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Livestock and avermectins in sub-Saharan Africa: a restricted systematic review of the impacts on productivity and documentation of resistance

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Abstract

There is growing interest in using avermectins in livestock as a vector control tool for mosquitoes involved in the transmission of human malaria in sub-Saharan Africa (SSA). If implemented, the potential health and productivity impacts across the livestock sector would need to be considered, as avermectins are already commonly used in veterinary medicine to treat gastrointestinal helminths and parasitic insects. Here we present the results of a restricted systematic review that summarizes what is known about the effects of avermectins on cattle and swine productivity in SSA and the presence of avermectin resistance in endo and ectoparasites of importance in these species. A total of 583 unique journal articles were identified using key search terms in three databases: Agriculture, Life, and Natural Sciences Databases from ProQuest, CAB Abstracts, and Scopus. Ten articles met the criteria for inclusion on impacts on productivity and four met the inclusion criteria related to avermectin resistance. All studies documenting impacts of avermectins on productivity were performed using ivermectin in cattle. Generally, these showed a positive significant effect on growth rates. Resistance to avermectins was documented in two of the four included articles. Considering the extensive literature documenting resistance to avermectins in other areas of the world, our findings may reflect a paucity of studies on the subject in SSA. The authors conclude that additional research is needed to quantify the potential benefits and challenges to the livestock sector of using avermectins for malaria control across different production systems, and in a variety of ecological settings.

Keywords: ivermectin, avermectins, livestock, anthelmintic resistance, malaria, endectocide

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Introduction

Avermectins are commonly used around the world in cattle, small ruminants, and swine to treat gastrointestinal nematodes and many ectoparasites. Ivermectin is perhaps the most widely used and well-known of the available avermectins, but other examples labeled for use in livestock include eprinomectin, and doramectin. Although there is strong evidence that treating livestock with avermectins to control parasites improves animal productivity, most of the research has been performed in Europe and the United States (Nødtvedt *et al*., 2002; Rehbein *et al*., 2003; Cringoli *et al*., 2009; Kunkle *et al*., 2013; Verschave *et al*., 2014; Rehbein *et al*., 2016). Location of the research is important as animal genetics, environmental conditions, and production systems (e.g., intensive vs. extensive) likely influence the relationship among parasite prevalence, impacts on productivity, and follow-on economic consequences of production losses (Lamy *et al*., 2012).

Currently, there is significant scientific interest in using ivermectin in mass drug administration (MDA) campaigns in humans and livestock as a vector control tool for mosquitoes involved in the transmission of malaria (Poché *et al*., 2015; Chaccour *et al*., 2023). This interest stems from evidence that *Anopheles* mosquitos that fed on ivermectin-treated blood sources, die or exhibit reduced reproductive success (Poché *et al*., 2015; Pooda *et al*., 2015; Lyimo *et al*., 2017), thereby serving to reduce the mosquito population. In areas where malaria vectors exhibit partial zoophagy (blood feeding on animals), the use of ivermectin in livestock in addition to humans serves to cover a greater proportion of blood sources available. There are several field studies underway to determine if this approach will have the anticipated effects of reducing mosquito populations and lowering malaria transmission.

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Even if successful relative to malaria control, there are other benefits and risks to consider that arise with the delivery of ivermectin in livestock populations (Ruiz-Castillo *et al*., 2022). For example, treated animals also derive health benefits from a reduced parasite burden, which can translate into increased productivity and follow-on economic and nutritional benefits for livestock owners and the community (Rist *et al*., 2015; Strydom *et al*., 2023). However, resistance to ivermectin and other avermectins in livestock species is a growing concern and has been well documented for decades across various parasites of importance to livestock health (Shoop, 1993; Kaplan, 2004; Sutherland *et al*., 2011, Wolstenholme *et al*., 2012, Kotze *et al*., 2016; Rodriguez-Vivas *et al*., 2017). If successful as a novel vector control tool, the increase in ivermectin use in livestock for malaria programs could contribute to the development of avermectin resistant parasites among livestock owned by some of the most vulnerable populations. This in turn could have negative impacts on animal productivity, household nutrition and economic security.

