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# Potential use of ash and lye to sterilize farm tools contaminated with *Xanthomonas vasicola* pv. *musacearum*

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**Introduction:** Tool sterilization is a critical component of managing *Xanthomonas* wilt of banana, because it disrupts a key transmission pathway of the causal agent *Xanthomonas vasicola* pv. *musacearum* (*Xvm*). Despite the availability of several sterilization options, uptake by smallholder farmers remains limited due to high costs, low accessibility, and practical constraints under field conditions. To broaden feasible and low-cost options, we evaluated locally sourced wood ash and homemade lye solutions (ash mixed with water) as alternative decontaminants for farm tools.

**Methods:** In the laboratory, iron or steel made knife blades coated with *Xvm* from freshly cut banana stems were inserted into i) dry ash, ii) un-boiled lye and iii) boiled lye for 2, 8, 16, 24, 48 and 72 h. In addition, blades were scrubbed with iv) un-boiled or v) boiled lye that had been allowed to settle for the same time durations. Tools scrubbed with household bleach and *Xvm*-coated tools left in shade served as controls. Each treatment was replicated nine times across three independent experiments.

**Results:** No *Xvm* colonies were recovered from blades scrubbed with household bleach whereas high colony counts were consistently recovered from untreated controls. Complete elimination of *Xvm* was achieved after immersion in boiled or un-boiled lye for at least 24 h, compared with 48 h when using dry ash. Scrubbing contaminated blades with lye that had settled for  $\geq 24$  h resulted in total removal of *Xvm* and was comparable in efficacy to household bleach. Boiling the lye did not enhance its disinfectant activity.

**Discussion:** These findings demonstrate that wood ash and lye provide practical, inexpensive alternatives for tool decontamination and can complement existing disease-management strategies, improving the feasibility of *Xanthomonas* wilt control for smallholder banana farmers.

## KEYWORDS

alkali, banana, decontamination, infection, disease management, hydroxide, *Xanthomonas* wilt

## Introduction

Xanthomonas wilt (XW) of banana and plantain (*Musa* spp., hereafter called banana) causes rapid wilting and plant death, leading to significant yield losses that exceed 80% where control is delayed (Blomme et al., 2017; Blomme et al., 2023; Ocimati et al., 2019). The disease is caused by *Xanthomonas vasicola* pv. *musacearum* (*Xvm*), a Gram-negative bacterium (Yirgou and Bradbury, 1968; Yirgou and Bradbury, 1974; Young et al., 1978). Xanthomonas wilt of banana spreads primarily through using contaminated farm tools, infected planting material, and via insect vectors (Ocimati et al., 2013; Nakato et al., 2014). Cultural management practices such as early detection and the timely removal of infected plants (i.e., the application of Single Diseased Stem Removal (SDSR)), the use of clean planting material, and tool sterilization are used to prevent introduction, and to reduce and eliminate *Xvm* inoculum when infections occur (Blomme et al., 2014; Blomme et al., 2023; Ploetz et al., 2015).

Garden tool sterilization is a crucial element of banana XW disease management. When farmers handle infected banana mats, the bacterial exudate produced by *Xvm* readily contaminates metal cutting implements. Subsequent use of these contaminated garden tools on healthy mats facilitates an efficient and direct route for *Xvm* transmission within a farm (Ploetz et al., 2015; Blomme et al., 2023). Because tools are frequently shared among community members, or even transported over long distances by hired labour, they also facilitate inter-farm and inter-village spread (Nakato et al., 2013; Blomme et al., 2020). Laboratory studies have shown that *Xvm* can survive up to six days on non-stainless steel knives and up to twenty days on stainless steel blades (Blomme et al., 2014). Consequently, sterilizing tools after use on infected mats can prevent this transmission pathway.

