

We draw here on the literature around 'willingness to adopt'. Several studies have investigated factors affecting willingness to adopt new technologies among rural farmers, pointing out that farmers' adoption behaviour, especially in low income countries, is often highly diverse and influenced by a complex set of technology and site-specific socio-economic variables (Zongo et al., 2015). In Tanzania, adoption of agricultural technology is generally low with research identifying various diffusion and adoption barriers mostly related to socio-economic factors and perceived disadvantages of the new technology over current practices (see, e.g, Qaim and de Janvry, 2003; Foltz and Chang, 2002; Adesina and Zinnah, 1993; Feder and Umali, 1993; Nowak, 1992 cited in, Blazy, Carpentier, & Thomas, 2011). From these, and other studies (Bwambale, 2015; Franceschinis et al., 2017; Kabiri et al., 2013; Ojango, Wasike, Enahoro, &

Okeyo, 2016; Ozaki & Sevastyanova, 2011; Vera Castillo et al., 2014), such factors and perceived disadvantages can be broken down into different determinants of technological adoption, such as feasibility, accessibility, profitability and suitability. Zongo et al. (2015) examine farmers' willingness to adopt irrigation technology in Burkina Faso, drawing more explicitly on the body of work under diffusion of innovation theory, and holding that the value of an innovation as perceived by farmers depends on its relative advantage, its compatibility, its complexity, its trial ability and the way it is observed (Rogers, 2003). This theoretically informed approach, they argue, can be likened to the spread of an epidemic (Zongo et al. 2015: 103).

Given the relative paucity of available diagnostic test technology in Tanzania, the lack of veterinary infrastructure, particularly with respect to smallholder and pastoral farming systems, and, amongst those communities, a lack of information around rapid diagnostic test technologies, the focus in this exploratory research has been on farmers' initial impressions and attitudes towards the possible adoption and possible practical use of rapid diagnostic test devices, rather than on any specific intentions to use a technology that they are already aware of (Karahanna et al. 1999). As such and drawing on the above literature, we constructed an analytical framework that combines an understanding of farmers' perception of the specific technology's attributes and advantages (or disadvantages) within the context of, first, their farming system, second, their own socio-economic circumstances and, third, the broader technological attributes and context of rapid tests as a component of animal health management (see Fig 1). The technological and economic attributes of a new technology tend to interact with individual farmer factors creating, what Blazy et al (2011) have described as a dual source of unobserved heterogeneity. Likewise, such contextual factors as individual user attributes

also interact with organizational (in this case farms and farming households) to influence possible decisions to adopt a new technology (Karahanna, et.al., 1999).

To explore farmer responses, we have deployed three composite variables to analyse the perceived characteristics and values of rapid diagnostic test devices for farmers, derived from the Model of Technological Acceptance (Davies, 1989) and Diffusion Innovation Theory (Rogers 2003). These are: (i) perceived usefulness; (ii) compatibility with existing practices; and (iii) ease of use.

'Perceived usefulness' in the context employed here represents the degree to which an innovation is perceived as being either an improvement on the status quo or as better than the idea/product it supersedes (Rogers, 1995, p.15.). According to Rogers, the greater the perceived usefulness, the more rapid the rate of adoption is likely to be. In this study, the relative advantage of rapid diagnostic tests is explored by establishing the perceived likelihood of specific gains in a context where farmers have poor access to vets, where most veterinary decisions to deploy antibiotics are made without laboratory-based diagnosis and where farmers and veterinary experts often rely largely upon trial and error procedures in animal treatment