The intent of this restricted systematic review is to summarize existing evidence on the effect of avermectins on cattle and swine productivity, and the distribution of avermectin resistance in internal and external parasites of cattle and swine in SSA. The scope was limited to cattle and swine as these are the two species for which studies have documented treatment with avermectins has a negative effect on the life span and reproductive success of blood-fed mosquitoes (Ruiz-Castillo *et al*., 2022). In addition, the scope was limited to SSA as this is where over 90% of malaria cases occur (Venkatesan, 2024) and is the geographical area most likely to implement the use of ivermectin MDA if the strategy proves effective.

Summarizing the available evidence for impacts on livestock productivity and parasite resistance is critical to the overall evaluation of the use of avermectins in livestock for vector

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control – what evidence do we have and what yet needs to be determined in order to implement such strategies in a manner that promotes the benefits to livestock health, while mitigating the risks? While avermectin resistance in parasites of importance to livestock health has been extensively studied, to the authors knowledge, no previous review has specifically focused on cattle and swine in SSA, and the small-holder livestock systems that predominate in this region of the world.

Materials and methods

Study protocol

This paper follows the guidelines for a restricted systematic review (i.e., rapid review) as outlined by Plüddemann *et al*. (2018). The original search protocol was previously published (Rist *et al*., 2020), so only a brief overview of the search process and inclusion criteria is described here. The only change to the published search protocol is that the search dates were updated to extend through April 30th, 2024.

A pair of focal research questions were addressed in this review and are outlined below:

- Research Question One: *What are the effects of avermectins on cattle and swine productivity in Sub-Saharan Africa, where productivity includes measures such as growth rate, reproductive success, or milk production?*
- Research Question Two: *What is known about the distribution of avermectin resistance in parasites of cattle and swine in Sub-Saharan Africa?*

The databases used were CAB Abstracts from Cab Direct, Scopus, and the Agriculture, Life, and Natural Sciences Databases from ProQuest (federated search comprised of databases within Virginia Tech's subscriptions).

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To address question one, the review protocol was developed based on the PICO framework, with inclusion criteria defined as:

- Population: a population of cattle and/or swine in SSA
- Intervention: treatment of livestock for endo- or ectoparasites utilizing ivermectin, eprinomectin, or doramectin
- Comparison: compared against a control group, or group treated with a rival anti-parasitic drug
- Outcome: a change in productivity measured as alterations in growth rate, reproductive success, or milk production (cattle only). Outcomes were later expanded to include reduction in cutaneous lesions and associated tissue trimming caused by parasites traditionally susceptible to avermectins.

To address question two, the review protocol was based on the PEO framework, with inclusion criteria defined as:

- Population: a population of cattle and/or swine in SSA
- Exposure: treatment with ivermectin, eprinomectin, or doramectin
- Outcome: measure of avermectin resistance in an endo- or ectoparasite

Results

Study Selection

Research question one – livestock productivity

A total of 901 articles were identified during the search process (Figure 1). Of this number, 260 were duplicates, leaving 641 articles available for initial screening. After initial screening, 13 articles were retrieved and reviewed in full. Three articles were excluded due to not pertaining to

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SSA (n=2) or not being pertinent to cattle or pigs (n=1), leaving a total of ten articles included in the review. The publication dates of included articles spanned from 1983 to 2001.

Research question two – ivermectin resistance

A total of 237 articles were identified through the search process (Figure 2). Sixty-two were duplicates, leaving 175 available for initial screening. After initial screening, 13 articles were retrieved and reviewed in full. Nine articles were excluded due to not pertaining to SSA (n=3), not including avermectins (n=5) and not being pertinent to cattle or pigs (n=1), leaving a total of four articles included in the review. The publication dates of included articles spanned from 2012 to 2017.

Cattle and Swine Productivity

The ten included studies were carried out in the following SSA countries: Kenya (n = 2), South Africa (n = 3), Sudan (n = 1), Zambia (n = 1), and Zimbabwe (n = 3) (Table 1). All studies were conducted on beef cattle, and there were no articles including dairy cows or swine that met the eligibility criteria. Additionally, there were no studies included that pertained to ectoparasites. Animals in all studies were naturally infected before the studies began, and the majority of gastrointestinal helminths identified were common species known to infect cattle globally (*Haemonchus, Trichostrongylus, Cooperia, Oesophagostomum,* and *Stronglyloides*).

