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# Hot water immersion disinfests enset (*Ensete ventricosum*) suckers from the enset root mealybug *Cataenococcus ensete* Williams and Matile-Ferrero

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**The enset root mealybug, *Cataenococcus ensete* Williams and Matile-Ferrero (Homoptera: Pseudococcidae) is a pest of national significance attacking enset in south and south-western Ethiopia. Adults and nymphs of several overlapping generations feed on the crops' underground corms and roots, making them hard to reach and thus control. The main means of pest spread is through infested planting material. The objective of this study was to evaluate the effect of a hot water treatment of enset suckers against enset root mealybugs. Small, medium and large-sized infested enset suckers were each exposed to water temperatures of 21, 55, 75 and 95°C for periods of 10, 30, 60 and 300 s. Complete mealybug mortality was obtained for 60 s at 55°C and at 10 and 30 s exposure times at 75 and 95°C without affecting the performance of enset suckers of all size groups. Considering the ease of using boiling water for small-scale enset farmers, immersing suckers for at least 10 and up to 30 s at 95°C is advocated in order to eliminate all enset root mealybugs from enset suckers. The immersion of enset suckers in boiling water for 10 to 30 s can be easily demonstrated, with a much higher envisaged adoption rate by farmers.**

**Key words:** Enset corm, enset roots, Ethiopia, integrated pest management (IPM), mortality, pseudostem, survival.

## INTRODUCTION

Enset (*Ensete ventricosum* (Welw.) Chessman) is mainly cultivated across south and south-western Ethiopia on a total land area estimated to be around 300,000 ha (CSA, 2011). It is a multipurpose crop which is used as a source of food, feed, fibre, construction material and often also for medicinal purposes (Shigeta, 1996). It is estimated that more than 20 million Ethiopians, belonging to over 45 ethnic groups inhabiting the highlands of southern, south-western and central Ethiopia depend on enset as a major or co-major staple food (Brandt et al., 1997; CSA, 2004).

Numerous biotic and abiotic constraints affect enset cultivation. Important abiotic constrains are drought especially during the latter part of the 6 to 7 month dry season and frost at high (>3000 masl) elevation sites mainly during December and January. Among the biotic constraints, Xanthomonas wilt of enset has been affecting

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enset cultivation since several decades and is considered the most important biotic constraint (Castellani, 1939; Yirgou and Bradbury, 1968; Welde-Michael et al., 2008; Blomme et al., 2017).

The enset root mealybug (*Cataenococcus ensete* Williams and Matile-Ferrero) is a major destructive insect pest of enset in southern, south-western and central Ethiopia having been first reported at Wonago (Tsedeke, 1988; Addis et al., 2008). The pest has not been reported on banana in Ethiopia (Addis, 2005, personal communication). Enset root mealybugs have an elongate-oval body covered with bright white wax secretions on the dorsal and lateral sides. Although the insect has been present in various parts of the enset growing belt, it has only become a serious threat to enset production since around 2000 (Addis, 2005). Although empirical yield loss data are not available, more than 30% of the enset farms visited in southern and south-western Ethiopia were infested with enset root mealybugs (Addis et al., 2008). Similarly, Kefelegn et al. (2014) reported that 26% of sampled farms were infested with enset root mealybugs and enset root mealybug counts per plant were respectively 64, 51 and 76 in the Dilla Zuria, Gedeb and Wonago districts of southern Ethiopia. The insect attacks enset of all age groups, but based on field observations and farmer feedback, 2-4 year old plants were more frequently found to be infested with this pest (Kefelegn et al., 2014).

In addition, Mulualem and Walle (2014) and Kefelegn et al. (2014) reported variation in susceptibility or tolerance of enset landraces to the enset root mealybug. Enset root mealybug symptoms include slow plant growth, a lack of vigor and eventual plant death, especially under moisture-stress. Kefelegn et al. (2014) reported that corm and root damage was highest during the dry and hot period of the year. These authors also reported that the majority of farmers can only recognize enset root mealybug symptoms once severe plant damage occurs. Infested plants often display retarded growth with dried out outer leaves, but with a green central shoot. Enset plants attacked by root mealybugs have a significantly lower number of roots as compared to healthy plants. As a result, mealybug-damaged enset plants are more easily uprooted. The mealybugs are mainly spread across farms, villages and regions through infested planting materials (Addis et al., 2008). Enset corms used for the production of new suckers may be infested with enset root mealybugs. The mealybugs often remain unnoticed by farmers and are consequently distributed to new regions and farms through exchange or sale in the market of infested planting materials (Bizuayehu, 2002). The production of mealybug-free clean planting materials is the key control measure used to manage enset root mealybugs. Transplanting contaminated planting material also facilitates mealybug spread (Azerefegne et al., 2009). Kefelegn et al. (2014) assessed farmer's indigenous knowledge on how to manage/control enset root mealybugs. The authors reported that farmers practice clean seedling selection, use of farmyard manure, increasing soil moisture, uprooting the infested plants and burning the hole, removing alternative hosts, control of ants and variety selection.