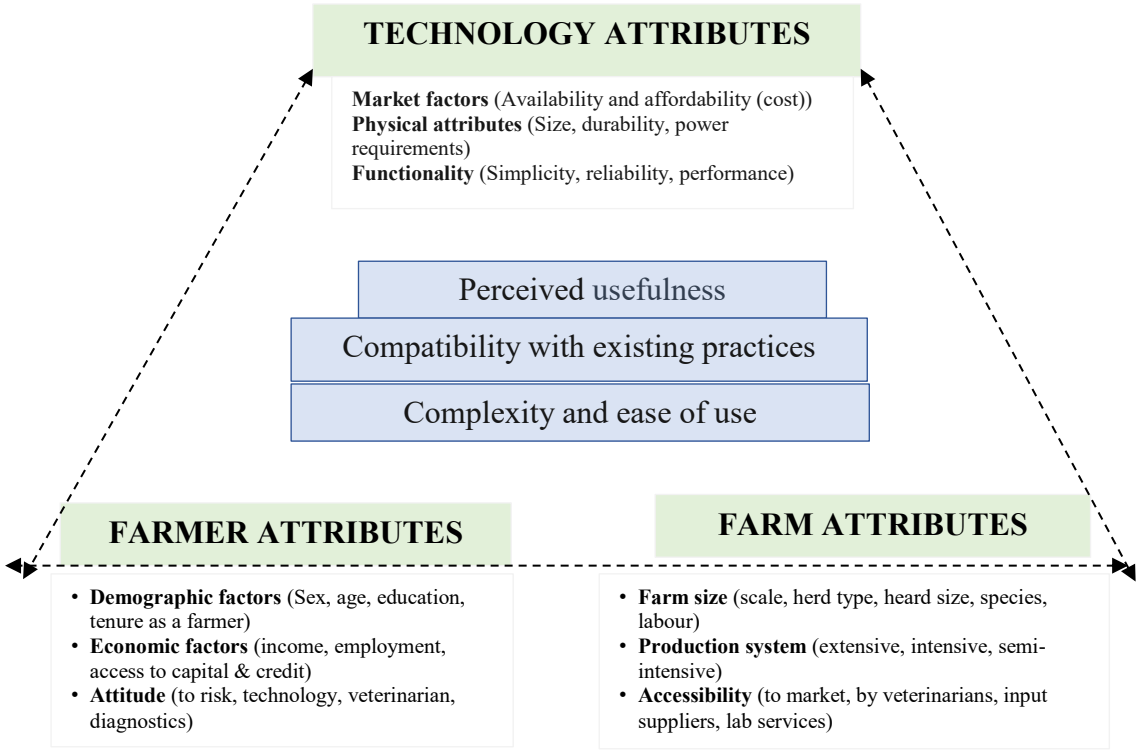

Fig 1: Concepts used to analyse the willingness to adopt veterinary rapid diagnostics in Tanzania

'Compatibility with existing practices', on the other hand, is the perceived consistency and compatibility with existing values, past experience, lifestyle, current practices and needs. A meta-analysis on drivers of intentional and behaviour (Arts, Frambach, & Bijmolt, 2011) establishes that perceived compatibility is one of the most influential innovation attributes affecting intention while relative advantage is the most important attribute stimulating both adoption intention and behaviour. Studies also link technology compatibility with acceptability which is primarily concerned with the suitability, its riskiness, cultural acceptance and compatibility with other farm enterprises (Nkonya et al., 1997). In this study, the analysis of 'compatibility' factors involves identifying attributes desirable by farmers if PSDs are to fit in their farming systems and socio-economic profiles. Such attributes form the demands (or requirements) from farmers who are potential users to diagnostics suppliers.

Finally, we use the term ‘ease of use’ to refer to the perceived ease of understanding and using the technology in question. It involves factors related to functionality and operability - i.e. how easy users can learn, operate, use and even maintain both the hardware and the software of the technology. Studies show that product complexity has a positive effect on adoption intention while being an important barrier for adoption behaviour (Arts et al., 2011). In this study, ‘ease of use’ is analysed in order to reveal both individual and shared functionality and operational requirements needed by farmers to ensure PSDs are usable, appropriate, efficient and technically available to users in Tanzania.

In this way, this paper contributes to the understanding of what needs to be in place as pre-conditions for adoption should policy makers and diagnostics suppliers decide to promote rapid diagnostic tests in Tanzania or in other developing countries as a contribution to reducing inappropriate antimicrobial use in livestock farming. Specifically, the study contributes to a better understanding of the antecedents of user acceptance and user resistance to adopting such technologies in smallholder and pastoral settings.

Methods

This study is part of a multidisciplinary project titled ‘Diagnostics Innovation and Livestock’ (DIAL) funded by the UK Economic and Social Research Council (ESRC) working in partnership with the UK Department of Health and the Arts and Humanities Research Council (AHRC) to tackle antimicrobial resistance (AMR) by demonstrating how improvements in diagnostics and treatment decisions can lead to better, more effective and sustainable reductions in antimicrobial use in livestock farming. The project covers both Tanzania and UK, led by the University of Exeter and collaborating with the University of Edinburgh, and the University of Bristol, School of Veterinary Medicine. The interdisciplinary investigation

brings together social, veterinary and innovation sciences with empirical work undertaken on farms, in laboratories, in veterinary practices and organizations and within policy-making and regulatory bodies and institutions. In Tanzania, where this particular study was conducted, the DIAL project sought to establish baseline information towards developing, trialling and promoting adapted technologies to improve on-farm diagnosis.