Ivermectin was used in all ten studies. One study also included abamectin and doramectin (Meeus *et al.*, 1997), and another tested ivermectin against ivermectin with Clorsulon (Waruiru & Ngotho, 2001). In nine studies, ivermectin was delivered subcutaneously at its labeled dose of 200 mcg/kg with one study testing a novel sustained release bolus delivering 12 mg/day for 135 days (Munyua & Ngotho, 1998). Abamectin and doramectin, when used, were also dosed at 200

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mcg/kg. Additionally, one study compared subcutaneous delivery with an oral 200 mcg/kg dose of ivermectin (Swan *et al*., 1983).

Six studies evaluated the effect of ivermectin on cattle growth rates, commonly measured as total live weight gain and/or average daily gain. Of the six studies, four monitored changes in cattle weight for four months or longer, while two studies followed the treated cattle for periods less than three months post-treatment. The four studies that monitored changes in weight for four months or longer all delivered more than one dose of ivermectin and demonstrated a significant positive effect on cattle growth (Duncan & Forbes, 1992; Vasileev, 1993; Munyua & Ngotho, 1998; Waruiru & Ngotho, 2001). When compared to untreated animals, significant positive effects ranged from 40-50 more pounds gained (Duncan & Forbes, 1992; Vasileev, 1993), and an increase in average daily gain from 0.064 – 0.098 kg/day (Vasileev, 1993; Munyua & Ngotho, 1998) for ivermectin only treatments, or up to 0.203 kg/day when Clorsulon was added in the study using a sustained release bolus in calves (Waruiru & Ngotho, 2001). The two studies that followed cattle for periods less than three months post-treatment (Abdalla, 1989; Meeus *et al*., 1997) did not find a significant difference in growth rates. In the Meeus *et al*. study (1997) there was no untreated control group and the comparison was only among animals treated with various avermectins versus albendazole.

The remaining four studies included in the review were related to *Parafilaria bovicola*, a filarial parasite of cattle that causes subcutaneous lesions that resemble bruises and may progress to more extensive muscle involvement (Spickler, 2020). These lesions often result in significant profit losses for livestock owners due to the damage to hides and required muscle trimmings at slaughter. In all four studies, ivermectin showed significant impact on lesion size and weight of trimmed tissue at the time of slaughter (typically above 90% reduction), when given as a single

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dose at least 70 days prior to slaughter as compared to untreated controls (Swan *et al*., 1983; Soll & Carmichael, 1984; Swan *et al*., 1991; Soll *et al*., 1991). In studies where some doses were given less than 70 days prior to slaughter (Soll & Carmichael, 1984), or when ivermectin was delivered orally (Swan *et al*., 1991), there was no or only partial improvement noted.

Avermectin resistance

The four included studies were carried out in: Kenya (n = 1), Cameroon (n = 1), and Nigeria (n = 2) (Table 2). Three of the studies were in beef cattle and one was in pigs. All of the studies were focused on the use of ivermectin against gastrointestinal helminths, and the animals were naturally infected prior to being enrolled in the studies. In two of the studies in cattle, ivermectin was delivered at the labeled dose of 200 mcg/kg subcutaneously (SC) (Idike *et al*., 2012; Mungube *et al*., 2015**)**, with the third study comparing 200 mcg/kg SC to 1ml/50kg SC and 1ml/50kg SC with Levamisole 7.5mg/kg orally (Jean *et al*., 2016). In the single study in pigs, the dose was 300 mcg/kg SC (Idika *et al*., 2017). All studies employed the Fecal Egg Count Reduction Test (FECRT) to determine resistance in the study population, which is recommended by the World Association for the Advancement of Veterinary Parasitology (WAAVP) in naturally infected animals (Geurden *et al*., 2022). The FERCT compares pre-treatment fecal egg counts with 14-day post-treatment fecal egg counts, and the WAAVP guidelines state that a greater than 90% reduction should be achieved to infer anthelmintic efficacy.