Current disease-management protocols recommend two main sterilization methods: briefly exposing the metal blade to flames for 20–40 seconds or cleaning the blade using a household bleach solution (3.5 % sodium hypochlorite, NaOCl) (Blomme et al., 2014; Blomme et al., 2019; PROMUSA, 2020). In practice, however, smallholder farmers adopt these practices inconsistently, undermining the effectiveness of XW control packages (Blomme et al., 2014; Kikulwe et al., 2019). Key barriers include limited access to bleach in remote areas and the degradation of metal tool integrity after repeated heating (Blomme et al., 2014; Ocimati et al., 2021). To identify less burdensome alternatives, Ocimati et al. (2021) evaluated a broader suite of tool decontamination options. Simple washing with soap or detergent proved to be a straightforward and effective method, while immersion in boiling water for one minute also achieved satisfactory decontamination, though maintaining boiling water in the field can be impractical. Ocimati et al. (2021) also observed a reduction in *Xvm* population when tools were inserted into cold and hot ash, albeit the tools were kept in ash over short time durations of 40s to 6 h. Lye was not evaluated in the above study or any other study for decontamination of tools contaminated with *Xvm*. Building on these findings, we further investigate cold wood ash over a longer time duration and homemade lye solutions that are locally available resources as viable options for decontaminating farm tools contaminated with

*Xvm*. These alternatives aim to diversify and simplify sterilization practices, thereby improving adoption among smallholders.

Wood ash and the lye solution obtained by leaching water through wood ash are readily available in smallholder farming communities, making them inexpensive and locally accessible options for tool sterilization. Both ash and the resulting alkaline lye have well-documented disinfectant properties. In settings where soap is unavailable, ash can serve as an alternative for hand-washing and general hygiene (Paludan-Müller et al., 2020; Morgan et al., 2021). Its antimicrobial activity extends to water treatment, where ash has been shown to disinfect grey-water (Mbiza et al., 2025) and to function as a viable substitute for conventional chemical disinfectants (Shithi et al., 2024). The antimicrobial potency of ash has been attributed to its alkaline composition, rich in potassium and sodium carbonates that form hydroxides (NaOH, KOH) when leached, compounds well known for their disinfectant properties (Onyegbado et al., 2002; Babayemi et al., 2011; Shithi et al., 2024). This aligns with longstanding African practices of producing lye from plant ash for soap making and sanitation (Ogunbiyi and Enechukwu, 2021). Consequently, we assessed the effectiveness of ash and ash-based lye for decontaminating tools contaminated with *Xvm*, to identify practical and sustainable alternatives for tool sterilization in XW management programs.

## Materials and methods

The experiment was carried out under controlled laboratory conditions at the National Agricultural Research Laboratories (NARL) in Kawanda, Uganda. Metal knife blades artificially contaminated with a bacterial ooze containing *Xanthomonas vasicola* pv. *musacearum* (*Xvm*) were decontaminated by immersing them in three different substrates: (i) dry ash, (ii) unboiled lye (ash mixed with water), and (iii) previously boiled lye. Each substrate's efficacy was evaluated after exposure times of 2, 8, 16, 24, 48, and 72 hours. An additional sterilization method by scrubbing the blade with the same two lye preparations (i.e., unboiled and boiled) was assessed. Here the water and ash preparations were allowed to react for 2, 8, 16, 24, 48 and 72 hours, before use for scrubbing tools. It was hypothesized that the antibacterial potency of the lye would increase with time.

Dry-ash from burned charcoal sourced locally from within NARL was used for the study. To prepare lye, 900 g of this dry ash was blended with 700 mL of distilled water and mixed until fully homogenised. For the boiled variant, the lye was transferred to an aluminium pot, covered (to limit evaporative loss), and boiled for 15 minutes. After heating, the boiled lye was permitted to cool and used for tool sanitation after at least two hours following the boiling.

*Xvm* bacterial inoculum was sourced from *Xvm*-infected banana plants with XW-characteristic symptoms within a field at NARL, Uganda. *Xvm* produces a typical yellowish bacterial ooze within the vascular tissue of infected banana plants (Blomme et al., 2023), which was collected from cut pseudostems. The bacterial ooze was directly transferred using a soft paint brush onto the 5 cm tips of sterile metal knife blades, previously surface-sterilized with

70 % (v/v) ethanol and passed through a flame. The inoculated metal blade tips were then placed on plastic trays, at room temperature, for 30 minutes, to allow the bacterial smear to set and dry. Care was taken to distribute the ooze uniformly, resulting in an initial inoculum of approximately  $3.5 \times 10^6$  colony-forming units per millilitre (CFU mL<sup>-1</sup>).