This study explores farmer willingness to consider adopting and using rapid, on-farm diagnostic technologies in a context where these technologies are not generally available on the market and few farmers are, as yet, aware of them or their potential. To achieve this, four groups of livestock-keeping households that differ in their production systems and, therefore, in their animal health management strategies were initially identified. Groups 1, 2 and 3 were smallholder farmers who keep dairy, poultry and pigs respectively at small scale commercial levels in both rural and peri-urban areas. Group 4 consists of pastoralists who move around with herds of cattle in search of pasture and water.

In-depth, semi-structured interviews were conducted in Tanzania between February and August 2018 on a sample of 30 beef, dairy, poultry and pig farms in Dar es Salaam, Pwani and Morogoro Regions. Out of the 30, eleven are pastoralists who keep between 200 and 4000 cattle under semi-nomadic system. An additional 30 interviews were conducted involving veterinary professionals, industry associations, veterinary drug suppliers and regulators to provide a broader context and to explore the potential for wider adoption and use of rapid diagnostic technology within the veterinary sector. Data was collected in Swahili using semi-structured questionnaire and focus group discussions and was later transcribed into English. The analysis was done using the 'Framework approach" (Spencer & Ritchie, 2003), a five-step process of data analysis beginning with familiarisation with the data set followed by

identification of a thematic framework (development of an initial coding system). Indexing was then done using the framework followed by a process of data abstraction and synthesis leading to "[searches] for structure rather than a multiplicity of evidence" (Ritchie & Spencer, 1994; p.186). Farmers were first asked about their existing animal health management and disease treatment practices along with their relationship to veterinary expertise. The interviews then turned to the possible advantages (and disadvantages) of having rapid test technologies available to them and to veterinarians. During interviews, the researcher/interviewer described the purpose of the study and encouraged farmers to "imagine a tool of any form and shape that can be used to diagnose diseases right at the farm". In this the study sought to treat the participant farmers not only as potential users (or consumers) of a specific test or device but also as potential co-designers of a new technology in the making.

Results

Perceived usefulness

Currently, laboratory diagnosis is only rarely done for most farms in Tanzania because it is costly and takes long to get results. Veterinarians and farmers interviewed for the current study both agreed that taking samples delays treatment, so both groups tended to rely on their experience even though this, as they admitted, was largely trial and error often resulting in the buying of unnecessary drugs and, on occasion, the death of animals.

Not all famers have timely access to a veterinarian in Tanzania. Registered veterinarians are few, under-resourced and tend to live in cities, far from most famers. In general, urban farmers tend to have greater access to veterinarians than those in rural areas and dairy farmers have more access than poultry and pig farmers because dairy animals are expensive, and a number of dairy projects and schemes exist to bring veterinarians to dairy farmers together. The larger poultry farms, with over 1000 birds, also tend to have better and

more regular contact with veterinarians. Urban farmers also reported specifically developing a relationship with an individual veterinarian in order to secure authentic medicines from a reputable source, and avoid 'fake drugs'. Other farmers rely on word of mouth or the experience of friends and neighbors when picking a veterinarian to work with or buy drugs from. Fake drugs are a lot more common in areas where relationships and contacts between veterinarians and farmers are weak.

Pastoralists generally claim to have developed good diagnosis skills. From the interviews, they maintain they can tell most diseases by just observing the animal. They administer the medicines themselves and tend not to involve a veterinarian at all. Each household has a stock of syringes and most adult family members are able to administer an injection. The syringes are not disposable, so they are sterilized in boiling water and stored in a special, transportable container which accompanies the farmer and herd. Disposable syringes are considered highly impractical for remote pastoral farmers as they would need to be bought frequently given herd sizes of between 200 and 4000 animals. In any case, veterinarians only tend to do lab tests during recognised disease outbreaks.

Although some farmers reported incidences of medicines not appearing to work, this is not perceived of, or recognized as, possible microbial resistance. Rather, it is explained in terms of a mistaken diagnosis, usually by young members of the family who have not mastered the visual diagnosis skills. When an animal dies, farmers habitually carry out their own post-mortem to confirm the disease and take appropriate action to save the rest of the herd.

Defining 'rapid' test use

Before exploring farmer perceptions of the possible value of rapid diagnostic test technologies, we needed to build a common understanding among interviewees around veterinary pen-side diagnostic tests. Since they are rarely, if at all, used in Tanzanian livestock farming, farmers were asked to imagine 'a tool or technology' that could be used by themselves, by vets or any other person to diagnose animal diseases on the farm or at the animal's side. The description of the tool or technology was purposely made generic and not linked to specific diseases treatable by antimicrobials.