Ivermectin resistance was documented via FERCT in one of the four included studies. The 2016 study in Cameroon found that ivermectin alone at either a 200 mcg/kg or 1 ml/50kg dose produced FERCT results ranging from a 64-85% reduction with wide confidence intervals when using arithmetic means (Jean *et al*., 2016). Parasite species identified in this study were

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Haemonchus, Trichostrongylus, and *Cooperia*. The study also found that when combined with Levamisole, ivermectin given at 1 ml/50kg was 100% effective. Although the 2015 study in Kenya found a 99% (95% CI: 91% - 100%) reduction in fecal egg count when considering all helminth eggs, post-treatment fecal culture found 100% of remaining larvae were *Ostertagia spp.*, which the authors interpreted as low or developing resistance in this particular species (Mungube *et al*., 2015**)**. Based on the WAAVP guidelines, this would be best confirmed through a pre- and post-treatment coproculture, or potentially by using newer molecular based tests. No evidence of resistance was found in the 2012 study in cattle or 2017 study in pigs, both from Nigeria (Idika *et al*., 2012; Idika *et al*., 2017).

Discussion

This restricted systematic review documents the paucity of research on the effects of avermectins on productivity outcomes in cattle and pigs in SSA. Among the ten included studies, there is evidence that multiple doses of ivermectin do have a significant positive effect on weight gain in cattle when assessed over time periods greater than three months; however, only one study from Zimbabwe in 1992 linked this effect to a financial benefit for cattle-owners (Duncan & Forbes, 1992). In this case, cattle treated with ivermectin had a net advantage of 47 Zimbabwean dollars (ZWL) per head over the control group. For reference, the average income for that year was 4,020 ZWL (World Bank, 2025). The four studies that investigated the use of ivermectin in cattle affected by the filarial parasite *Parafiliaria bovicola* showed marked efficacy against the parasite, resulting in reductions in lesion size. Two of the studies also documented a financial benefit due to the reduced trimming of subcutaneous and muscular tissue associated with lesion reduction. The 1982 study from Zimbabwe found an increase of 4.9 cents/kg (ZWL) paid at the

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time of slaughter for animals that received ivermectin at 70 days pre-slaughter, as compared to controls (Soll & Carmichael, 1984). The other study, performed in South Africa in 1991, found a difference in mean price realized per steer of 4.66 Rand between treated and control groups, with a benefit-to-cost ratio of 4:1 (Soll *et al*., 1991).

Although the use of most avermectins is contraindicated in lactating dairy cows, studies in other regions of the world have documented the use of avermectins in cows during their reproductive dry period and have assessed interval from calving to conception and volume of milk production in the subsequent lactation cycle (Walsh *et al*., 1995; Gross *et al*., 1999). However, studies in SSA documenting other anticipated productivity outcomes, such as milk production or reproduction metrics, were not identified in this review. Additionally, no studies in swine that met inclusion criteria were identified.

Most of the ten included studies were performed in the 1980's and 1990's, with the most recent study published in 2001, suggesting that perhaps other anthelminthics are now the focus of research in SSA or that related research is not published in journals included in the comprehensive databases selected for this review. Globally, there have been efforts to estimate and document the economic impact of parasites and their associated diseases in livestock (Rashid *et al*., 2019; Charlier *et al*., 2020; Strydom *et al*., 2023), but most are focused on intensive livestock systems and not small-holder herds, which may be another reason there are few studies in SSA. Extensive livestock production systems dominate in SSA, but measuring production-based outcomes within these systems can be challenging given the complex role that livestock play in the lives of 70% of the rural poor that depend on livestock or livestock related activities for their livelihoods (Erdaw, 2023). However, if the use of ivermectin MDA in livestock for malaria vector control is proven effective, it offers an opportunity to consider how public health,

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and veterinary sectors might collaborate for mutual benefit to the populations they serve. For example, the use of ivermectin MDA in cattle (for malaria vector control) would likely be repeated as multiple doses during the rainy season (i.e., the malaria season). Results of this review suggest that multiple doses will have a positive effect on cattle growth over time, but whether this would translate into financial benefit for owners is unknown. This is an example that demonstrates our need to better understand how the use of avermectins in small holder livestock systems not only affects parasites, but how the effective treatment of parasites leads to quantitative changes in production metrics and subsequent economic impacts.