Sterilisation of the contaminated knife blade tips was evaluated by inserting the coated blade sections in three different substrates housed in plastic containers: (i) dry wood ash, (ii) un-boiled lye, and (iii) boiled lye. The blades remained in each substrate for 2, 8, 16, 24, 48, or 72 hours, after which the surviving *Xvm* bacteria were recovered and quantified. In a parallel set of experiments, un-boiled and boiled lye that had been allowed to settle for the same time intervals (2–72 hours) were used to scrub the contaminated blades, immediately rinsed with distilled water, directly followed by recovery of residual *Xvm*. For each set of trial, a positive control consisting of contaminated knives left exposed on the workbench for each of the specified time intervals, and a negative control consisting of *Xvm* contaminated knives scrubbed with 3.5% Sodium hypochlorite (household bleach) were incorporated. Each treatment combination (3 substrates  $\times$  6 exposure times for immersion; 2 lye preparations  $\times$  6 settling times for scrubbing; control  $\times$  6 interval times) was performed on three knives per sterilisation cycle, and the entire series was repeated at three independent times.

After each treatment, residual *Xvm* was recovered by rinsing each side of the blades five times with 10 mL of double distilled water while scrubbing with a sterile soft paint brush, under a laminar flow hood. Separate sterilized brushes were used. The rinse water, now potentially containing the dislodged *Xvm* bacteria, was captured for subsequent quantification. Each suspension was first thoroughly mixed and then serially diluted to 10<sup>-2</sup>. From both the undiluted sample (10<sup>0</sup>) and the 10<sup>-2</sup> dilution, 10  $\mu$ L sub-samples were plated in three replicates onto 90 mm Petri dishes containing the non-selective yeast-peptone-glucose agar (YPGA) medium. The YPGA formulation (per litre of distilled water) comprised 5 g yeast extract, 5 g peptone, 10 g glucose, and 15 g agar (Schaad et al., 2001). Plates were incubated for 72 h at 28 °C, after which the number of *Xvm* colonies were recorded. When colonies coalesced, they were recorded as a smear. CFU for the original suspension were calculated for each replicate using the standard dilution-factor formula [(CFU in dilution  $\times$  dilution factor)/Volume plated (mL)]. The bacterial ooze from cut plants and *Xvm* characteristic colonies on media were confirmed to be *Xvm* using *Xvm*-specific AvP1 primers that amplify Avirulence protein KFA14425.1 genes (Nakato et al., 2018).

The effect of dry ash and lye on the aluminium cooking pans and the iron or steel made knives was monitored. To determine the risk of lye and dry ash to human skin, the technicians at separate times used lye to scrub a few knives or worked with dry wood ash without protective gloves.

