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Effectiveness of food safety intervention in improving meat handlers' food safety knowledge and practices and reducing *Escherichia coli* contamination in butcher shops: A Randomised Controlled Trial

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Abstract

Introduction: Foodborne diseases remain major public health and socioeconomic concerns worldwide, disproportionately affecting low- and middle-income countries (LMICs). Evidence suggests that food safety interventions are more effective when they are context-adapted, multicomponent, guided by behavioural change frameworks, and supported by an enabling food safety ecosystem. This study aimed to assess whether such an intervention could reduce microbial contamination in butcher shops by improving meat handlers' food safety knowledge and practices.

Methods: We conducted a randomized controlled trial (RCT) involving 302 butcher shops, randomly allocated to two intervention groups (n = 101 each) and a control group (n = 100). One meat handler from each shop participated in the study. Butcher shops in intervention 1 (TNM) received training, nudges and hygiene materials while those in intervention 2 (TNMI) received all TNM components and were inspected and their ratings were publicly posted. Controls received nothing during intervention but were given training, nudges and materials after endline data collection.

Results: Intervention shops demonstrated decreased odds of *E. coli* contamination (adjusted odds ratio [aOR] = 0.60, 95% CI: 0.44–0.84). Although reduced odds of contamination were observed across all sample types in both intervention groups, statistically significant reductions were limited to meat handlers' hands (aOR = 0.50, 95% CI: 0.28–0.88) and meat hanging boards (aOR = 0.57, 95% CI: 0.32–1.00). Intervention shops also demonstrated higher odds of adhering to proper food safety practices, (aOR= 1.35, 95%CI: 1.235–1.45) for observed and (aOR= 1.15, 95%CI: 1.07–1.524) for self-reported practices.

Conclusions: A food safety intervention that combined training, provision of hygiene materials, nudges and inspection with 'scores on doors' was significantly effective in improving food handlers' food safety knowledge and practices, and in reducing microbial contamination in LMICs setting.

Keywords: nudge, food safety training, hygiene materials, food inspection, food safety, food handling, food contamination

1 Introduction

Despite being largely preventable, foodborne hazards are responsible for more than 200 human diseases, varying from acute diarrhoeal illnesses to a life-threatening cancers [1]. According to the World Health Organisation (WHO) global burden of foodborne diseases (FBD) estimate in 2021, 42 foodborne hazards caused 866 million cases of illnesses and 1.52 million deaths, leading to an estimated loss of 57.1 million healthy life years measured in disability-adjusted life years (DALYs) [2]. This study also identified the WHO African subregions as having the highest per capita burden of FBD. The study further reported that productivity losses attributable to these 42 foodborne hazards were estimated at US$310 billion, with low- and middle-income countries (LMICs) accounting for 65% of the total economic burden.

Evidence suggests that FBDs cause considerable public health and socioeconomic impacts in Ethiopia. Ethiopia was grouped under the WHO subregions (the African subregions) with the second-highest per capita FBD burden [2], indicating that the 42 hazards caused 33 million illnesses, 17, 117 deaths and over 1 million DALYs attributed to FBDs in 2021[3]. Another study also estimated that the burden of FBD due to only three major foodborne hazards including non-typhoidal *Salmonella enterica*, *Campylobacter* spp., and enterotoxigenic *Escherichia coli* (*E. coli*) was 255 DALYs per 100,000 population in 2017 [4]. The economic cost associated with these three hazards was estimated at US$723 million, nearly 1% of the country's gross national income, with children under five years bearing up to 75% of the costs [5]. However, the study acknowledged that the true economic costs may be as much as four times higher due to uncertainties in disease burden estimates and the underlying economic data [5]. These findings highlight the need for effective food safety interventions to mitigate the public health risks associated with FBDs.

Effective food safety interventions require interdisciplinary collaboration among professionals from various fields, such as veterinary science, public health, and social sciences, within a One Health framework. They also require engagement of key stakeholders across the food safety ecosystem because ensuring food safety is a shared responsibility. The Codex Alimentarius Commission (CAC) recommends the implementation of good hygiene practices (GHPs) as a core requirement for ensuring food safety in food businesses [6]. However, compliance with GHPs is influenced not only by the internal conditions of food businesses but also by external factors, including the actions of key food safety stakeholders, including consumers and regulators [7,8]. Factors associated with food businesses such as low level of food handlers food safety knowledge, insufficient supply of materials and limited institutional (food businesses) support for food safety constrain food handlers' adherence to GHPs [9–11]. In Ethiopian butcher shops, meat handlers often have low levels of food safety knowledge [12–14] as few have been trained in food safety [13,15]. Workers in such food establishments tend to underperceive the risk that the work environments are contaminated and

could cause illness [12,14], and commonly engage in unsafe food handling practices [13–16]. Research also shows that consumers frequently express concerns about food safety risks related to foodborne hazards [17–20] and the hygiene conditions of food handling environments [19,21], and such concerns often influence their purchasing behaviour [21,22]. As consumer demand for food safety increases, food businesses are more likely to adopt and uphold higher food safety standards to remain competitive and protect their reputation [22,23]. However, consumer demand may not be always sufficient to incentivize food operators to meet food safety standards at the required level especially in settings where consumers have low levels of demand for safer food. For example, consumers in Ethiopia demonstrate low levels of food safety awareness and risk perception [24,25] which may limit their influence on food business operators to adhere to proper food safety practices to the required level. This limitation necessitates the intervention of food safety regulators to ensure safe food production.Food safety regulators play a crucial role in developing food legislation and guidelines and in enforcing food laws to create an enabling food safety environment [6–8].However, although Ethiopia has made several efforts to enhance the effectiveness of its national food control system, the system still has some gaps such as weak coordination among food safety stakeholders, weak food law enforcement, lack of regular food safety communication mechanisms, and lack of regular food safety training such as for food business operators [26–28]. These findings indicate the importance of engaging and influencing key food safety stakeholders in the food safety ecosystem to enhance the effectiveness of food safety interventions.

Further to this, evidence suggests that food safety interventions are more likely to be effective when designed using behaviour change frameworks as such approaches enable integrating multiple food safety behavioural determinants (such as knowledge, skills, beliefs about consequences, etc) into intervention design, understanding mechanisms of actions of interventions, and allow research replication and evidence synthesis [29–31]. Nevertheless, studies indicate that food safety interventions are rarely and insufficiently informed by behaviour change frameworks [32–34]. Further evidence indicates that behaviour change interventions are more effective when they include multiple components and are tailored to specific contexts [35–37]. Although designing multicomponent and context-specific food safety interventions informed by behaviour change frameworks and engaging key food safety stakeholders is considered a desirable approach, robust evaluation remains essential to determine their effectiveness. Rigorous study designs such as randomized controlled trials (RCTs)are gold standards to provide stronger evidence regarding effectiveness of interventions.

To address these gaps, we developed a context-adapted, multicomponent food safety intervention informed by behaviour change frameworks by involving an interdisciplinary team comprising veterinary and public health scientists, food scientists, and social scientists under a One Health framework. The intervention development processes and implementation of this food safety intervention in butcher shops in Addis

Ababa, Ethiopia, have been described elsewhere [38] . The present RCT evaluated whether targeted food safety intervention at the butcher shops influenced meat handlers' food safety knowledge and practices and microbial contamination (measured by *E. coli* contamination) of beef sold in the butcher shops.

2 Methods

2.1 Study design and setting

A parallel RCT food safety intervention was conducted in butcher shops across all 11 sub-cities of Addis Ababa, Ethiopia (Figure 1), between 15 July and 10 November 2024. Addis Ababa is the capital city of Ethiopia with an estimated population of 4.1 million in 2025 [39], equivalent to 30% of the total urban population of the country.

Ethiopian Public Health Institute (EPHI) and Addis Ababa Food and Drug Authority (AA-FDA) [40] reported in their survey of food establishments in 2019 that there were 13,155 food establishments serving either food exclusively or drink and food, 2,248 food industries (processors) and 914 butcher shops in Addis Ababa [40]. In Ethiopia, butcher shops are the primary food service establishments that specifically sell meat and meat products, with those shops in Addis Ababa receiving meat for sale from government approved abattoirs operating in Addis Ababa.

Cattle for slaughter at these abattoirs are purchased from local live animal markets or feedlots [41,42]. Ante and post-mortem inspections are conducted in Ethiopian domestic abattoirs [43]. Additionally, these abattoirs implement knife trimming and water washing of carcasses to prevent cross-contamination, however, studies indicated that they have low level of adherence to basic GHPs [44,45] and application of advanced postharvest carcass decontamination interventions such as steam vacuuming, carcass washing with chemical solutions [46] and hazard analysis and critical control point (HACCP) are absent [47]. Carcasses from the abattoirs are transported to butcher shops using trucks specifically designed for carcass transport. Upon receipt, butcher shops conduct knife trimming of the carcasses (removing visible contamination such as faces, hair, blood etc. from carcasses) and sorting of the carcasses into various types. Then, they hang or display the carcass on meat hanging boards for sale at ambient temperature (approximately 20–25 °C in Addis Ababa) ([48], which is within the danger zone temperature for food storage as it allows microbial growth.