There is some evidence that resistance to ivermectin is developing in intestinal parasites of cattle in SSA (Kenya and Cameroon). However, the inclusion of only four studies in this review does not confirm widespread resistance, but rather a lack of investigation and documentation in cattle and swine parasites for the avermectins class, at least within the literature captured in the databases used in this study. Resistance to avermectins has been documented globally for decades across various species of livestock nematodes and ectoparasites. Mechanisms of resistance include alterations in ligand-gated ion channels and increased expression of ATP-binding cassette transporters, with multigenic mechanisms for resistance making it complex to understand and manage (Silvestre *et al*., 2011; Fissiha *et al*., 2021). Population level resistance to anthelminthics typically occurs in under 10 years (Fissiha *et al*., 2021), so in areas where avermectins have been used extensively and consistently, we would expect to find it.

Although there are no consistent data collected on avermectin access and use, Imbahale *et al*. (2019) mapped the areas in SSA where MDA for malaria vector control would potentially be best implemented, using overlapping maps of cattle density, zoophillic *Anopheles arabiensis*

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habitat, and malaria prevalence. Areas identified include countries in the savanna region south of the Sahel in West Africa, and a scatter of areas within several countries in central and eastern SSA that are not dominated by rainforest or desert. An investigation or collaboration with national and local Veterinary Services within these areas would be critical to understanding the potential for existing avermectin resistance in areas where ivermectin MDA might be considered. This kind of collaboration would be valuable for implementation of ivermectin MDA as well, as local veterinary personnel could assist in community engagement and lead drug delivery in livestock. With some innovative thinking, there could be options for cost savings and benefit across sectors and beyond malaria control, for example by combining MDA with livestock vaccination campaigns or working with NTD programs.

There are two limitations to this study that should be noted. The first is that rapid systematic reviews are inherently limited by the extent of their search strategy. They are designed to quickly synthesize evidence on a particular topic, and in doing so may leave out some relevant data. Therefore, inclusion of additional databases or grey literature to capture regionally relevant publications may provide further insight into the two questions posed in this study. Second, the search terms used did not include all possible avermectins. Although broad terms such as anthelminthic and avermectin were used, it is possible that some relevant studies were not returned in the results, and therefore were not incorporated in this review. Despite these limitations, we believe this review provides a reasonable synthesis of peer-reviewed literature from which we can draw some conclusions.

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Conclusions

Despite the common assertion that control of endo- and ectoparasites in small holder livestock systems would improve productivity outcomes, there actually exists little evidence to quantify this impact as it relates to the use of avermectins in cattle and swine in SSA. Ivermectin, the most commonly used of the avermectins, is readily available in many animal health pharmacies and feed stores throughout SSA. Although we may suspect that avermectin resistance would therefore be widespread, the literature does not currently support or refute this. As the public health community considers the use of ivermectin (or other avermectins) in livestock for malaria vector control, it becomes critical to better quantify potential benefits and risks within the animal health sector.

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Author's contribution. CR conceptualized the review, created the methodology, provided supervision in the review process, and was primarily responsible for writing, reviewing and editing. RZ supported method development, led initial data curation and analysis, and contributed to reviewing and editing the final draft. LM supported follow-on data curation and analysis, supported writing the original draft, and reviewing and editing.

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Ethical standards. Not applicable

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Table 1. Summary of the studies (N=10) describing the effect of avermectins on cattle and swine productivity in Sub-saharan Africa

Authors	Year	Title of Study	Country	Type of Avermectin, Dose and Delivery	Parasite Species Identified	Comparison Group	Results
Swan *et al*.	1983	Efficacy of ivermectin against *Parafilaria bovicola*	South Africa	Ivermectin 200mcg mcg/kg, PO or SC	*Parafilaria bovicola*	Untreated	88.2% reduction in number of subcutaneous lesions, 98.7% reduction in total lesion area and 98.8% reduction in weight of tissue trimmed from carcasses 83 days post-treatment with SC delivery. No effect in cattle treated orally.
Soll & Carmichael	1984	The influence of pre-slaughter treatment with ivermectin on *Parafilaria bovicola* infestation in cattle in	Zimbabwe	Ivermectin 200 mcg/kg, SC given 50 or 70 days pre-slaughter	*Parafilaria bovicola*	Untreated	<u>50 days:</u> 57.6% reduction in lesion size and 71.7% reduction in trimmed tissue.