Interviewed farmers understood that with such a new tool or device, comes a new role, most obviously that of diagnosing and possibly treating disease. Currently, farmers observe symptoms and rely on their experience to 'suspect' the presence of disease. Some would typically call a veterinarian either to have the veterinarian confirm their suspicions or come up with a different diagnosis. Some farmers, mainly pastoralists and those keeping poultry would trust their own experience in identifying disease and would treat the animals themselves. While most interviewed farmers expressed an interest in the potential of using rapid tests on the farm, the extent of that interest varied across different farming systems and across individual farmer attributes such as age, income and education. Older farmers were habitually more confident in their own diagnostic skills, believing that rapid tests would only be useful to younger, less experienced farmers. Paradoxically, however, older farmers also had greater confidence in veterinary skills in general, holding that veterinarians should really do the sampling, testing, interpreting test results, prescribing and administering injectable drugs.

Poultry farmers were the least convinced by the possibilities of rapid testing technologies arguing that they needed tools capable of detecting diseases before birds fell sick

as, once sick, there was little possibility (or value) in treatment. Veterinarians supporting this maintain that poultry diseases are detected during post-mortem or from environmental monitoring rather than from the testing of individual birds. For interviewed poultry farmers, the future lay not in rapid tests but in effective environmental and flock level detection.

Interviewed farmers identified three key areas of potential gain resulting from the adoption and use of rapid diagnostic tests: empowerment, cost savings and increased labour efficiency. With respect to empowerment , smallholder respondents saw rapid tests as a means of enabling them to take a more active role in disease management by helping them to diagnose the disease, to communicate with a distant or busy veterinarian and to be able to buy appropriate medicines directly: *"I will now be able to tell the Vet exactly what the animal is suffering from and help the vet prepare accordingly, for example, it will help him to know which medicine to carry. The vets will also be able to judge if it is an emergency case or not, and act accordingly"* (Dairy farmer, Pwani).

As such, rapid tests which might be used by the farmers themselves were seen as contributing to a form of farmer empowerment both in terms of using technology and in terms of longer-term expertise in animal health management; *"If I use the tool, I will know what vet is doing and be able to discuss with him. I can even ask questions […] or even challenge him"* (Pig farmer, Morogoro). *"I believe if I use it for years I will be an expert. I will see repeated symptoms and what the tool says […] and learn*." (Dairy farmer, Pwani).

For some, such newly acquired expertise represented a possible source of countervailing power to that of the otherwise dominant scientific veterinary elites. In being able to carry out tests and, on presenting the results, acquire a medicine directly, rapid tests

would not only ensure that animals would be treated on time, but that ultimately farmers would also have greater choice on where to buy drugs instead of relying on a single veterinarian who might, in their eyes, inflate medicine prices or stage a false positive just to sell an expensive drug. Interestingly, while smallholder farmers maintained that rapid tests should not replace the veterinarian, pastoralists, many of whom considered themselves to know more about cattle diseases and treatment than veterinarians, and have developed good diagnosis skills over the years, argued that, if rapid tests were effective, the role of the veterinarian would become limited to selling medicines and responding to outbreaks.

As a means of reducing costs, rapid tests – and more accurate diagnoses - were seen by interviewees as a possible mechanism for reducing unnecessary antimicrobial medicine purchases. One farmer explained that whenever her cow was injected with antibiotics, she would be forced to waste 30 litres of milk over three consecutive days. This would amount to around 60,000 TZS or £20.00 per day per cow. If these injections were erroneously administered due to a mistaken diagnosis, this would represent for her, a significant loss.

The adoption of rapid tests might, for some farmers, impact upon labour efficiency on their holdings. On the one hand, dairy and poultry are mostly part-time activities for urban dwellers, who frequently employ people to work on the farms on their behalf. For these farmers, rapid tests would enable farm employees to make treatment and medicine purchasing decisions together with veterinarians and thereby reduce management pressure on the owners. Rapid tests might also improve communication between farm owners and workers in an atmosphere of more informed understanding and evidence around animal health and would – as at least one urban farmer maintained - reduce the impact of staff turnover, which is high in farms in Tanzania. On the other hand, in pastoral systems, older pastoralists claimed they

would feel more at ease leaving their herds in the hands of younger less experienced farmers if rapid, on-site tests were available to help them make appropriate treatment decisions.

Compatibility

Pastoralists stated that they would ideally want any rapid diagnostic test device to be portable and easy to carry around as they themselves move with the herd. Such devices should also be water and dust proof, adaptable to conditions in the field. As pastoralists cover large areas, often at a considerable distance from retail facilities and dispensaries, rapid tests should not be disposable but re-usable. Neither should they be dependent upon electrical charging. Also, the test device should neither be too small as it can easily get lost, nor too big as it requires space and men to handle it. The device should also be easy to maintain and repair.