2.2 Participants

The RCT included 302 butcher shops, with one meat handler recruited from each shop. Participants were eligible if they were 18 years or older and were routinely responsible for meat handling activities, including receiving, sorting, cleaning, hanging, cutting, and selling meat.

2.3 Randomization and masking

Based on previous studies in LMICs [49,50], findings from a pilot study, baseline data from this RCT, and expert judgement on the level of contamination of beef with *E. coli* in Ethiopian butcher shops and the expected hygiene improvement post-intervention, we anticipated a success rate (i.e., no detectable *E. coli*) of 20% in the control shops (that is, at baseline, 80% of butcher shops were expected to be contaminated with *E. coli*, and this level was assumed to remain unchanged in the control group at the post-intervention), and a success rate of 40% in the intervention shops (corresponding to a 20-percentage point reduction in contamination due to the intervention). Using a two-sided significance level of 0.05, a power of 80%, and Cohen's **h** approach [51], the required sample size was estimated at 81 shops per experimental arm. However, we increased the sample size to 100 shops per arm to accommodate up to 19% loss to follow-up. Sample size calculations were performed using the *pwr* package (version 1.3-0) [52] in R (version 4.4.1) [53].

An initial sample of 400 butcher shops was selected from AA-FDA 2019 census database using an algorithm that maximized the minimum distance between included shops. This spatial separation approach was taken to minimize potential spillovers of food safety knowledge and practices, sharing of intervention materials as well as potential competitive effects on business outcomes (the latter to be analysed in a companion study). The field team visited these shops using GPS and contact information to verify whether the shop was operational, confirm eligibility, obtain informed consent, and collect and update basic shop information (e.g., GPS location, shop name, and the names and contact details of the managers and meat handlers). Shops were considered eligible for inclusion if they sold only beef, and consent was obtained from the managers or shop owners and workers. In addition, eligible shops had to be located at least approximately 250 meters from other participating shops to minimize potential spillover effects, and at least 20 meters from non-participating neighbouring shops to minimize the risk of potential conflicts between shop owners, due to potential business advantages conferred through the study interventions. Finally, shops located on roads slated for imminent expansion – where demolition of the butcher shops due to road expansion during the study period was likely – were excluded from participation.

Shops that did not meet criteria or were no longer operating were replaced with the nearest eligible alternatives, subject to the additional criterion (as per the max-min sampling strategy for the initial sample) of being at least 250 meters from any other included shop. Of the original 400 shops, only 204 were both eligible and operational. An additional 134 replacements were made to reach the target of 300 shops, plus 38 extras to account for refusals and loss to follow-up, resulting in 338 shops approached to participate in the study. Ultimately, 302 shops enrolled and participated in a baseline survey. Random allocation was performed by a statistician not involved in the study using computer generated random numbers. Butcher

shops were individually randomized in a 1:1:1 ratio and were stratified by sub-city (stratum) using Stata's randtreat command with the misfits(global) option. Shops that could not be evenly distributed across arms within a stratum were randomized separately to balance the number of shops per study arm across the sample overall. The shops were randomised to one of the following experimental arms (Figure 2):

- **TNM** (Training + Nudges + Materials) *(n = 101)*: Received food safety training, nudges and a hygiene material.
- **TNMI** (TNM + Inspection with 'scores on doors') *(n = 101)*: Received all TNM components, plus inspection of the butcher shops with public posting of their ratings ('scores on doors') on voluntary basis.

- **Control** *(n = 100)*: Received no interventions during the study but were provided training, nudges and hygiene materials after the study concluded (after endline data collection).

The field team who assessed eligibility of the butcher shops for enrolment, data collectors (at baseline and endline), and laboratory staff were all blinded to the allocation of butcher shops across experimental arms.

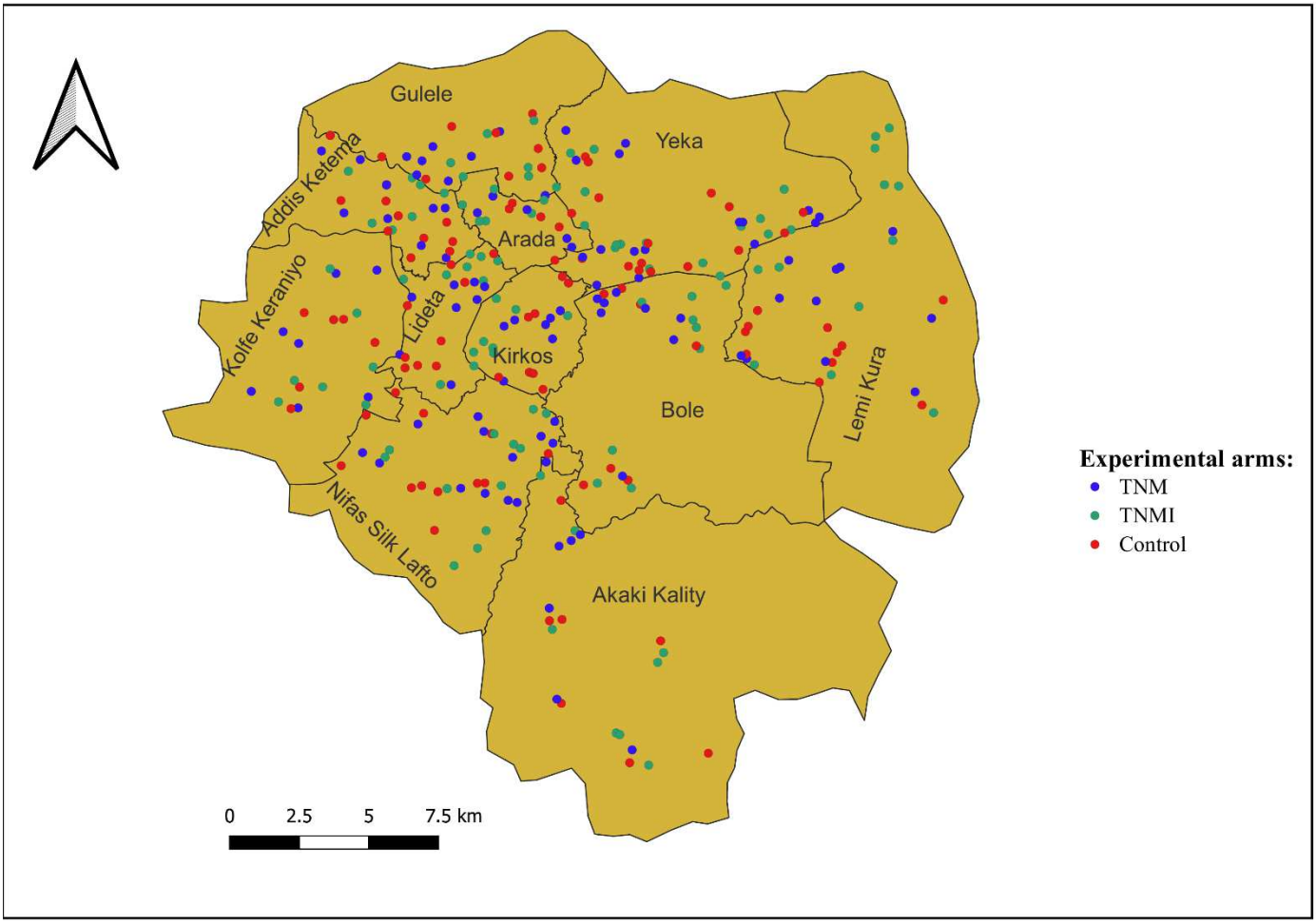


Figure 1. Map of Addis Ababa depicting its 11 sub-cities (indicated with their names in the map) and locations of participating shops: blue for TNM, green for TNMI, red for control shops.

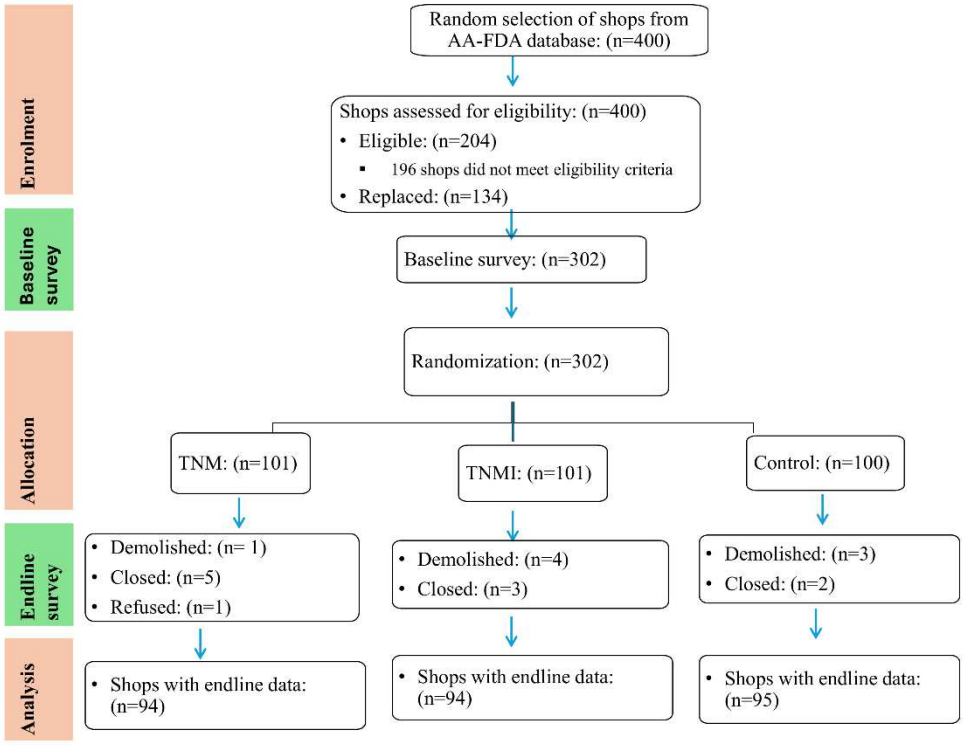


Figure 2. Flow chart showing processes of the RCT food safety intervention.