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		Zimbabwe					70 days: 93.3% reduction in lesion size, and 92.4% reduction in trimmed tissue.
Abdalla	1989	Effects of endoparasites on the growth rate of Sudanese sheep and cattle	Sudan	Ivermectin 200 mcg/kg, SC	*Haemonchus*, *Trichostrongylus*, *Cooperia*, *Oesophagostomum*, *Stronglyloides* and *Chabertia*	Untreated	No statistical difference in liveweight gain between treated and control cattle over a 28-day period
Swan *et al*.	1991	Efficacy of ivermectin against *Parafilaria bovicola* and lesion resolution in cattle	South Africa	Ivermectin 200 mcg/kg, SC given 15, 30, 50 or 70 days pre-slaughter	*Parafilaria bovicola*	Untreated	Cattle treated 70 days pre-slaughter had significant reductions in number and surface area of lesions (1 lesion), and the weight of trimmed tissue (no tissue trimmed) as compared to controls. There was no significant

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							difference in cattle treated at < 70 days as compared to control.
Soll *et al*.	1991	Ivermectin treatment of feedlot cattle for *Parafilaria bovicola*	South Africa	Ivermectin 200mcg/kg, SC at day 0, 21, or 54 upon entry into a feedlot	*Parafilaria bovicola*	Untreated	83.3% reduction in lesion area and 89.9% reduction in mean mass trimmed from carcass across all groups as compared to control when slaughtered > 84 days post-entry.
Duncan & Forbes	1992	Comparison of productivity and economic benefits of strategic anthelmintic use in young beef cattle in Zimbabwe.	Zimbabwe	Ivermectin 200 mcg/kg, SC on Day 0, 194, 354, and 391 (4 doses)	No fecal analysis performed	1) Untreated 2) Levamisole hydrochloride 7.5 mg/kg, PO on Day 0, 194, 354, and 391 (4 doses) 3) Oxfendazole 2.5 mg/kg, PO on Day 0, 194,	Increase in mean total weight gain over 480 days across all treatment groups as compared to untreated control. Ivermectin treated group gained 40lbs more than control group, and 20 pounds more than the

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						354, and 391 (4 doses)	Oxfendazole group
Vassilev	1993	Activity of ivermectin and albendazole in the control of gastrointestinal nematode parasites and growth performance of two-year-old beef cattle.	Zimbabwe	Ivermectin 200 mcg/kg, SC every 10 weeks for 3 doses; Ivermectin 200 mcg/kg, SC two doses given 20 weeks apart.	*Cooperia, Haemonchus placei, Oesophagostomum*	1) Untreated 2) Albendazole 7.5 mg/kg PO every 10 weeks for 3 doses	Over 1 year, 3 doses of ivermectin showed 23.4 kg greater average live mass gain as compared to control, 25.7kg greater gain as compared to 2 doses of ivermectin and 10.5kg greater gain as compared to the Albendazole group; Cattle treated with 3 doses of ivermectin had an average daily gain of 0.212 kg/day in treated vs 0.148 kg/day in untreated cattle. <u>2 doses ivermectin:</u> No significant

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							difference as compared to untreated.
Meeus *et al*.	1997	Comparison of the persistent activity of ivermectin, abamectin, doramectin and moxidectin in cattle in Zambia	Zambia	Abamectin 200mcg/kg, SC; Doramectin 200 mcg/kg, SC; Ivermectin 200 mcg/kg, SC	*Cooperia and Haemonchus*	Albendazole 7.5 mg/kg, PO	No statistical difference in total body weight gain was found between any of the groups over the 84-day study period, despite significant reduction in fecal egg count in Avermectin groups compared to the Albendazole group.
Munyua & Ngotho	1998	Efficacy of ivermectin delivered from a sustained-release bolus against gastrointestinal nematodes in field grazing calves in	Kenya	Ivermectin as a sustained-released bolus designed to deliver 12 mg/day for 135 days	*Haemonchus placei, Trichostrongylus axei*, *Cooperia spp., Nematodirus helvetianus, Oesophagostomum*	Untreated	Significant increase in average daily gain up to 120 days post-treatment (0.335 kg/day vs. 0.005 kg/day in controls).