Dairy farmers in particular emphasised the importance of test reliability. "*We know nothing can be 100% accurate, but the degree of error should not exceed 5% and the manufacturer should tell us how to tell the error and even what to do when the machine has errors. It should not fail".* (Dairy farmer, Morogoro)

In Tanzania, in general, farmers in the dairy rely more heavily upon veterinary advice and intervention than in other animal production sectors. Interviewees were concerned about the number of tests required for the numerous diseases in Tanzania, and how test results would be communicated. One interviewee asked: *"What will the tool say? Will it say Disease or No disease or will it say use or don't use antibiotics, that this is pathogen X?"* (Dairy farmer. Morogoro).

Another said: "*I don't want to have many of them. i.e. one for ECF, one for Mastitis, etc. If possible one tool, possibly with different parts should be able to test all diseases."* (Dairy farmer, Morogoro).

All of the interviewed farmers reported multiple sources of income, of which livestock keeping is just one. Hence money to spend on the farm comes from different sources. Those with off-farm employment, like teachers, nurses, carpenters, etc., believed they could possibly afford rapid tests if they were affordable and efficient. Pastoralists depend more on livestock for food and income and rely on live animal sales to pay for animal health services. Generally, all respondents expressed a certain potential willingness to purchase rapid tests provided the technology works and the price is reasonable /affordable. *"We buy mobile phones, so we should be able to buy such an important tool, which can also ensure my cow makes more money for me"* (Dairy farmer, Pwani).

For more expensive test equipment, some suggested that it be bought by a cooperative or a veterinary practice. Respondents were more concerned that the introduction of rapid testing would increase the overall cost of diagnosis, particularly if this was accompanied by a strengthening of the legislation requiring all medicines to be obtained via a veterinary prescription. Paying for a test, then paying the veterinarian to prescribe and then paying for the medicines would significantly increase the costs of animal health management. Currently, farmers only pay for a few mandatory tests such as Brucellosis. If different rapid tests are introduced for different diseases, and if the prescription process becomes more rigorous, costs to the farmers will rise as no one expects rapid tests to be capable of identifying a wide range of different pathogens in different contexts.

Ease of Use

All of the dairy, poultry and pig farmers who participated in the interviews had formal education, though in only three cases did this extend to tertiary education. In contrast, none of the interviewed pastoralists had any formal education, although they could read and write. While the literature commonly associates low levels of formal education with low technology adoption rates in poor farming communities, we found that the ability to use mobile phone is high in Tanzania regardless of the level of education attained.

Respondents emphasized that any new rapid diagnostic technology should be technically easy to set up and use; and that no specific calibration should be required to interpret results. It should not be difficult to operate and, importantly, it should be easy to tell when it is not working. In other words, 'not working' should not be confused with a negative result. Results should be simple, easy to interpret and preferably in symbols that even the illiterate can understand, thus avoiding complicated figures that require re-calculation. One respondent farmer put it succinctly: *"It should not tell me 'Not ECF', or 'Not Mastitis' […] rather it should say 'It is Brucellosis."* (Dairy farmer, Morogoro).

Tests should indicate positive results, rather than absences or negative results. It should also be possible, maintained one farmer, to store the results long enough to allow consultations (validation) with family and veterinarians. Moreover, the results should be transferable, specifically through mobile phones or computers to allow comparisons with repeated testing and validation before they are erased.

Any such new technology requires some degree of skill transfer. As demonstrated by Foster and Rosenzweig, imperfect knowledge about a new technology can lead to a strategic

incentive to delay adoption (Foster and Rosenzweig, 1995). Most respondents clearly said they are happy to use such a tool provided they are properly trained on how to use it. Using the mobile phone as an example, respondents explained that once few farmers have been trained, they will train others. They also mentioned the importance of simple but detailed manuals, again preferably using symbols.

Of course, once farmers begin to use diagnostic tools, often based around the existence or otherwise of specific pathogens or other biotic indicators, then other, often new and perhaps unfamiliar knowledge is either directly or indirectly implicated. If the choice to use a new piece of diagnostic test technology relies upon the effective, and accurate, observation of clinical or even sub-clinical signs presented by a sick animal, then this demands a degree of knowledge and/or experience on the part of the farmer that they may not have or even recognise as needed. *"[…] all we see, is a sick animal. So how will I know which tool to use? Otherwise, the machine will assume that I already suspect what the disease is."* (Pig farmer, Pwani).

Ultimately, the adoption and use of rapid diagnostic tests by farmers, whether in Tanzania or elsewhere, requires familiarity with and understanding of new processes and phenomena, such as, in this case, bacterial infections, antimicrobial medicines and broader disease management, for which many farmers will need training and advice. For the possible adoption of a single piece of hand-held 'kit' to become effective, entirely new areas of decision making and prioritization is required.