Note: A total of 19 shops were lost to follow-up at endline resulting in 94 for TNM and TNMI treatment arms, and 95 for the control. Eight shops were demolished as part of government construction activities in the study area (Addis Ababa, Ethiopia); four shops were closed due to taxation issues as data collection coincided with the government's tax collection period, and six other shops permanently ceased selling meat. One shop refused to participate in data collection at follow-up.

2.4 Interventions

The components of the current food safety intervention package included training, nudges, hygiene material provision and inspection with 'scores on doors'. In addition to these components, innovative hygiene practice approaches and enabling food safety ecosystem were applied We present a brief description of these components of the intervention package below, but a detailed description of these is provided elsewhere [38].

2.4.1 Training

The training program comprised of four modules each with distinct learning objectives and was provided in three sessions. The first four-hour training was provided at a hotel near their shops (offsite training) conducted by two of the authors (DG, AK). The second on-the-job training at each shop (2-hour training per shop) was delivered by food inspectors working at AA-FDA a week after the first training. The food inspectors also provided the third the on-the-job training (2-hour training at each shop) as an on-site refresher training at butcher shops. Training modules were summarized in a booklet [54] and the field team

used this booklet while providing on-the-job training. The booklet was also given to the shop managers or butcher shop staff at the end of the first on-the-job training.

2.4.2 Environmental nudges ("nudge kit")

During the first on-the-job training, both TNM and TNMI shops received a set of materials designed to serve as reminders of the training messages and as nudges to adopt the recommended GHPs. This "nudge kit" included posters (supplementary material 1), instructions on how to perform the recommended food safety practices (such as treating water with chlorine tablets, decontaminating meat with electrolysed water, etc), and a booklet (summary of training modules), all provided in the local language (Amharic).

2.4.3 Hygiene material provision ("hygiene kit")

Both TNM and TNMI shops received an identical set of hygiene materials ("hygiene kits") (Supplementary material 2). The hygiene kits were aligned with the intervention training and intended to facilitate the adoption and implementation of the targeted GHPs in butcher shops.

2.4.4 Food safety inspection of butcher shops with 'scores on doors'

Butcher shops in the TNMI group were inspected and encouraged to voluntarily display their inspection ratings ('scores on doors') at their premises. Inspections were conducted using a 29-item checklist aligned with the training content and targeted GHPs in butcher shops [55]. Food inspectors from the AA-FDA, who had delivered the on-the-job training, conducted the inspections and assigned ratings based on the checklist. Each shop was inspected twice, with each inspection lasting approximately one hour: the first was conducted one week after the on-the-job training and the second two months later. Based on their food safety performance, shops received one of four food safety ratings (Supplementary material 3):

- No star (score <50): warning of closure.
- One red star (50≤ score <65): urgent hygiene improvement is required.
- Two yellow stars (65≤ score <75): hygiene standards are good.
- Three green stars (score ≥75): hygiene standards are very good.

2.4.5 Innovative approaches

The intervention incorporated innovative hygiene practice approaches including application of food sanitisers (such as slightly acidic electrolysed water [hypochlorous acid]), colour-coded hygiene materials (eg., colour-coded wiping cloths, colour-coded buckets for cleaning purposes) and deep cleaning procedures (comprehensive cleaning and disinfection) to enhance effectiveness of the intervention.

2.4.6 Creating enabling food safety ecosystem

Key food safety stakeholders encompassing butcher shops, consumers and regulatory authorities were involved in the intervention. For example, we implemented multiple food safety interventions aimed at strengthening food safety culture of butcher shops. Hygiene materials were given to the shops, and training was delivered both offsite and onsite (on-the-job) to facilitate participation of all shop staff, including shop managers. Shops were inspected, and inspection results were publicly displayed to enhance consumers influence on butcher shops. Additionally, food safety information on GHPs (nudges) posted at the shops to reinforce food safety practices. Furthermore, butchers took part in sensory evaluations comparing raw meat treated with electrolysed water or citric acid with untreated meat. Throughout the exercise, the study objectives and experimental procedures were explained, which was intended to improve their awareness and understanding of the potential application of food sanitisers for raw meat.

Posters and inspection scorecards were displayed in shops to enhance consumer awareness of food safety. As part of the study, consumers also assessed the sensory attributes of raw meat treated with electrolysed water or citric acid in comparison with untreated meat. The purpose of the study and the evaluation procedures were explained before the assessments, which may have improved consumers' understanding of the application of food sanitisers on raw meat. Furthermore, we trained local food regulators in risk-based food inspection [56] and collaborated with them throughout the intervention.

2.5 Outcomes

The primary outcome was the presence of *E. coli* contamination on raw beef carcass surface. Whilst presence of *E. coli* contamination on meat handlers' hands, meat cutting board, meat hanging board, and in water samples was secondary outcome. Changes in food safety knowledge and practices of meat handlers were also secondary outcomes.

2.6 Sample collection and processing for *E. coli*

Samples for generic *E. coli* detection were collected (at baseline and endline) using MicroSnap™ Coliform & *E. coli* enrichment swab (Hygiena Int. Ltd., UK) following manufacturer's instructions. An area of 100 cm^2 (10 x 10 cm) was swabbed from surface samples including meat handler hand (palm, fingers, between fingers), meat cutting board, meat hanging board and raw beef carcass surface (beef carcass hung on hanging board) using MicroSnap™ Coliform & *E. coli* incubation device (enrichment swab). For irregular surfaces such as meat handler hands, meat hanging boards and meat surfaces, a sufficient sample area of roughly equivalent to 100 cm^2 was swabbed to obtain representative samples (supplementary material 4). In the field after swabbing, the swab was re-attached back into the swab tube. In addition, a 250mL water

sample (this is water that the shops routinely use for cleaning activities) was collected from each shop in a sterile bottle. These samples were transported to the Microbiology laboratory of the International Livestock Research Institute, Addis Ababa in a portable fridge and maintained at temperature between 2 and 8 °C.

After arriving at the laboratory, 1mL of water from each 250 mL water sample was transferred into a coliform enrichment swab (coliform incubation device) for incubation using a micropipette. The coliform enrichment swabs (coliform incubation device) of all sample types (surface and water samples) were subsequently activated, prior to incubation by breaking the snap-valves using thumb and forefinger by bending bulb forward and backward. The incubation device bulb and swab tube were separated by about 2 inches to relieve internal pressure, and the tube bulb was squeezed to flush all media to bottom of swab tube. The swab was re-attached back into swab tube to firmly seal device and the tube was gently shaken to mix sample and broth. Finally, the swab was incubated at 37°C for 8 hours.

Following 8 hours of incubation, 0.1mL of enriched sample was aseptically transferred from coliform enrichment swab to an *E. coli* detection device (according to manufacturer's instructions). The *E. coli* detection device was then activated by breaking snap-valve using thumb and forefinger by bending bulb forward and backward. After this, swab bulb was squeezed three times to release liquid into tube and the tube was shaken for 2 seconds to mix the sample in the liquid. The *E. coli* detection device was then incubated for 10 minutes at 37°C. *E. coli* presence or absence was measured using EnSURE™ Touch luminometer (Hygiena Int. Ltd., UK) device as per the manufacturer's instruction. The presence or absence of *E. coli* was measured per 100 cm^2 (10 x 10 cm) area of food contact surfaces (meat cutting board, meat hanging board), meat handlers' hand, meat surfaces or per 1 mL of water sample.