A number of techniques have been developed to protect or disinfest banana suckers (*Musa* planting materials) from pests and pathogens (Speijer, 1999). Insecticides can be used to control root mealybugs. However, the high cost of insecticides and their often unavailability to resource poor subsistence farmers, residues on the corms and the possible development of resistance justify the search for new strategies. Moreover, enset is often intercropped with coffee and the application of insecticides is against the norm of organic coffee production. A combination of hot water treatment with insecticides is often used for quarantine security work to eliminate pests such as mealybugs, aphids, thrips, soft scales and ants (Hara et al., 1995; Hu et al., 1996). Exposure of weevil [larvae] and nematode-infested banana and plantain suckers to hot or boiling water for varying time durations has been used to obtain clean planting materials (Colbran, 1967; Gold et al., 1998; Speijer et al., 1999; Hauser, 2000, 2007; Tenkouano et al., 2006). Immersion of pared banana or plantain suckers in boiling water for at least 20 s and up to 30 s has been advised for the control of nematodes and weevil larvae (Coyne et al., 2010). Enset root mealybugs (*C. ensete* Williams and Matile-Ferrero) are currently not a pest on banana in Ethiopia and other countries in Africa (Blomme et al., 2017, personal communication). Another root mealybug *Geococcus* spp. has been reported in Kerala, India on banana. Various control options (e.g. soil ameliorants, botanicals, chemical insecticides and fungal bio-agents) were screened against this banana root mealybug (Smitha and Maicykutty, 2010). However, a hot/boiling water treatment for the control of *Geococcus* spp. on banana has not yet been reported in literature. In Ethiopia, the optimum hot water temperature and immersion duration for disinfesting enset suckers from root mealybugs without jeopardizing the growth and vigour of enset suckers has not yet been assessed. Therefore, this study was carried out in Ethiopia to evaluate the effectiveness of hot water immersion at different temperature levels and exposure durations for the control of enset root mealybugs. In case multiple effective options/combinations are obtained, ease of adoption by farmers will guide optimum temperature by immersion duration combination selection.

## MATERIALS AND METHODS

### Collection of infested enset plants and assessment of plant size and infestation level

Two to three-year old enset plants of the landrace 'Genticha' highly infested with enset root mealybugs were uprooted and collected from numerous farms in Aleta Wondo in the Sidama Zone, and Yirga Cheffe and Kocherre in the Gedeo Zone, southern Ethiopia. A total of over 600 plants were collected. The aboveground part of the plants was cut at a height of 20 cm above the corm. In addition, dried up pseudostem leaf sheaths were trimmed off. All the cord roots were gently cut at their junction point with the corm using a knife and all decayed plant debris was removed from the corms together with the soil. Only infested plants/corms were retained. Subsequently, the plants were categorized into three size classes: small (a pseudostem circumference at soil level of <15 cm), medium (15-30 cm) and large (31-45 cm). A total of 160 infested suckers were randomly selected from each size class, totalling 480 suckers for the overall experiment. The average number of adult enset root mealybugs in each size class was estimated by counting the adult mealybugs on 40 selected enset plants from each size class (that is, 25% of corms). Suckers were moved from one heap to another heap and each $4^{th}$ sucker was used for mealybug counts. On average, 58, 72 and 116 adult mealybugs/plant were found on the small, medium and large enset corm classes, respectively.

#### Thermal water treatments

Eighty litres of tap water were heated to 55, 75 and 95°C (that is, boiling water; 95°C as a result of the higher elevation at Hawassa, that is, 1665 m above sea level) on a wood-fired stove in a 100 L metal barrel. A volume of 20 L was left for the displacement of water while immersing 10 enset plants of the same size class at a time. The required temperature was inspected with a thermometer immersed in the water. When the water reached the required temperature ten enset suckers of each size class kept in a locally-made woven-leaf basket were entirely immersed in the hot water for each of the exposure durations of 10, 30, 60 and 300 s. Immersion of the three classes of enset plants (10 plants per treatment) in water at room temperature (21°C) was included as a control. After the thermal treatments, the suckers were planted in plastic pots of 25 cm diameter and 20 cm in height, having drainage holes in the bottom and filled with 8 kg of soil free from mealybug infestation. The soil was collected from the same site as the enset suckers and kept in sealed plastic bags for more than a month before transferring to pots in order to avoid any infestation from the soil. The insects cannot survive for more than three weeks in the absence of a host (Addis et al., 2008). The potted suckers were maintained in a semi-controlled greenhouse for 120 days and watered as required/when the soil was no longer moist. The screenhouse protected the plants from adverse weather conditions (e.g. heavy rain and related flooding) and from nocturnal animals which often eat corm parts such as porcupines and mole rats.