Discussion

The willingness to adopt rapid diagnostic tests is largely driven by current inefficiencies in the animal health systems, specifically with respect to access to veterinary and diagnostics services. Farmers are looking for ways to improve the overall treatment decision-making

process by reducing the risks posed by the common 'trial-and-error' approaches to treatments made by both veterinarians and farmers. Moreover, they want to save time and money associated with animal health management. The question here, however, is how far can farmers participate in diagnostic processes without infringing into the mandated territory of veterinarians set by society and formerly reinforced through regulatory procedures?

Most farmers believe that even with the use of rapid diagnostics by themselves, veterinarians would still be needed to prescribe and even administer drugs. One farmer maintained that: "calculating doses involves estimating the animals' weight and knowing where to inject […] I cannot do that." Another argued: "Drugs must be prescribed by veterinarians and should also come from veterinarians, just in case anything goes wrong, [...] they should be responsible". Rapid diagnostic tests, undertaken by farmers are, therefore, not expected to replace veterinarians in the smallholder farms. However, it seems inevitable that some shift in the respective roles of farmers and veterinarians will result. Pastoralists, in particular, as we have seen, but also some medium scale farmers, believe that if rapid diagnostic tests are adopted on a significant scale by Tanzanian farmers, then the role of veterinarians will be to limited to selling drugs and responding to outbreaks.

Despite the seemingly general consensus among interviewees that the use of rapid diagnostic tests would take place in conjunction with services of the veterinarians, respondents nonetheless raised concerns on the costs that come with this combination, arguing that they will be triply charged to buy and use tests, to pay veterinarians to write prescriptions and to buy medicines. Therefore, unless the total cost of all this is lower than that of the cumulative losses incurred through not doing diagnosis, the adoption and usage of rapid tests by farmers

may be low with little impact, therefore, on the drive to obtain more sustainable antimicrobial usage.

Conclusion

In this article, we have drawn on the model of technology acceptance (MTA) and the diffusion of innovation theory (DIT) to examine the willingness of pastoralists and smallholder poultry and dairy producers in Tanzania to adopt veterinary rapid or pen-side diagnostic tests as means to achieve sustainable uses of antibiotics in food producing animals. The study uses data from a series of interviews with Tanzanian farm owners at a time when rapid diagnostic tests have not been disseminated in Tanzania and are, therefore, unknown to most farmers. The empirical results provide insights into how Tanzanian farmers perceive the possibilities of adopting and using such tests and their role and place within broader animal health management practice.

The results suggest that smallholder farmers would be willing to adopt and use pen-side diagnostics provided they are affordable and easy to use – a common referential being mobile phones. Most importantly, such devices would need to work effectively even in harsh farm conditions. Rapid tests are seen by respondent farmers as a means of addressing some of the current structural inefficiencies in the animal health-care sector, such as poor and limited access to veterinary advisory services and costly (and often infrequent) veterinary diagnostic services. While adopting on-farm rapid tests has the potential to improve how antibiotics are used in smallholder farms, this study shows that such tests are more likely to instigate broader and more general improvements in how treatment-decisions are made and shared both by veterinarians and farmers, without necessarily having an immediate impact upon unnecessary antimicrobial use on farms.

The findings here suggest that if effectively used, on-farm point of care or rapid diagnostic tests have the potential to reinforce treatment decisions especially among pastoralists who move long distances with animals, often with little or no access to veterinarians. Integrating a portable diagnostic tool into their mobile livestock system is, therefore, welcome as a solution to the tacit-knowledge and experience gap currently observed between the old and new generations, where the former consider themselves riche in tacit knowledge they would apply in disease identification, but no longer have the strengths to move around with animals in search of pasture and water. The question, however, is whether the improved ability of farmers to diagnose diseases brought about by these new test devices changes the relationship of farmers to veterinarian. One interviewee asked: *"If I have a tool that correctly tells the disease, then why would I pay a veterinarian to tell me which drug to buy after I have used the tool under his guidance more than twice? I have to learn from him and do without him the second time."* (Dairy farmer, Pwani)

The adoption and use of rapid tests may imply a diminishing need for traditional veterinary services, and would, therefore, make farmers more self-sufficient in animal health care — including independent treatment decision-making.

The technological attributes required for new rapid tests that are adoptable by smallholder farmers discussed in the paper are generally consistent with the requirements for other technologies that need to function in most developing countries. Attributes such as manageable physical size, durability, sensitivity to rain and dusts, easy to maintain, low energy use, simple operability and affordability are all very important. These attributes are particularly important to small farms where the cost of acquiring, using and maintaining devices is typically assessed against the value it is expected to bring to the farm. Farms with fewer animals expect

to spend less on diagnostic tests; yet the risk and impact of losing animals is relatively higher. This suggests a place for innovative business models that provide room for joint ownerships of test devices and technologies where the cost of one kit is spread across farms.