2.7 Data collection for food safety knowledge and practices

We prepared a questionnaire based on the contents of the intervention to enhance effective evaluation of the intervention on meat handlers' food safety knowledge and practices. This is in alignment with the basic GHPs requirement of food business as indicated in the Codex General Principles of Food Hygiene [6] and Ethiopian national food hygiene requirements [57]. The questionnaire was designed in SurveyCTO, with data collectors accessing the questionnaire on tablets. The questionnaire has three sections (supplementary materials 5): sociodemographic characteristics, food safety knowledge and practices of meat handlers. Th study was piloted to test intervention materials and intervention methodologies. In the sociodemographic characteristics section of the questionnaire, meat handlers' gender, age, work experience in butcher shops, responsibilities and education level as well as types of services provided by butcher shops were collected. Whilst items for food safety knowledge questions were classified into seven knowledge domains including hand hygiene (12 items), proper and clean clothing (7 items), keeping water clean (6 items), cleaning and disinfection of work surfaces (7 items), keeping meat safe (9 items), preventing cross-contamination (5

items) and foodborne diseases (21 items) (supplementary materials 6). Food safety practices were classified into two main categories: self-reported (data collected through face-to-face interviewing) and observed (data collected through direct observation) practices. Further, items for food safety practices were classified into 10 GHP domains including keeping hand hygiene (23 items), using proper and clean worksite clothing (7 items), cleaning and disinfection of work surfaces (57 items), preventing cross-contamination (8 items), using proper food contact surfaces (4 items), environmental sanitation (25 items), keeping water clean (7 items), keeping meat safe (12 items), worker health (2 items) and food safety training (14 items) (supplementary materials 7). Prior to data collection, enumerators were trained in effective interview techniques and on the contents of the questionnaire by reviewing the questionnaire question by question to improve their understanding of each question. Using this pretested and structured questionnaire, trained data collectors collected data at baseline (pre-intervention) and endline (post-intervention) through face-to-face interview. Additionally, data collectors used direct observation to collect data on food safety practices of meat handlers. The survey questionnaire was designed in English, translated to the local language (Amharic) and administered in the local language.

2.8 Statistical analysis

Intention-to-treat analysis method was used [58,59]. Missing data was handled using complete case analysis method [60,61]. We estimated causal effects of the intervention on *E. coli* contamination of butcher shops, meat handlers' food safety knowledge and practices using mixed-effects logistic regression (MELR) model. We included experimental arms (TNM, TNMI, control) and the stratification stratum (sub-city) as fixed effects, and individual butcher shops as random effects to account for variability due unknown sources related to individual shops [62]. MELR analysis was done using the *glmer ()* function of the lme4 package with binomial family using a *logit link function* [63] in R (version 4.4.1 and higher) [53]. MELR models the linear relationship between the outcome and predictors in terms of log odds. We used the *exponentiate ()* function of model parameters package [64] in R to convert log odds into odds ratio for ease of interpretation of the intervention effect estimate. We compared the effects of the intervention on the outcomes associated with TNM, and TNMI shops with controls (model 1); intervention shops (TNM and TNMI combined) with controls (model 2) and TNMI shops with TNM shops (model 3). These models are indicated below:

$$endline_outcome \sim \beta_0 + \beta_{1,2}\ (experimental_arms) + \beta_{1-10}\, sub_city + (1|shop_ids) \ldots \text{(model 1)}$$

Where:

- $endine_outcome$: log odds of the outcomes (food safety knowledge, food safety practices, *E.coli* contamination)

- $\beta_{0:}$ population (avarage) intercept
- $experimental_arms$: is a dummy variable of three levels (TNM, TNMI, control) with control as a reference
- β_1: log odds of outcome associated with TNM
- $\beta_{2:}$ log odds of outcome associated with TNMI
- sub_city: is a dummy variable of 11 levels which is associated with each sub-city
- $\beta_{1-10:}$ is log odds of oucomes associated with each sub-city
- $(1|shop_ids)$: random intercept of participating shops

$$endline_outcome \sim \beta_0 + \beta_1\ (experimental_arms) + \beta_{1-10}\, sub_city + (1|shop_ids) \ldots \text{(model 2)}$$

Where:

- $endine_outcome$: log odds of the outcomes (food safety knowledge, food safety practices, *E.coli* contamination)
- $\beta_{0:}$ population (avarage) intercept
- $experimental_arms$: is a two level dummy variable (intervention [TNM & TNMI combined, control) with control as a reference
- β_1: log odds of outcome associated with intervention (TNM & TNMI combined)
- sub_city: is a dummy variable of 11 levels which is associated with each sub-city
- $\beta_{1-10:}$ is log odds of oucomes associated with each sub-city
- $(1|shop_ids)$: random intercept of participating shops

$$endline_outcome \sim \beta_0 + \beta_{1,2}\ (experimental_arms) + \beta_{1-10}\, sub_city + (1|shop_ids) \ldots \text{(model 3)}$$

Where:

- $endine_outcome$: log odds of the outcomes (food safety knowledge, practices, *E.coli* contamination)
- $\beta_{0:}$ population (avarage) intercept
- $experimental_arms$: is is a dummy variable of three levels (TNM, TNMI, control) with TNM as a reference
- β_1: log odds of outcome associated with TNMI
- $\beta_{2:}$ log odds of outcome associated with control
- sub_city: is a dummy variable of 11 levels which is associated with each sub-city

- β_{1-10} *are logs odds of outcomes being in the respective sub_city*
- $(1|shop_ids)$: random intercept of participating shops

Presence of *E. coli* in the assessed samples was assigned 1 and its absence was assigned 0. The baseline level of *E. coli* contamination was summarized as the proportion of samples testing positive for *E. coli* divided by the total number of samples assessed. At endline, causal effects of the interventions on *E. coli* contamination of each of the samples from intervention shops was compared with those from control shops using MELR (control shops used as a reference in the MELR model). We also compared effects of the intervention on *E. coli* contamination of samples from intervention shops as a whole (based on all sample types combined without classifying into the sample types mentioned above) with those from control shops. Moreover, we compared effects of the intervention on *E. coli* contamination level of samples from TNMI shops with those from TNM shops (TNM shops used as a reference in the MELR model). The model accounted for variability in *E. coli* contamination level due to the individual participating butcher shops [62]

Meat handlers' responses to food safety knowledge questions were assigned 1 for correct and 0 for incorrect answers. At baseline, the percentage of correct responses to food safety questions was calculated by dividing the number of correct answers by the total number of expected correct responses within each knowledge domain. The causal effect of our intervention on each of these knowledge domains of intervention shops were compared with those of control shops using MELR (control shops used as a reference in the MELR model). We also compared causal effects of the intervention on knowledge domain of intervention shops as a whole (based on all knowledge items combined without classifying into the domains mentioned above) with those of control shops. Moreover, we compared causal effects of the intervention on knowledge domains of TNMI shops with those of TNM shops (TNM shops used as a reference in the MELR model) following the same way as we did between intervention and control shops. The model accounted for variability in food safety knowledge due to the individual participating butcher shops [62].

Meat handlers' food safety practices were assigned 1 for proper and 0 for improper food safety practices. At baseline, meat handlers' proper food safety practices compliance percentage was calculated by dividing the number of proper food safety practices performed by the total number of expected proper food safety practices. Causal effects of our interventions were estimated separately for self-reported and observed behaviours using MELR in the same way as for knowledge analysis mentioned above. The model accounted for variability in food safety practices due to the individual participating butcher shops [62]. We reported the

intervention using the Consolidated Standards of Reporting Trials (CONSORT) guideline [65] (supplementary material 8).

2.9 Ethical considerations and RCT registration

Ethical approval for this study was granted by the International Livestock Research Institute (ILRI) Institutional Research Ethics Committee (Approval No. ILRI-IREC2023-04), in accordance with the ILRI Institutional Research Ethics Committee (IREC) operating guidelines [66]. Additional approvals were obtained from the Faculty of Engineering and Science Research Ethics Committee (FES-FREC -23.06.56) of the University of Greenwich, UK, Institutional Review Board of the International Food Policy Research Institute (MTID-23-0211) and the City Government of Addis Ababa Health Bureau (ref: A/A/H/9/08/227). Only the study subjects who provided informed consent and willing to participate were included in the study. This study is registered 04 September 2023 with AsPredicted.org (https://aspredicted.org/T5G_CRT), number 142627. The study protocol and statistical analysis plan can also be accessed at Open Science Framework (https://osf.io/p3kwh/files/osfstorage).

3 Results

3.1 Baseline characteristics

3.1.1 Sociodemographic characteristics

Overall, baseline characteristics were similar among the three experimental arms (TNM, TNMI, control). All participants were men, with median age of 26 years (interquartile range, 23 to 30). The median years of experience of working as a meat handler was 5 years. Over 95% of respondents had attained some formal education at the primary (60.3%) or secondary (35%) level. All respondents were responsible for meat handling (meat cutting) (Table 1).

386

387 Table 1. Characteristics of meat handlers and butcher shops at baseline

Characteristics	TNM (N=101)	TNMI (N=101)	Control (N=100)
Male sex—n (%)	101 (100%)	101 (100%)	100 (100%)
Age in year — median (IQR)	24 (21–29)	26 (23–30)	26 (23–30)
Work experience in year (as meat handler in butcher shops) —median (IQR)	5 (3–7)	5 (4–8)	5 (3–10)
Educational status—n (%)			
None	2 (2%)	3 (3%)	1 (1%)
Adult education	--	1% (1)	1% (1)
Some primary (1-8 grades)	58 (58%)	60 (59.4%)	63 (64%)
Some secondary (9-12 grades)	37 (37%)	35 (35%)	33 (33%)
Some college level (diploma level)	1 (1%)	2 (2%)	--
Some degree level	2 (2%)	--	1 (1%)
Respondent responsibilities—n (%)			
Cutting meat	101 (100%)	101 (100%)	100 (100%)
Handling money	9 (9%)	5 (5%)	5 (5%)
Cleaning shop	1 (1%)	1 (1%)	1 (1%)
Managing shop	11 (11%)	7 (7%)	10 (10%)
Service provided by butcher shops—n (%)			
Sells raw meat for consumption at home	65 (65%)	77 (76.2%)	74 (75%)
Serves raw meat at premise	56 (56%)	45 (45%)	61 (62%)
Serves other foods at premises	44 (44%)	41 (41%)	45 (45%)
Serves beverages at premises	11 (11%)	21 (21%)	23 (23%)

388 ***Note***: IQR: interquartile range, --: no data, percentage was calculated as n/N.