## Data analysis

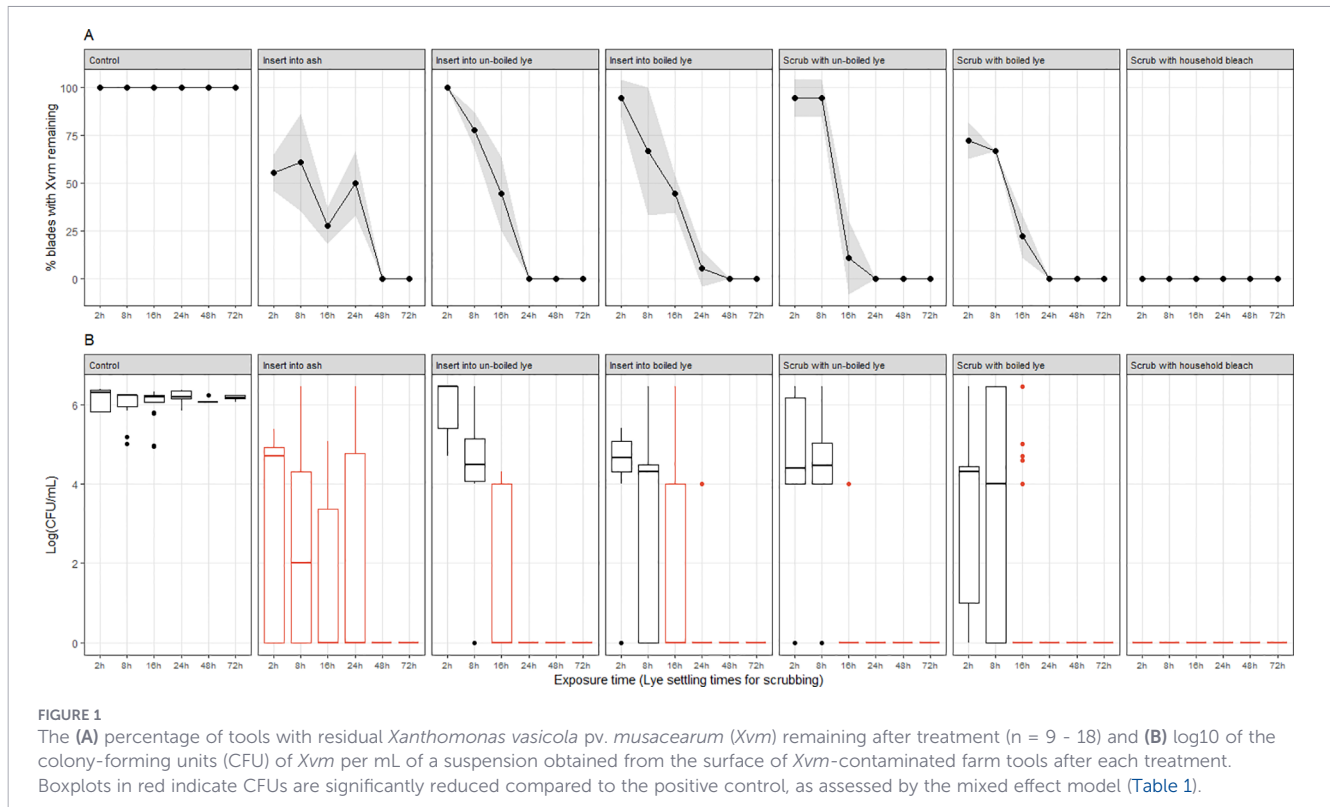
Some of the values ( $x$ ) of the *Xvm* colony forming units/counts (CFU) had zero values and thus each CFU value was transformed to  $x+1$  followed by a log<sub>10</sub>-transformation. A linear mixed-effects

model was employed to evaluate how the different treatment options affected *Xvm* colony counts (CFU) on knife blades. Because the *Xvm* inoculum originated from various pseudostem tissues, each with its own initial *Xvm* concentration, these sources were incorporated as nested random effects to control for that variability. Sterilization cycles were also modelled as random effects, while the log<sub>10</sub>-transformed CFU values served as the fixed effect of interest. The model was fitted with the 'lme' function from the 'nlme' package (Pinheiro et al., 2025; R Core Team, 2025). Random-effect structures were retained as they improved model fit, as judged by lower Akaike Information Criterion (AIC; Burnham and Anderson, 2002) and reduced residual standard error relative to a fixed-effects-only model (Pinheiro and Bates, 2000). Statistical significance of the fixed effect and estimated treatment contrasts were derived from the resulting p-values. Beyond quantifying overall CFU reductions relative to positive controls, the time required for each treatment to achieve complete *Xvm* elimination (CFU = 0) across all blade replicates, resulting from each substrate type and removal technique (insertion versus scrubbing) was examined.

## Results

Colony-forming units (CFU) of *Xvm* remained stable on the positive-control blades that were left exposed on the workbench throughout the 72-hour trial (Figure 1; Table 1). No *Xvm* was recovered from knives cleaned with household bleach, the conventional approach recommended for tool sterilization. Insertion into dry ash showed a significant reduction in CFU by 2 hours of immersion, yet 56% of the blades still harboured substantial residual *Xvm* (averaging 4.2% of the initial CFU). CFU continued to fall with increasing exposure time to dry ash, and by 48 hours no detectable *Xvm* remained on any replicate blade. Significant differences (5% LSD) were visible between the untreated controls and the dry ash treatment, whereas no significant differences were visible between ash treatment and tools cleaned with household bleach.