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		Nyandarua district of Kenya			*radiatum, Trichuris spp.*		
Waruiru & Ngotho	2001	Influence of ivermectin and clorsulon strategic treatments on liveweight gain and helminth infections of grazing calves in Kenya.	Kenya	Ivermectin 200 mcg/kg, SC every 4 months; Ivermectin 200 mcg/kg with Clorsulon, SC every 4 months x 1 year	Strongyles (general) and *Fasciola hepatica* (not treatable by ivermectin)	Untreated	Calves treated with ivermectin alone had significantly higher average daily gains as compared to untreated controls (0.410 kg/day vs. 0.312 kg/day), but the greatest gain was seen in claves treated with ivermectin and clorsulon (0.515 kg/day).

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Table 2. Summary of studies (N=4) assessing resistance to avermectins in cattle and swine in Sub-saharan Africa

Authors	**Year**	**Title of Study**	**Country**	**Type of Avermectin, Dose and Delivery**	**Species**	**Parasite Species Identified**	**Measure of Resistance**	**Results**
Idika *et al*.	2012	Efficacy of levamisole and ivermectin in the control of bovine parasitic gastroenteritis in the sub-humid savanna zone of southeastern Nigeria	Nigeria	Ivermectin 200mcg/kg, SC	cattle	*Haemonchus*, *Trichostrongylus*, *Cooperia*, *Bunostomum*	FECRT	100% reduction in fecal egg count for all cattle treated with ivermectin (no resistance)
Mungube at al.	2015	Prevalence of multiple resistant *Haemonchus* and *Ostertagia* species in goats and cattle in Machakos,	Kenya	Ivermectin 200mcg/kg, SC	cattle	*Haemonchus*, *Trichostrongylus*, *Ostertagia*, *Oesophagostomum*, *Cooperia*	FECRT	99% (95% CI: 91% - 100%) reduction in fecal egg count when considering all helminth eggs; however, post-

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		Eastern Kenya						treatment fecal culture found 100% of remaining larvae were *Ostertagia spp.*
Jean *et al*.	2016	Efficacy testing of anthelmintics against field strains of *Trichostrongyles* in cattle farms of the periurban zone of Ngaoundere in Cameroon.	Cameroon	Ivermectin at 1ml/50kg SC; ivermectin at 200mcg/kg SC; and ivermectin 1ml/50kg SC with Levamisole 7.5 mg/kg PO	cattle	*Haemonchus*, *Trichostrongylus*, *Cooperia*	FECRT: arithmetic mean and geometric mean	Overall low levels of resistance were detected with the two groups that received ivermectin alone (primarily *Cooperia spp.*), however the use of levamisole with ivermectin resulted in a 100% fecal egg count reduction.
Idika *et al*.	2017	Efficacy of ivermectin against gastrointestinal nematodes of pig	Nigeria	Ivermectin 300 mcg/kg SC	pigs	*Oesophagostomum dentatum*, *Ascaris suum*, *Trichuris suis*	FECRT	Ivermectin reduced *O. dentatum* eggs by 98.36% ± 0.43%, and demonstrated a 100%

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		in Nsukka area of Enugu State, Nigeria.						reductions in *A. suum* and *T. suis*.

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Figures

Figure 1. Objective one flow chart based on PRISMA guidelines, illustrating the total number of records (research articles) identified on initial search, and number of records filtered out with each stage of the selection process. Figure was created using Haddaway *et al*., 2022.

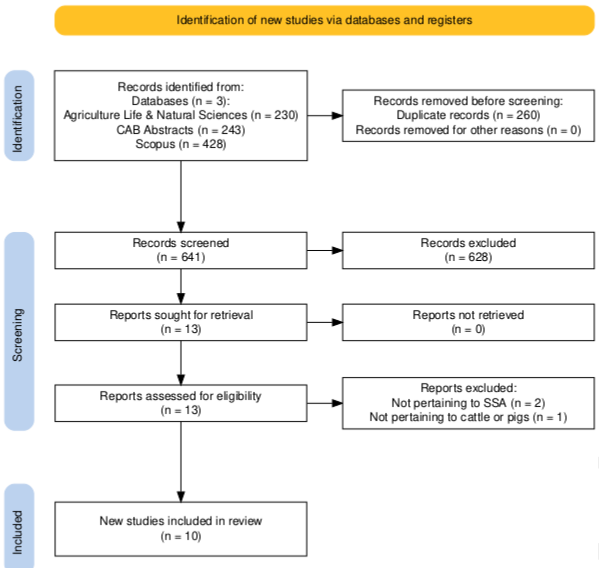

Figure 2. Objective two flow chart based on PRISMA guidelines, illustrating the total number of records (research articles) identified on initial search, and number of records filtered out with each stage of the selection process. Figure was created using Haddaway *et al*., 2022.