389 ### 3.1.2 *Escherichia coli* contamination level at baseline (pre-intervention)

390 At baseline (pre-intervention), over seven in ten of samples (72% (1059/1470, 95%CI: 70–74%)) from
391 butcher shops were contaminated with *E. coli*. The highest *E. coli* contamination was found on meat
392 handlers' hands, but it was comparable with contamination level on beef carcass surfaces. Water samples
393 had the least contamination level (23% (67/294, 95%CI: 18–28%)) compared with other samples. Levels
394 of *E. coli* contamination of samples from each experimental arm was comparable (Table 2).

395

Table 2. Percentage of butcher shops samples with *E. coli* contamination at baseline by experimental arms (control, TNM, TNMI and overall)

Sample types	Control (N=100)	TNM (N=101)	TNMI (N=101)	Overall (sample types)
Overall (experimental arms)	**71% (348/490,95%CI: 67–75%)**	**72% (351/485, 95%CI: 68–76%)**	**73% (360/495, 95%CI: 69–76%)**	**72% (1059/1470, 95%CI: 70–74%)**
Meat handlers' hands	85% (83/98, 95%CI: 76–91%)	90% (87/97, 95%CI: 82–94%)	89% (88/99, 95%CI: 81–94%)	88% (258/294, 95%CI: 82–90%)
Meat cutting boards	85% (83/98, 95%CI: 76–91%)	78% (76/97, 95%CI: 69–85%)	81% (80/99, 95%CI: 72–87%)	81% (239/294, 95%CI: 76–86%)
Meat hanging boards	79% (77/98, 95%CI: 69–86%)	86% (83/97, 95%CI: 77–91%)	81% (80/99, 95%CI: 72–87%)	81% (240/294, 95%CI: 77–86%)
Beef carcass surfaces	87% (85/98, 95%CI: 78–92%)	85% (82/97, 95%CI: 76–90%)	91% (90/99, 95%CI: 83–95%)	87% (257/294, 95%CI: 82–90%)
Water samples	22% (22/98, 95%CI: 15–32%)	24% (23/97, 95%CI: 16–33%)	22% (22/99, 95%CI: 15–31%)	23% (67/294, 95%CI: 18–28%)

3.1.3 Food safety knowledge and practices

At baseline (pre-intervention), meat handlers had low levels of food safety knowledge, on average, providing correct answers to less than four out of ten food safety questions (37% (680/18300, 95%CI: 37–38%). Concerning the food safety knowledge domains, although meat handlers showed slightly over 50% in providing correct answers to questions related to cleaning and disinfection, and preventing cross-contamination, they provided under 40% correct responses against questions in the remaining domains. Meat handlers from all experimental arms (TNM, TNMI, and control) demonstrated equivalent levels of food safety knowledge (Table 3).

Overall, meat handlers also had low level of compliance with proper food safety practices: 43% (6888/16145, 95%CI: 42–43%) for observed and 36% (6095/16899, 95%CI: 35–37%) for self-reported practices. Considering observed practices, meat handlers showed the least adherence to proper cleaning and disinfection of work surfaces while the highest adherence was associated with preventing cross-contamination and using of proper food contact surfaces. Whereas, for self-reported practices, they had the highest compliance in wearing proper and clean worksite clothing while the least related to keeping water clean. Meat handlers in all experimental arms also showed comparable proportions of adhering to proper food safety practices related to both observed and self-reported behaviours (Table 4).

Table 3. Percentage of correct responses provided by meat handlers to food safety questions at baseline

Food safety knowledge domains	**Control (N=100)**	**TNM (N=101)**	**TNMI (N=101)**	**Overall (sample types)**
Overall (experimental arms)	**38% (2312/6100, 95%CI: 30–46%)**	**37% (2270/6100, 95%CI: 28–46%)**	**36% (2219/6100, 95%CI: 28–45%)**	**37% (680/18300, 95%CI: 37–38%)**
Hand hygiene	41% (436/1056, 95%CI: 38–44%)	40% (408/1012, 95%CI: 37–43%)	39% (403/1023, 95%CI: 36–42%)	41% (1336/3300, 95%CI: 39–42%)
Proper and clean clothing	34% (198/576, 95%CI: 31–38%)	33% (181/552, 95%CI: 29–37%)	33% (186/558, 95%CI: 30–37%)	33% (599/1800, 95%CI: 31–36%)
Keeping water clean	26% (127/480, 95%CI: 23–31%)	26% (118/460, 95%CI: 22–30%)	26% (122/465, 95%CI: 22–30%)	26% (391/1500, 95%CI: 24–28%)
Cleaning and disinfection of work surfaces	50% (338/672, 95%CI: 47–54%)	54% (349/644, 95%CI: 50–58%)	49% (318/651, 95%CI: 45–53%)	52% (1083/2100, 95%CI: 49–54%)
Preventing cross-contamination	56% (269/480, 95%CI: 52–60%)	55% (252/460, 95%CI: 50–59%)	56% (262/465, 95%CI: 52–61%)	56% (836/1500, 95%CI: 53–58%)
Keeping meat safe	26% (173/672, 95%CI: 23–29%)	24% (152/644, 95%CI: 20–27%)	22% (142/651, 95%CI: 19–25%)	24% (493/2100, 95%CI: 22–25%)
Foodborne diseases	30% (467/1536, 95%CI: 28–33%)	30% (446/1472,95%CI: 28–33%)	28% (420/1488, 95%CI: 26–31%)	30% (1420/4800, 95%CI: 36–42%)

Note: The percentage of correct responses to food safety questions was calculated by dividing the number of correct answers by the total number of expected correct responses.

Table 4. Percentage of food safety practices compliance among meat handlers at baseline

Food safety practice domains	Control (N=100)	TNM (N=101)	TNMI (N=101)	Overall (sample types)
Observed practices				
Overall (experimental arms)	**43% (2299/5371,95%CI: 41–44%)**	**43% (2277/5361,95%CI: 41–44%)**	**43% (2312/5413, 95%CI: 41–44%)**	**43% (6888/16145, 95%CI: 42–43%)**
Keeping hand hygiene	41% (485/1188, 95%CI: 38–44%)	42% (498/1198, 95%CI: 39–44%)	43% (524/1211, 95%CI: 41–46%)	42% (1507/3597, 95%CI: 40–44%)
Using proper and clean worksite clothing	53% (245/459, 95%CI: 49–58%)	52% (237/457, 95%CI: 47–56%)	53% (246/463, 95%CI: 49–58%)	53% (728/1379, 95%CI: 50–55%)
Cleaning and disinfection of work surfaces	30% (180/602 95%CI: 26–34%)	25% (142/576, 95%CI: 21–28%)	25% (151/607, 95%CI: 22–28%)	27% (473/1785, 95%CI: 25–29%)
Preventing cross-contamination	73% (272/372, 95%CI: 68–77%)	69% (266/384, 95%CI: 64–74%)	70% (255/362, 95%CI: 66–75%)	71% (793/1118, 95%CI: 68–74%)
Keeping environmental sanitation	32% (657/2030, 95%CI: 30–34%)	34% (698/2043, 95%CI: 32–36%)	33% (684/2051, 95%CI: 31–35%)	33% (2039/6124, 95%CI: 32–35%)
Keeping meat safe	58% (245/426, 95%CI: 53–62%)	57% (236/416, 95%CI: 52–61%)	58% (249/430, 95%CI: 53–62%)	57% (730/1272, 95%CI: 55–60%)
Using proper food contact surfaces	73% (215/294,95%CI: 68–78%)	70% (200/287,95%CI: 64–75%)	70% (203/289, 95%CI: 65–75%)	71% (618/870, 95%CI: 68–74%)
Self-reported practices				
Overall (experimental arms)	**36% (2056/5681, 95%CI: 35–38%)**	**36% (1992/5502,95%CI: 35–38%)**	**36% (2047/5716,95%CI: 35–38%)**	**36% (6095/16899, 95%CI: 35–37%)**
Keeping hand hygiene	23% (106/456, 95%CI: 20–27%)	21% (81/384, 95%CI: 17–25%)	23% (112/480, 95%CI: 20–27%)	23% (299/1320, 95%CI: 21–25%)

Using proper and clean worksite clothing	96% (178/186, 95%CI: 92–98%)	97% (180/186, 95%CI: 93–99%)	93% (177/191, 95%CI: 88–96%)	95% (535/563, 95%CI: 93–97%)
Keeping water clean	16% (29/184, 95%CI: 11–22%)	14% (23/160, 95%CI: 10–21%)	20% (42/207, 95%CI: 15–26%)	17% (94/551, 95%CI: 14–20%)
Cleaning and disinfection of work surfaces	33% (1306/3921, 95%CI: 32–35%)	34% (1330/3939, 95%CI: 32–35%)	33% (1321/3971, 95%CI: 32–35%)	34% (3957/11831, 95%CI: 33–34%)
Preventing cross-contamination	54% (131/241, 95%CI: 48–61%)	49% (117/239, 95%CI: 43–55%)	56% (127/227, 95%CI: 49–62%)	53% (375/707, 95%CI: 49–57%)
Keeping meat safe	10% (14/135, 95%CI: 6–17%)	4% (4/110, 95%CI: 1–9%)	10% (14/145, 95%CI: 6–16%)	8% (32/390, 95%CI: 6–11%)
Worker health	88% (144/163, 95%CI: 83–92%)	84% (138/165, 95%CI: 77–89%)	83% (144/174, 95%CI: 76–88%)	85% (426/502, 95%CI: 82–88%)
Food safety training	37% (148/395, 95%CI: 33–42%)	37% (119/319, 95%CI: 32–43%)	34% (110/321, 95%CI: 29–40%)	36% (377/1035, 95%CI: 34–39%)

Note: Meat handlers' proper food safety practices compliance percentage was calculated by dividing the number of proper food safety practices performed by the total number of expected proper food safety practices.