Finally, with regard to the use of antimicrobials, the results in this research reveal that farmers are generally a lot more concerned by false negatives leading to sick animals missing vital treatment, than by false positive where drugs will be administered to healthy animals. This is perhaps a challenge to the emphasis placed on reducing unnecessary antimicrobial use. Some respondents in this research maintained that a diagnostic tool can be employed to justify a false positive by an unscrupulous drug seller, even where veterinarians are legally mandated to prescribe, sell and administer drugs. Rapid diagnostic tests technologies bring with them, perhaps inevitably, requirements for new controls, procedures and regulations.

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References

Academy of Medical Sciences (2016*), 'Improving the development and deployment of rapid diagnostic tests in LMICs'*. Workshop report, 21 November 2016. London, United Kingdom. https://acmedsci.ac.uk/file-download/18597310

Adesina A A, Zinnah M M. (1993), '*Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone'*. Agric Econ, 9(4): 297–311.

Arts, Joep W.C., Ruud T. Frambach, and Tammo H.A. Bijmolt (2011), *'Generalizations on consumer innovation adoption: A meta-analysis on drivers of intention and behavior,'* International Journal of Research in Marketing, 28 (2), 134–44.

Blazy, Jean-Marc & Carpentier, Alain & Thomas, Alban. (2011), *'The willingness to adopt agro-ecological innovations: Application of choice modelling to Caribbean banana planters'*. Ecological Economics - ECOL ECON. 72. 10.1016/j.ecolecon.2011.09.021.

Buller H, Adam K, Bard A, Bruce A, (Ray) Chan KW, Hinchliffe S, Morgans L, Rees G and Reyher KK (2020) *Veterinary Diagnostic Practice and the Use of Rapid Tests in Antimicrobial Stewardship on UK Livestock Farms*. Front. Vet. Sci. 7:569545. doi: 10.3389/fvets.2020.569545

Bwambale, Naboth (2015), *'Farmers' Knowledge, Perceptions, and Socioeconomic Factors Influencing Decision Making For Integrated Soil Fertility Management Practices in Masaka and Rakai Districts, Central Uganda'*. Graduate Theses and Dissertations. 15671. https://lib.dr.iastate.edu/etd/15671

Castillo, Yolanda & Pritchard, Hugh & Frija, Aymen & Chellattan veettil, Prakashan & Sanchez, J.A. & Van Damme, Patrick & Van Huylenbroeck, Guido. (2014), '*Production viability and farmers' willingness to adopt Jatropha curcas L. as a biofuel source in traditional agroecosystems in Totonacapan, Mexico*'. Agricultural Systems. 125. 42–49. 10.1016/j.agsy.2013.12.003.

Covarrubias Katia, Longin Nsiima and Alberto Zezza (2012), *Livestock and livelihoods in rural Tanzania. A descriptive analysis of the 2009 National Panel Survey'.* Joint paper of the World Bank, FAO, AU-IBAR, ILRI and the Tanzania Ministry of Livestock and Fisheries Development with support from the Gates Foundation. http://documents1.worldbank.org/curated/ar/141341468132878632/pdf/866280WP0Lives00Box385181B00PUBLIC0.pdf

Davis, F. D. (1989), *'Perceived usefulness, perceived ease of use, and user acceptance of information technology'*. MIS Quarterly, 13(3). 319-340. doi: 10.2307/249008.

Feder, G., & Umali, D. L. (1993), *'The adoption of agricultural innovations: a review. Technological Forecasting and Social Change*', 43 (3-4), 215-239.

Foltz, J. and Chang, H.H. (2002), '*The Adoption and Profitability of rbST on Connecticut Dairy Farms.'* American Journal of Agricultural Economics 84 (2002):1021-1032.

Franceschinis, C., Thiene, M., Scarpa, R., Rose, J., Moretto, M., Cavalli, R., (2017), *'Adoption of renewable heating systems: an empirical test of the diffusion of innovation theory'.* Energy 125, 313–326.

Foster, A., and M. Rosenzweig. '*Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture'*. Journal of Political Economy 103(1995):1176–209.

Kabiri, Stella & Kabanyoro, Ruth & Mugisa, Immaculate & Nakyagaba, Winfred & Nasirumbi Sanya, Losira & Kituuka, George. (2013), '*Willingness of farmers to adopt rice intercrops in the Lake Victoria Crescent Agro-ecological Zone of Uganda*.' Journal of Biology, Agriculture and Healthcare. 3. 121-130.