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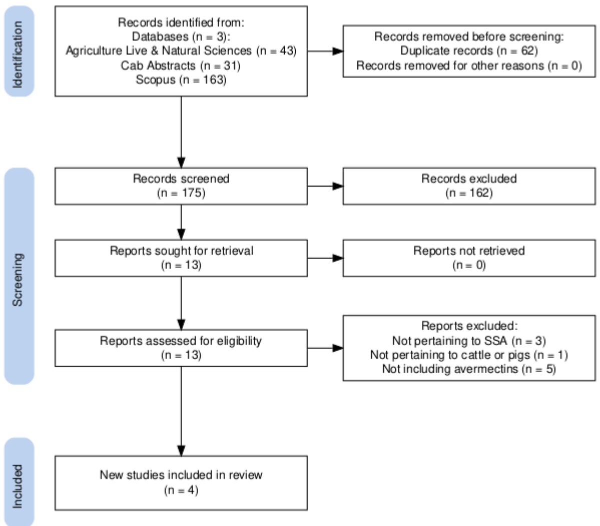

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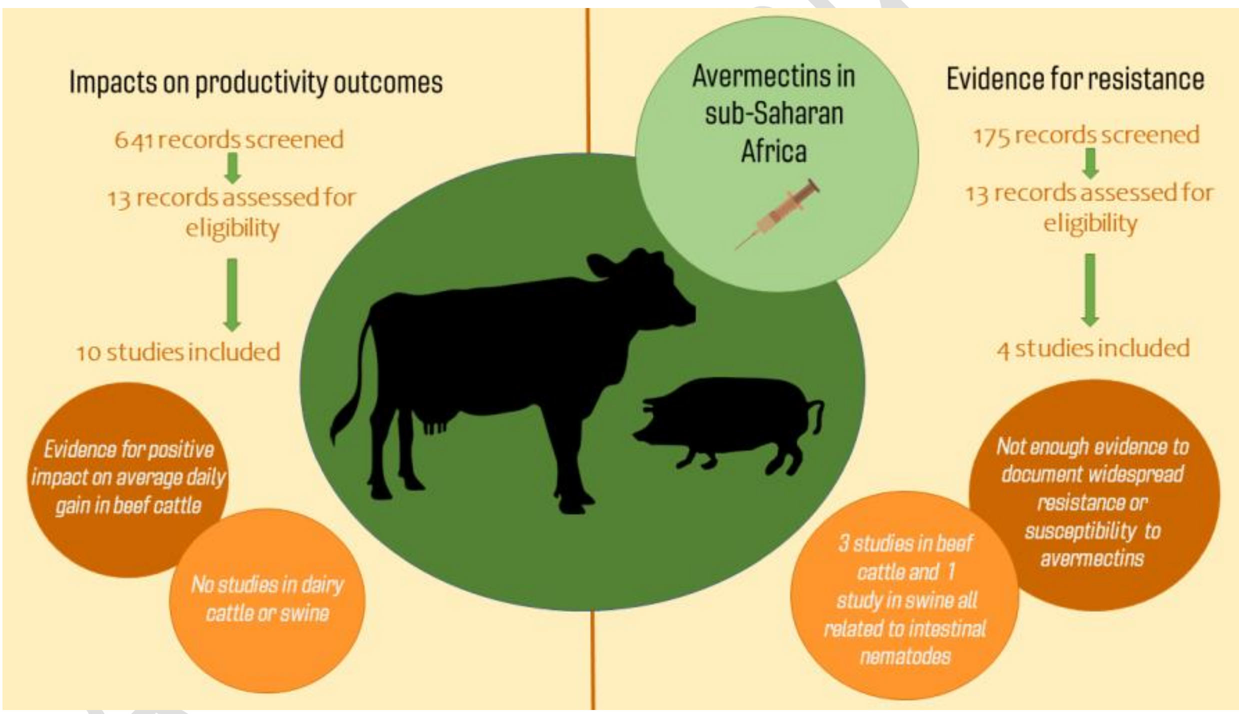

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