3.2 Primary outcome

3.2.1 *Escherichia coli* contamination level at endline (post-intervention)

At endline (post-intervention), compared with control butcher shops, intervention butcher shops had decreased odds of *E. coli* contamination (aOR = 0.60, 95% CI: 0.44–0.84). Lower odds of *E. coli* contamination were also observed for meat handlers' hands (aOR = 0.50, 95% CI: 0.28–0.88) and meat hanging boards (aOR = 0.57, 95% CI: 0.32–1.00) in intervention shops. Although lower odds of *E. coli* contamination were observed on meat cutting boards, beef carcass surfaces, and water samples in intervention shops, these reductions in contamination were statistically not significant (Table 5).

Compared with control butcher shops, TNMI butcher shops showed lower odds of *E. coli* contamination for overall sample types (aOR = 0.59, 95% CI: 0.41–0.86) and meat hanging boards (aOR = 0.50, 95% CI: 0.26–.98). However, they demonstrated statistically not significant reductions in *E. coli* contamination for other sample types. TNM butcher shops also exhibited decreased odds of *E. coli* contamination for overall sample types (aOR = 0.62, 95% CI: 0.42–0.90) and meat handlers' hands (aOR = 0.46, 95% CI: 0.24–0.89), but reductions in contamination were statistically not significant for other sample types. Although TNMI shops showed lower odds of *E. coli* contamination than TNM shops for meat hanging boards, beef carcass surfaces, water samples, and overall samples, these differences were statistically not significant (Table 5).

Table 5. Post-intervention comparison of *Escherichia coli* contamination level of intervention shops with those of control shops using mixed-effects logistic regression. Comparison was also made between TNMI and TNM (used as a reference in MELR model) shops.

Sample types	aOR (95% CI)			
	TNM vs control	TNMI vs control	Intervention vs control	TNMI vs TNM
Overall	0.62 (0.42–0.9) *	0.59 (0.41–0.86) *	0.60 (0.44–0.84) *	0.96 (0.65–1.40)
Meat handler hands	0.46 (0.24–0.89) *	0.54 (0.28–1.02)	0.50 (0.28–0.88) *	1.17 (0.62–2.19)
Meat cutting boards	0.76 (0.40–1.45)	0.95 (0.50–1.80)	0.85 (0.49–1.48)	1.24 (0.65–2.36)
Meat hanging boards	0.63 (0.33–1.20)	0.50 (0.26–0.97) *	0.57 (0.32–1.00) *	0.80 (0.42–1.51)
Beef carcass surfaces	0.62 (0.32–1.20)	0.56 (0.29–1.08)	0.59 (0.33–1.05)	0.90 (0.47–1.72)
Water samples	0.66 (0.31–1.41)	0.46 (0.21–1.01)	0.55 (0.29–1.07)	0.70 (0.31–1.57)

Note: aOR: adjusted odds ratio; overall: analysis without categorizing sample into its types; TNM: shops received training, nudges, and hygiene materials; TNMI: shops received training, nudges, hygiene materials and, were inspected, and ratings publicly displayed in the form of 'scores on doors'; intervention: comparing intervention groups combined (without classifying into TNM and TNMI) with control group; *: statistically significant improvement at $P < 0.05$ (or confidence interval contained no unity).

3.3 Secondary outcomes

3.3.1 Food safety knowledge

Overall, meat handlers from intervention shops had greater odds of providing correct answers to food safety questions than those from control shops (aOR = 1.18, 95%CI: 1.05–1.32). While improvements were observed across all food safety knowledge domains, statistically significant gains were evident only in hand hygiene and, cleaning and disinfection (Table 6).

Considering overall food safety knowledge, meat handlers from TNMI shops had higher odds of correctly answering food safety knowledge questions than those from control shops (aOR = 1.15, 95% CI: 1.01–1.31). Although higher odds of correct responses were observed across all knowledge domains, a statistically significant improvement was found only for keeping meat safe. Similarly, meat handlers from TNM shops demonstrated significantly higher odds of correctly answering knowledge questions compared with controls (aOR = 1.20, 95% CI: 1.05–1.37). While improvements were noted across all knowledge domains, statistically significant increases were limited to hand hygiene and cleaning and disinfection. Although TNMI shops exhibited slightly higher, but not statistically significant, odds of providing correct answers to food safety questions related to prevention of cross-contamination, and keeping meat safe compared with TNM shops, the overall odds of correct responses were comparable between the two groups (Table 6).

Table 6. Post-intervention comparison of meat handlers' food safety knowledge from intervention shops in providing correct answers to food safety questions with those from control shops using MELR. Comparison was also made between TNMI and TNM (used as a reference in MELR model) shops.

Food safety knowledge domains	**aOR (95% CI)**			
	TNM vs control	**TNMI vs control**	**Intervention vs control**	**TNMI vs TNM**
Overall	1.20 (1.05–1.37) *	1.15 (1.01–1.31) *	1.18 (1.05–1.32) *	0.96 (0.84–1.09)
Hand hygiene	1.26 (1.05–1.51) *	1.17 (0.98–1.40)	1.21 (1.04–1.42) *	0.93 (0.77–1.12)
Proper and clean clothing	1.21 (0.95–1.55)	1.20 (0.94–1.55)	1.21 (0.98–1.49)	0.99 (0.78–1.27)
Keeping water clean	1.30 (0.99–1.70)	1.14 (0.87–1.50)	1.22 (0.96–1.54)	0.88 (0.67–1.15)
Cleaning and disinfection of work surfaces	1.38 (1.07–1.78) *	1.20 (0.94–1.55)	1.29 (1.04–1.60) *	0.87 (0.67–1.13)
Keeping meat safe	1.15 (0.93–1.42)	1.23 (1.00–1.52) *	1.19 (0.99–1.43)	1.07 (0.87–1.32)
Preventing cross-contamination	1.09 (0.84–1.42)	1.13 (0.86–1.47)	1.11 (0.88–1.39)	1.04 (0.79–1.36)
Foodborne diseases	1.21 (0.99–1.48)	1.12 (0.91–1.37)	1.16 (0.97–1.39)	0.92 (0.75–1.13)

Note: aOR: adjusted odds ratio; overall: analysis without categorizing sample into its types; TNM: shops received training, nudges, and hygiene materials; TNMI: shops received training, nudges, hygiene materials and, were inspected, and ratings publicly displayed in the form of 'scores on

doors'; intervention: comparing intervention groups combined (without classifying into TNM and TNMI) with control group; *: statistically significant improvement at $P < 0.05$ (or confidence interval contained no unity).

3.3.2 Food safety practices

Concerning observed practices, overall, the odds of performing proper food safety practices were higher for meat handlers from intervention shops than those from control shops (aOR= 1.35, 95%CI: 1.25–1.45). Both TNMI and TNM shops also showed greater odds of adhering to proper food safety practices than control shops, with odds ratio of 1.36 (95%CI: 1.24–1.48) and 1.34 (95%CI: 1.22–1.46), respectively. Intervention shops, TNMI and TNM shops demonstrated higher odds of adhering to proper food safety practices across all domains of GHPs, although, improvement was statistically nonsignificant for proper and clean worksite clothing. Using proper food contact surfaces was also showed statistically nonsignificant improvement in TNMI shops. Compared with TNM shops, TNMI shops demonstrated greater adherence to good food safety practices based on overall observed practices, using proper and clean worksite clothing and keeping environmental sanitation but appeared to be comparable in other domains (Table 7).

Regarding self-reported practices, overall, intervention shops demonstrated greater odds of compliance to proper food safety practices than control shops (aOR= 1.15, 95%CI: 1.207–1.24). They also showed higher odds of performing proper food safety practices across all food safety practice domains, but the improvements were statistically nonsignificant for keeping hand hygiene, cleaning and disinfection of work surfaces and proper and clean worksite clothing. Increased odds of enacting proper food safety practices were observed among TNMI shops than controls across all food safety practice domains, but improvements were statistically nonsignificant for cleaning and disinfection of work surfaces and proper and clean worksite clothing. Similarly, TNM shops showed higher odds of adhering to proper food safety practices than controls across all food safety practice domains, but changes were statistically nonsignificant for keeping hand hygiene and, proper and clean worksite clothing. Compared with TNM shops, TNMI shops demonstrated greater adherence to good food safety practices related to using proper and clean worksite clothing, keeping environmental sanitation, keeping hand hygiene, keeping water clean, keeping meat safe and worker health but these differences are statistically non-significant. However, the performance of the two groups seemed comparable for most of the GHP domains (Table 7).