For all lye-based treatments, no significant ( $p > 0.05$ ) decrease in CFU compared to the control household bleach occurred during the first two sampling intervals (2 h and 8 h) or when scrubbed with lye left to react for 2h and 8h (Figure 1; Table 1). For tool inserted in to un-boiled and boiled lye, by the 16-hour mark, mean CFU values had dropped to zero, although 44% of blades still exhibited contamination. Similar observation occurred with tools scrubbed with un-boiled and boiled lye used 16-h after preparation, with 11% and 22% of blades, respectively, retaining detectable CFU. However, no significant differences occurred between tools cleansed by inserting in lye for at least 16 h or scrubbing with 16 h old lye and the conventional practice of using household bleach. At 24 h, sterilization by inserting knives into lye was essentially complete, with the sole exception of one blade inserted into boiled lye that still yielded colonies. In contrast, scrubbing with 24 h old lye eliminated all bacteria irrespective of whether the lye had been priorly boiled or not.



Consequently, the following conditions achieved full eradication of *Xvm* (no CFU detected): (i) scrubbing with lye preparations (un-boiled or boiled) aged 24–72 h, (ii) insertion into freshly prepared un-boiled lye for 24–72 h, (iii) insertion into freshly prepared boiled lye for 48–72 h, and (iv) insertion into dry ash for 48–72 h.

Dry ash had no effect on the Aluminium made cooking pans, iron or steel made knives and human skin. In contrast, Lye was corrosive to the Aluminium made pans and the human skin. Lye had no visible effect on the iron or steel made knives.

## Discussion

The experiment demonstrates that both wood ash and lye are effective in eliminating *Xanthomonas vasicola* pv. *musacearum* on metal tools. These results align with earlier work documenting the broad antimicrobial properties of alkaline agents, which compromise bacterial viability by disrupting cell-membrane integrity and denaturing essential proteins (McDonnell and Russell, 1999; Hijikata et al., 2016; Luvielmo et al., 2016). Lye's very high pH (typically > 12) creates an environment that destabilises the bacterial cell wall and inflicts irreversible damage on intracellular structures, leading to irreversible inactivation. Alkaline agents also lower the viscosity and weaken the biofilm created by Xanthan, a polysaccharide gum structure that protects *Xanthomonas campestris* (Luvielmo et al., 2016). Comparable alkaline-decontamination strategies have been applied for decontaminating livestock housing, food-processing equipment, and wastewater treatment systems (Štukelj et al., 2021; Shithi et al., 2024; Mbiza et al., 2025).

The fact that insertion into lye alone required a longer time to eliminate the bacteria whereas scrubbing with 24 h old lye immediately eliminated all the bacteria suggests that the chemical action of lye was complemented by the mechanical action of scrubbing. In hand washing trials, the mechanical act of rubbing hands with ash compared with rubbing hands with soap had comparable effects in reducing faecal coliform units/hand (Hoque et al., 1995; Baker et al., 2014). Mechanical scrubbing during cleaning of tools helps to reduce or remove biofilm i.e., the complex aggregation of bacteria adhering to surfaces of the tools in an exopolysaccharide matrix (Dvorak, 2008).

The duration of exposure to ash or freshly prepared lye is a key determinant of sterilisation success. When metal blades are inserted into buckets containing ash, a minimum of 48 hours is required to achieve complete inactivation (CFU = 0). In contrast, insertion into either boiled or un-boiled lye achieves the same result after 24 h. The longer exposure required for wood ash compared with lye can be attributed to its lower and more variable alkalinity, which is influenced by factors such as moisture content and ash composition.

The progressive increase in the disinfectant efficacy of both ash and lye with time is likely due to prolonged contact with alkaline conditions, allowing sufficient disruption of bacterial cells and complete inactivation. In addition, increasing contact time may be associated with a gradual rise in pH, further enhancing antimicrobial activity. For example, Mbiza et al. (2025) reported increased removal of coliform bacteria over time following the addition of ash to bathroom greywater. This improved removal coincided with an increase in pH from 7 to 12, with the maximum pH reached after approximately 2 h.

The relatively long exposure time required to achieve complete elimination of *Xvm* through tool immersion in lye or ash (24–48 h)

TABLE 1 Fixed effects of different methods of tool sterilization on the colony-forming units (log10 transformed) of *Xanthomonas vasicola* pv. *musacearum* (*Xvm*) per mL of a suspension obtained from the surface of *Xvm*-contaminated metal farm tools.