Karahanna, Elena & Straub, Detmar & Chervany, Norman. (1999), *Information Technology Adoption Across Time: A Cross-Sectional Comparison of Pre-Adoption and Post-Adoption Beliefs'*. MIS Quarterly. 23. 183-213. 10.2307/249751.

MLF (2015), *Tanzania Livestock Modernization Initiativ'e*. United Republic of Tanzania, Ministry of Livestock and Fisheries. Dar es Salaam.

NBS (2012), *National Sample Census of Agriculture 2007/2008: Smallholder Agriculture.* National Bureau of Statistics, Dar es Salaam.

Nkonya, Ephraim & Schroeder, Ted & Norman, David. (1997), '*Factors Affecting Adoption of Improved Maize Seed and Fertiliser in Northern Tanzania'.* Journal of Agricultural Economics. 48. 1-12. 10.1111/j.1477-9552.1997.tb01126.x.

Nowak, R. M. (1992), '*The red wolf is not a hybrid'*. Conservation Biology 6:593-595: In Blazy, J.-M., Carpentier, A. and Thomas, A. 2011. '*The willingness to adopt agro-ecological innovations: Application of choice modelling to Caribbean banana planters'*. Ecological Economics 72:140-150.

Ojango, Julie & Wasike, Chrilukovian & Enahoro, Dolapo & Okeyo, Ally. (2016), *Dairy production systems and the adoption of genetic and breeding technologies in Tanzania, Kenya, India and Nicaragua'.* Animal Genetic Resources/Ressources génétiques animales/Recursos genéticos animales. 59. 81-95. 10.1017/S2078633616000096.

Ozaki, Ritsuko & Sevastyanova, Katerina, (2011). *'Going hybrid: An analysis of consumer purchase motivations,'* Energy Policy, Elsevier, vol. 39(5), pages 2217-2227, May.

Persistence Market Research (2019), '*The Veterinary Rapid Diagnostic Tests Market: Global Industry Trend Analysis 2012 to 2017 and Forecast report of 2017 – 2025'*. Persistence Market Research, NY United States. https://www.persistencemarketresearch.com/market-research/veterinary-rapid-diagnostic-tests-market.asp

Qaim, M. and de Janvry, A. (2003) *'Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina'*, American Journal of Agricultural Economics, Vol. 85, No. 4, pp.814–828.

Review on Antimicrobial Resistance (2016), 'Tackling Drug-Resistant Infections Globally: Final Report and Recommendation'. The Review on Antimicrobial Resistance chaired by Jim O'Neill. UK. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf

Ritchie, J., & Spencer, L. (1994, *'Qualitative data analysis for applied policy research'*. In A. Bryman, & R. G. Burges, (Eds.), *'Analysing qualitative data'* (pp. 173-194). London, UK: Routledge.

Rogers, E.M. (2003), '*Diffusion of innovations'* (5th ed.). New York: Free Press

Spencer, L., Ritchie, J., Lewis, J., & Dillon, L. (2003). *Quality in Qualitative Evaluation : A framework for assessing research evidence A Quality Framework'*. Social Research, 108(21/08/05), 170.

The Global Antibiotic Resistance Partnerships-Tanzania Working Group (2016), '*Situation Analysis and Recommendations: Antibiotics Use and Resistance in Tanzania'.* Washington DC and New Delhi: Center for Diseases Dynamics, Economics and Policy.

United Republic of Tanzania, (2017), '*The National Action Plan on Antimicrobial Resistance 2017-2022'.* United Republic of Tanzania, Ministry of Health Community Development Gender Elderly and Children, Ministry of Livestock and Fisheries, and WHO.

Wellcome Trust (2016). '*Four diagnostic strategies for better-targeted antibiotic use. Drug Resistant Infection*'. https://wellcome.org/sites/default/files/diagnostic-strategies-for-better-targeted-antibiotic-use-wellcome-jul15.pdf

WHO (2015), '*Global Action Plan on Antimicrobial Resistance'*. World health Organization, ISBN 978-92-4-150976 3. Geneva.

WHO (2017), '*WHO Guidelines on use of medically important antimicrobials in food-producing animal's*. Geneva: World health Organisation; 2017. License CC BY-NC-SA 3.0 IGO. ISBN 978-92-4155013-0

Zongo, Beteo & Diarra, Abdoulaye & Barbier, Bruno & Zorom, Malicki & Yacouba, Hamma & Dogot, Thomas. (2015). '*Farmers' practices and willingness to adopt supplemental irrigation in Burkina Faso'*. International Journal of Food and Agricultural Economics. 3. 101-117.