Table 7. Post-intervention comparison of meat handlers' adherence to proper food safety practices from intervention shops with those from control shops using MELR. Comparison was also made between TNMI and TNM (used as a reference in MELR model) shops.

Food safety practice domains	**aOR (95%CI)**			
Observed food safety practices	**TNM vs control**	**TNMI vs control**	**Intervention vs control**	**TNMI vs TNM**
Overall	**1.34 (1.22–1.46) ***	**1.36 (1.24–1.48) ***	**1.35 (1.25– 1.45) ***	**1.02 (0.93–1.11)**
Keeping hand hygiene	1.40 (1.17–1.68) *	1.39 (1.16–1.66) *	1.40 (1.19–1.63) *	0.99 (0.83–1.19)
Using proper and clean worksite clothing	1.11 (0.85–1.44)	1.28 (0.98–1.68)	1.19 (0.94–1.50)	1.16 (0.88–1.52)
Cleaning and disinfection of work surfaces	2.59 (1.80–3.73) *	2.56 (1.77–3.69) *	2.57 (1.86–3.56) *	0.99 (0.70–1.38)
Preventing cross-contamination	1.60 (1.18–2.18) *	1.61 (1.23–2.09) *	1.61 (1.23–2.09) *	1.00 (0.73–1.38)
Keeping environmental sanitation	1.15 (1.01–1.31) *	1.18(1.04–1.34) *	1.17 (1.04–1.31) *	1.02 (0.90–1.16)
Keeping meat safe	1.56 (1.18–2.06) *	1.54 (1.17–2.03) *	1.55 (1.22–1.97) *	0.99 (0.75–1.29)
Using proper food contact surfaces	2.07 (1.13–3.79) *	1.78 (0.99– 3.20)	1.92 (1.17–3.15) *	0.86 (0.45–1.65)
Self-reported food safety practices				
Overall	**1.16 (1.07–1.26) ***	**1.14 (1.05–1.24) ***	**1.15 (1.07–1.24) ***	**0.98 (0.91–1.06)**
Keeping hand hygiene	1.25 (0.87–1.79)	1.47 (1.03–2.09) *	1.36 (0.99–1.88)	1.18 (0.87–1.59)
Using proper and clean worksite clothing	1.43 (0.58–3.54)	0.84 (0.37– 1.87)	1.06 (0.51–2.20)	0.58 (0.25–1.39)
Keeping water clean	1.84 (1.14–2.98) *	2.23 (1.39–3.56) *	2.04 (1.32–3.17) *	1.21 (0.85–1.73)
Cleaning and disinfection of work surfaces	1.10 (0.99–1.22)	1.05 (0.95–1.17)	1.07 (0.98–1.18)	0.96 (0.87–1.06)
Preventing cross-contamination	2.41 (1.53–3.80) *	1.97 (1.25–3.09) *	2.18 (1.48–3.22) *	0.82 (0.51–1.31)
Keeping meat safe	6.03 (2.96– 12.30) *	6.12 (3.01–12.43) *	6.08 (3.03–12.20) *	1.01 (0.77–1.34)
Worker health	1.50 (0.82–2.74)	2.05 (1.07–3.91) *	1.73 (1.03–2.92) *	1.36 (0.69–2.69)
Food safety training	4.78 (2.49–9.17) *	3.67 (1.92–7.04) *	4.19 (2.35–7.48) *	0.77 (0.42–1.39)

Note: aOR: adjusted odds ratio; overall: analysis without categorizing sample into its types; TNM: shops received training, nudges, and hygiene materials; TNMI: shops received training, nudges, hygiene materials and, were inspected, and ratings publicly displayed in the form of 'scores on doors'; intervention: comparing intervention groups combined (without classifying into TNM and TNMI) with control group; Using proper food contact surfaces were collected only through direct observation while worker health and food safety training were collected only through self-reports; *: statistically significant improvement at $P < 0.05$ (or confidence interval contained no unity).

4 Discussion

This food safety intervention is, to the best of our knowledge, the first to test effectiveness of food safety intervention packages (training, nudges, hygiene material provision, inspection with 'scores on doors') in improving meat handlers' food safety knowledge and practices and reducing microbial contamination in butcher shops in LMICs using an RCT study design. To the best of our knowledge, this intervention is also the first food safety intervention with development of its intervention design guided by behaviour change frameworks including the behaviour change wheel model with its capability, opportunity and motivation (COM-B) model, theoretical domains framework and behaviour change techniques taxonomy [38]. We also believe that this is the first food safety intervention to identify and incorporate potentially effective BCTs into its intervention process. Moreover, this is the first time that food business inspection with 'scores on doors' has been used as component of an intervention package of a food safety intervention.

This RCT assessed the effectiveness of a multifaceted food safety intervention comprising training, behavioural nudges, hygiene materials provision, and inspection with 'scores on doors' in improving meat handlers' food safety knowledge and practices and reducing *E. coli* contamination Consistent with the intervention objectives, we found that intervention shops demonstrated lower odds of *E. coli* contamination than control shops. Meat handlers from intervention shops also showed higher odds of adhering to proper food safety practices than those in control shops. Further, meat handlers working in intervention shops showed higher odds of providing correct answers to food safety questions than those in control shops.

We found a considerable reduction of *E. coli* contamination in all sample types from intervention shops compared with those from control shops. Intervention shops demonstrated 0.60 times lower odds of *E. coli* contamination than control shops, with TNM shops showing 0.62 times lower odds and TNMI shops showing 0.59 times lower odds. This reduction in microbial contamination that was due to intervention suggests that the intervention was highly effective considering the widespread cross-contamination in Ethiopian butcher shops. Several studies in Ethiopian butcher shops reported high contamination with bacterial foodborne hazards on meat handlers' hands [45,67], meat cutting boards [44,68,69], meat [44,67–69] and in washing water [45]. For example, Zelalem et al [67] found that *E. coli* prevalence in butcher shops was 82% on beef carcasses, 82% on knives and 65% on meat handlers' hands. Consistent with these findings, we found at our baseline (pre-intervention) that *E. coli* prevalence was 87% on beef carcass surfaces, 88% on meat handler hands, 81% on meat cutting boards, 81% on meat hanging boards and 23% in water routinely used in butcher shops. The intervention tested through this study improved food safety practices related to hand hygiene, prevention of cross-contamination, cleaning and disinfection of work surfaces, environmental sanitation, safe meat storage and use of safe water which could likely contributed to the observed reduction of *E. coli* contamination. For example, previous studies indicated that proper handwashing [70,71] and cleaning

and disinfection [72,73] reduced microbial contamination. We also trained butcher shop workers to apply chemical decontamination measures, including the use of electrolysed water (hypochlorous acid) for decontaminating meat and work surfaces. In addition, we introduced deep cleaning procedures and stepwise cleaning protocols, such as the use of colour-coded wiping cloths and cleaning buckets to match the level of surface contamination with cleaning steps. These practices likely improved the effectiveness of cleaning and disinfection and contributed to reduced microbial contamination.

However, comparing intervention with controls, although *E. coli* contamination was significantly reduced overall and on meat handlers' hands and meat hanging boards, the reductions were not statistically significant for beef carcass surfaces, meat cutting boards, or water samples. Several factors may explain the weaker effects of the intervention on these sample types. Microbial contamination of meat is common in Ethiopian slaughterhouses [44,45], leading to contaminated meat entering butcher shops [44,45,68,69] where cross-contamination is also widespread [44,45,68,69]. These findings suggest that improving microbial safety of meat at butcher shops may require direct decontamination with food-grade sanitisers, as basic GHPs alone may be insufficient. In this intervention, butcher shop workers were trained to apply food sanitisers (specifically electrolysed water [hypochlorous acid]) to decontaminate meat, however, the absence of a significant reduction in *E. coli* contamination on meat may indicate suboptimal decontamination of meat using the sanitisers. Each intervention shop received two spray bottles of electrolysed water (hypochlorous acid), sufficient to treat approximately two carcasses, with the intention of encouraging subsequent purchase and continued use. However, only a small number of shops procured additional supplies, despite information on sources and repeated visits during which vendors offered the product at a discounted price. Further, in butcher shops, all meat intended for sale is processed on meat cutting boards, resulting in cross-contamination, which likely limited improvements in the microbial safety of the cutting board. This cross-contamination influence was even exacerbated as samples were collected from cutting boards in their observed state upon arrival, without prior cleaning or wiping. Frequent handling increases cross-contamination [74] and food residues on contact surfaces such as cutting boards are associated with prolonged bacterial transfer [75,76].

Effectiveness of food safety interventions in LMICs have mostly been evaluated in terms of their effects on food handlers' food safety knowledge and/or practices [32,77–79], with only a few interventions evaluated for their effectiveness in reducing microbial contamination [49,50,80]. Consistent with our findings, these studies suggested their effectiveness in reducing microbial contamination. However, we are unable to make direct comparisons with our findings because of differences in study design (non-randomized or small sample size) and settings of these studies.