Treatments	Value	St. error	DF	t-value	p-value
(Intercept)	6.033	1.004	529.000	6.006	0.000
Control - 2h	0.107	1.420	23.000	0.076	0.940
Control - 8h	-0.071	1.423	23.000	-0.050	0.961
Control - 48h	0.148	1.420	23.000	0.104	0.918
Control - 24h	0.066	1.740	23.000	0.038	0.970
Control - 72h	0.137	1.740	23.000	0.079	0.938
Insert in dry ash - 2h	-3.272	1.420	23.000	-2.304	0.031
Insert in dry ash - 8h	-3.455	1.420	23.000	-2.433	0.023
Insert in dry ash - 16h	-4.726	1.420	23.000	-3.328	0.003
Insert in dry ash - 24h	-3.829	1.420	23.000	-2.696	0.013
Insert in dry ash - 48h	-6.033	1.740	23.000	-3.468	0.002
Insert in dry ash - 72h	-6.033	1.740	23.000	-3.468	0.002
Insert in un-boiled lye - 2h	-0.057	1.740	23.000	-0.033	0.974
Insert in un-boiled lye - 8h	-2.276	1.421	23.000	-1.602	0.123
Insert in un-boiled lye - 16h	-4.188	1.740	23.000	-2.407	0.025
Insert in un-boiled lye - 24h	-6.033	1.420	23.000	-4.247	0.000
Insert in un-boiled lye - 48h	-6.033	1.740	23.000	-3.468	0.002
Insert in un-boiled lye - 72h	-6.033	1.740	23.000	-3.468	0.002
Insert in boiled lye - 2h	-1.576	1.420	23.000	-1.109	0.279
Insert in boiled lye - 8h	-2.877	1.740	23.000	-1.654	0.112
Insert in boiled lye - 16h	-4.049	1.420	23.000	-2.851	0.009
Insert in boiled lye - 24h	-5.810	1.420	23.000	-4.091	0.000
Insert in boiled lye - 48h	-6.033	1.740	23.000	-3.468	0.002
Insert in boiled lye - 72h	-6.033	1.740	23.000	-3.468	0.002
Scrub with un-boiled lye - 2h	-1.344	1.420	23.000	-0.946	0.354
Scrub with un-boiled lye - 8h	-1.613	1.420	23.000	-1.136	0.268
Scrub with un-boiled lye - 16h	-5.588	1.740	23.000	-3.212	0.004
Scrub with un-boiled lye - 24h	-6.033	1.420	23.000	-4.247	0.000
Scrub with un-boiled lye - 48h	-6.033	1.740	23.000	-3.468	0.002
Scrub with un-boiled lye - 72h	-6.033	1.740	23.000	-3.468	0.002
Scrub with boiled lye - 2h	-2.754	1.420	23.000	-1.939	0.065
Scrub with boiled lye - 8h	-2.507	1.420	23.000	-1.765	0.091
Scrub with boiled lye - 16h	-5.009	1.413	23.000	-3.544	0.002
Scrub with boiled lye - 24h	-6.033	1.420	23.000	-4.247	0.000
Scrub with boiled lye - 48h	-6.033	1.740	23.000	-3.468	0.002
Scrub with boiled lye - 72h	-6.033	1.740	23.000	-3.468	0.002
Scrub with household bleach - 2h	-6.033	1.420	23.000	-4.247	0.000
Scrub with household bleach - 8h	-6.033	1.740	23.000	-3.468	0.002
Scrub with household bleach - 16h	-6.033	1.420	23.000	-4.247	0.000
Scrub with household bleach - 24h	-6.033	1.420	23.000	-4.247	0.000
Scrub with household bleach - 48h	-6.033	1.740	23.000	-3.468	0.002
Scrub with household bleach - 72h	-6.033	1.740	23.000	-3.468	0.002

Selected model with nested random effect: AIC = 2007, RSE = 1.182; compared to null model: AIC = 2167, RSE = 1.448.

means that, tools remain unavailable to the farmers for up to two days. This limitation that may be acceptable only after field operations have been concluded. During field management, particularly when working consecutively on *Xvm*-infected and healthy banana plants, insertion of tools is not practical. A more practical approach is to keep pre-prepared lye on-hand and scrub tools directly in the field. If lye is prepared at least 24 h in advance, thorough scrubbing followed by a water rinse eliminates detectable *Xvm* (no residual CFU) regardless of whether the lye was boiled or not. This approach makes lye-based sterilization comparable to currently recommended practices such as the use of household bleach, flame sterilization, or washing tools with soap (Ocimati et al., 2021).