The intervention significantly enhanced adherence to proper food safety practices among meat handlers. Concerning observed food safety practices, intervention shops showed 1.32 times higher odds of adherence to food safety practices recommended through the training provided, compared with control shops; TNM and TNMI shops demonstrated 1.31 and 1.34 times higher odds, respectively. For self-reported food safety practices, the odds of compliance were 1.16 times higher in intervention shops. Although improvements were observed across all GHP domains, some domains did not reach statistical significance. These results mirror those of prior studies which have generally shown that food safety interventions improve food handlers' food safety practices [32,49,50].

Several factors may explain the observed improvements in meat handlers' food safety practices. We incorporated 30 behavioural change techniques (BCTs) into our intervention designing process which were mapped onto psychological capability, social and physical opportunity and, reflective and automatic motivation of the COM-B model, aiming to enhance knowledge and skills and motivation of meat handlers and environmental factors impacting meat handlers' adherence to proper food safety practices. We reported detailed description of BCTs used in this intervention elsewhere [38]. For example, we used various BCTs such as contextualizing training contents to butcher shops, using instructional materials that facilitate essential information processing and providing training at multiple sessions to enhance food safety knowledge of meat handlers. Increased knowledge can influence beliefs and intentions, encouraging adoption of desired behaviours [81–83]. Indeed, we found in this intervention that meat handlers from intervention shops showed 1.18 times higher odds of providing correct responses to food safety questions compared with those from control shops. We also incorporated BCTs including instruction on how to perform behaviour, demonstration of the behaviour and behavioural practice into our intervention to enhance meat handlers' beliefs about their capabilities in performing proper food safety practices. For example, during offsite training, they practiced proper handwashing and demonstration was provided on step-by-step cleaning and disinfection of work surfaces and disinfection of water with chlorine tablets. Additionally, we provided butcher shops guidelines on decontaminating meat with electrolysed water (hypochlorous acid), treating water with chlorine tablets and summary of what they learned in a booklet form [54] to improve their skills in proper food safety practices. If individuals believe they have the required knowledge and skills to perform a behaviour, they are more likely to enact the behaviour [30,81,83]. Whereas BCTs (such as information about health consequences, information about social and environmental consequences, pros and cons, comparative imagining of future outcomes, imaginary punishment and imaginary reward) were incorporated to the intervention design to enhance meat handlers' beliefs about consequences associated with food safety issues such as foodborne illness risks, importance of maintaining hygiene of their shops to attract customers and so on. Individuals are motivated to enact a behaviour when they value it and link some likelihood of consequences to the behaviour [83,84]. Further, we attempted to

motivate meat handlers to perform GHPs by providing feedback on their hygiene performance strengths and weaknesses, providing hygiene rating based on their hygiene level and repeatedly exposing to the contents of the intervention such as aligning contents across intervention packages. Studies show reinforcement systems such as rewards and feedback can motivate organizational workers to engage in the desired behaviours [10,85,86].

We also applied BCTs such as information about others' approval or expectation, creating enabling food safety ecosystem, adding objects to the environment (such as hygiene material provision, provision of instruction on how to conduct behaviours), restructuring the physical environment and prompts/cues to enhance food safety ecosystem of butcher shops associated with butcher shops, consumers and regulators. The provision of hygiene materials, on-the-job training of butcher shops, inspection of butcher shops and publicly displaying inspection ratings and posting food safety information at the butcher shops were implemented to enhance food safety practices of the shops. Posting food safety information at food work environment improved food handlers food safety practices [33,87]. One of the posters advised consumers what they should check regarding butcher shops hygiene to decide their meat purchase at the shops. Studies show consumers use food safety information to make informed purchase decisions [22,23,88]. We trained local food safety regulators in food safety and engaged them throughout our intervention which we believe would improve their food safety capacity [89]. Food safety training and interaction with stakeholders are key elements of national food control system [6,7,90].

Considering overall samples, one interesting finding is that TNMI shops demonstrated slightly higher performance in *E. coli* contamination reduction than TNM shops. Multiple factors could contribute to this higher performance of TNMI shops. We aligned GHPs in butcher shops inspection checklist with training contents to reinforce learning. During inspection, inspectors provided feedback to butcher shops on their strengths and weaknesses related to the GHPs, which could incentivize butcher shops to improve their hygienic practices. Research shows that food business inspection can also serve as a source of education on food safety for food business operators [91]. Food inspectors also encouraged butcher shops to publicly display their food hygiene ratings assuming to enhance consumers influence on butcher shops through their purchase behaviours based on the hygiene ratings posted [23,88]. Consumer influence is expected to be minimal given their limited familiarity with inspection ratings in the study area, however, publicly displaying ratings may still motivate shop operators to improve hygiene practices to align with their posted scores. Although comparisons between TNMI and TNM shops were conducted, the original sample size calculation was not specifically designed to evaluate performance differences between these two

experimental arms. As a result, the study may have had insufficient statistical power to detect meaningful differences between the groups.

5 Limitation of the study

Our study had some limitations. First, we implemented this intervention in a single city setting (Addis Ababa, capital city of Ethiopia), limiting our understanding of the effectiveness of the intervention package across diverse settings. We suggest future studies to implement the intervention in diverse settings to generate evidence of the effectiveness of the intervention in varying contexts. However, because food safety standards are set at the federal level and enforced through regional food and drug authorities, butcher shops nationwide are expected to follow similar GHPs and food safety principles, still supporting generalizability of our findings to butcher shops across the country. Second, our findings suggest that TNMI shops performed slightly better than TNM shops in *E. coli* contamination reduction, but the study was not designed with sufficient statistical power to detect these differences. Third, we did not assess the effectiveness of each of the components of our intervention (training, nudges, hygiene material provision, inspection with 'scores on doors') individually. As such, we are unable to draw conclusions about whether the use of any other combinations of these components or while used individually would be sufficient to achieve improvements in the food safety practices and microbial safety of shops. We recommend that future studies investigate each component or in different combinations from the current application to better understand effectiveness of the intervention components.

6 Conclusion

Findings of our intervention demonstrate that a food safety intervention which combines training, nudges, and provision of hygiene materials can be effective at improving food handlers' food safety knowledge and practices, leading to microbial reduction in foodservice establishments such as butcher shops. Our intervention findings further demonstrated that adding inspection with 'scores on doors' to this package of interventions could enhance its effectiveness further. This intervention package can be effective for improving food safety practices of food handlers having low level of education as over 95% of our participants had attained no more than a secondary education, and 60% had not gone beyond primary completion. Our findings also suggest that guiding the development of intervention design of food safety intervention by behaviour change frameworks and incorporating relevant BCTs to the intervention process could improve its effectiveness.

Results of our intervention demonstrated substantial reduction of *E. coli* contamination in butcher shops, however, weaker effects were observed in reducing the contamination on beef carcasses, cutting boards and

water. This reflects that our food safety intervention was effective at reducing public health risk from foodborne illnesses as reduced *E. coli* contamination would imply lower risk from other foodborne hazards. Our intervention also improved meat handlers' food safety knowledge across all domains; however, the improvement was statistically significant for knowledge related to only hand hygiene, cleaning and disinfection of work surfaces and keeping meat safe. Moreover, although the intervention showed statistically nonsignificant improvement of meat handlers' food safety practices linked to proper and clean worksite clothing, all other food safety practices demonstrated statistically significant improvement. These findings suggest that a food safety intervention that improved food safety knowledge of food handlers and applied various BCTs can be effective in improving multiple food safety practices.

We recommend that policymakers could consider using our tested intervention package to enhance GHPs and reduce microbial contamination in butcher shops and similar food service establishments. Our findings suggest enhancing food handlers' compliance with the food safety practice domains used in our intervention could enhance microbial safety of food handling environments. We also recommend that policymakers may consider adopting public disclosure ('scores on doors') of food safety inspection results of food businesses as part of the national food inspection system. We also suggest establishing regular food safety training programmes and certification for meat handlers working in butcher shops.

7 CRediT authorship contribution statement

GD: conceptualization, methodology, software, investigation, resources, validation, data curation, formal analysis, visualization, project administration, writing - original draft, writing- reviewing and editing. **SD:** investigation, supervision, project administration, writing- reviewing and editing. **DNM:** investigation, supervision, project administration, writing- reviewing and editing. **AMG**: methodology, investigation, resources, writing- reviewing and editing. **VH**: conceptualization, methodology, investigation, supervision, project administration, writing- reviewing and editing. **DG:** conceptualization, methodology, validation, investigation, resources, supervision, project administration, funding acquisition, writing- reviewing and editing. **AK:** methodology, investigation, validation, project administration, writing- reviewing and editing**.** **GTA:** conceptualization, methodology, investigation, resources, supervision, project administration, writing- reviewing and editing**. HN:** conceptualization, methodology, validation, investigation, supervision, project administration, funding acquisition, writing- reviewing and editing**.** **KA:** conceptualization, methodology, validation, investigation, supervision, project administration, writing- reviewing and editing.

8 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

9 Data availability statement

Data are available from the corresponding author upon reasonable request.

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