An additional advantage of lye is its stability during storage. Pre-prepared lye can be stored for extended periods without significant loss of efficacy. For instance, Shithi et al. (2024) reported that lye stored for up to six months exhibited only minor changes in pH ( $\pm 0.5$ ), indicating sustained alkalinity and disinfectant potential.

When preparing lye for sterilization through scrubbing, boiling does not confer a meaningful advantage in sterilising potency. Farmers can therefore cleanse tools routinely in the field by scrubbing with 24-hour-old lye immediately followed by a water rinse, ensuring continuous availability of their implements while maintaining effective disease control.

Practical implementation must take the corrosive nature of concentrated lye into account, so safe handling procedures are essential. In the trial, aluminium pans used to boil and contain the lye got corroded, and technicians reported skin irritation after scrubbing with lye without protective gloves. Therefore, it is recommended to mix and store lye in plastic buckets. The boiling step in the aluminium pan can be omitted because it did not improve sterilisation potency. Scrubbing using bare hands was done on a large number of blades consecutively during the trial, which is likely not representative for routine field work. When scrubbing tools, farmers could be advised to wear disposable nitrile or rubber gloves, or at a minimum rinse their hands thoroughly with water after each cleaning session to remove any residual lye. Importantly, the knife blades themselves, generally made of iron or steel, showed no signs of corrosion after repeated exposure, suggesting that standard agricultural steel or iron made tools can tolerate the shorter exposures to lye without degradation.

However, several limitations of this study warrant consideration. First, ash used in the experiments was obtained from a single source, and ash from different substrates may vary in chemical composition, alkalinity, and disinfectant efficacy. Second, the experiments were conducted under controlled laboratory conditions, which may not fully capture field realities. Under farmer-managed conditions, variation in factors such as lye dilution, duration and rigor of scrubbing, and availability of water could influence effectiveness. In addition, the bacterial loads applied to knife blades in this study were deliberately high to ensure consistent contamination, whereas under field conditions, lower levels of bacterial ooze are more likely to be encountered. Furthermore, the mechanical shear generated during cutting of banana tissues may reduce bacterial loads on tools, potentially

enhancing the effectiveness of ash- and lye-based sterilization in practice.

Future research should address these gaps by evaluating the performance of ash and lye under field and farmer-managed conditions, including across different ash sources, preparation methods. Additional studies should assess the efficacy of lower lye concentrations, quantify the contribution of mechanical cleaning during cutting, and examine the cost-effectiveness of these lye alternatives relative to conventional tool sterilization methods. Such work would strengthen the evidence base for scaling up ash- and lye-based practices within integrated *Xanthomonas* wilt management programs.

## Conclusion

Immersion of contaminated tools in dry wood ash or lye required 48 h and 24 h, respectively, to eliminate *Xvm* from blade surfaces. Under field conditions, this approach is only practical where farmers cut diseased plants during a single field operation before leaving tools immersed for extended periods. In contrast, scrubbing tools with pre-prepared lye that had settled for at least 24 h resulted in complete elimination of *Xvm*, making this method comparable to household bleach and other currently recommended tool decontamination practices. Boiling lye did not confer any additional disinfectant advantage and is therefore not recommended, particularly given its corrosive effects on aluminium containers. Care is also required to prevent skin irritation during handling, and the use of protective gloves is strongly advised.

Overall, tool sterilisation with wood ash or lye provides a practical, low-cost complement to existing strategies for limiting the spread of *Xvm*, especially where commercial soaps or detergents are unavailable (Ocimati et al., 2021). Because both ash and lye are inexpensive, locally sourced, and pose minimal environmental risk, they can be readily incorporated into broader banana XW disease-management programmes.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

WO: Writing – original draft, Data curation, Writing – review & editing, Investigation, Conceptualization, Methodology, Validation, Supervision. EK: Software, Writing – review & editing, Writing – original draft, Formal Analysis, Visualization. GO: Formal Analysis, Visualization, Software, Writing – review & editing. GB: Resources, Project administration, Conceptualization, Writing – review & editing, Funding acquisition, Supervision.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Correction note

This article has been corrected with minor changes. These changes do not impact the scientific content of the article.

## Generative AI statement

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