#### Data collection and analysis

Four months after planting the treated enset suckers, plant above and below ground growth traits were assessed. The enset plants were assessed visually and plants with fresh and green leaf laminas, pseudostem, corm and roots were considered as having survived the hot water treatment. For these surviving plants, plant height was measured from the ground (soil surface) to the lowest part of the petiole of the last emerging leaf (Tsegaye and Struik, 2003). Plants were subsequently dug up and the number of cord roots of each surviving plant in each treatment was recorded by counting all healthy-looking and functional cord roots. In addition, data were collected on the number of adult mealybugs present. All cord roots and dead corm tissues were carefully lifted up/removed in order to count each and every mealybug.

The overall effects of water immersion temperature and exposure duration were categorized into two effectiveness classes: treatments which completely disinfested enset from the root mealybug but with no death of enset suckers were categorized as “Effective”, while those treatments for which root mealybugs survived or caused any death of enset suckers as “Not effective”. The data were analysed as a two-factor experiment (temperature and exposure durations) in a completely randomised design per enset class size using Minitab (Minitab Inc., 2010). Treatment means were separated using Tukey’s honestly significant difference test (HSD) ($p< 0.05$). Percent whole plant dry weight gain was calculated per plant size class, by comparing the total dry weight of the 21°C treatment (control) with the other treatment and exposure duration combinations.

## RESULTS

### Effectiveness of hot water immersion to disinfest enset suckers from root mealybugs

The hot water treatment had varied effects on the survival of enset plants (Table 1). The survival of small, medium and large-sized enset suckers was not affected when immersed in water at 21°C for all exposure durations. Similarly, exposing the three size classes to all temperature treatments for up to 30 s did not affect plant survival. Reductions in plant survival started to appear at 75 and 95°C with exposure periods starting from 60 s. The 55°C hot water treatment did not affect the survival of the large sized enset plants, but it decreased the survival of both small and medium sized plants by 10% when exposed for 300 s (Table 1).

The 75°C thermal treatment reduced survival of the small sized plants to 70 and 10% for 60 and 300 s exposures, respectively, and survival of medium sized enset plants to 90 and 70%, respectively (Table 1). The survival of the large sized plants was not affected by a 300 s exposure. The boiling water treatment severely affected the survival of young enset plants. Only 60% of the small sized plants tolerated 95°C treatment for 60 s, while all of them died when exposed for 300 s. For the medium sized enset, 80 and 20% survived the 95°C treatment for durations of 60 and 300 s, respectively. The survival of the large sized enset was not affected at 95°C for durations up to 30 s, while 10 and 20% of plants died when exposed for 60 and 300 s, respectively. On the other hand, the complete removal of mealybugs was found at 55°C for 60 s and at 75 and 95°C for 10 and 30 s without affecting enset suckers of all size groups and was considered effective (E) (Table 1).

### Effect of hot/boiling water immersion on the growth of small-sized suckers

The small-sized enset suckers achieved significantly greater plant height, leaf dry weight and pseudostem dry weight for the hot water immersion treatment combinations of 55°C for 60 s, 75°C for 10 and 30 s, and 95°C for 10 and 30 s (Table 2). On the other hand, the temperature levels of 75 and 95°C for 300 s resulted in a significantly lower performance of the above-ground plant parts. Similar observations were also made for the below ground plant traits. The small enset suckers immersed in water at 21°C had an average total plant dry weight of 53 g/plant at 120 days post treatment, while it was around or > 100 g/plant for the combinations of 55°C for 60 s, 75°C

**Table 1.** Effectiveness of hot water immersion to disinfest enset suckers from enset root mealybugs. (The first number in parenthesis denotes the number of surviving mealybugs, while the second number after the comma represents the percentage of surviving suckers). Ten plants were assessed for each treatment combination.

| Water temperature(°C) | Exposure time(s) | Size of enset sucker | | |
|---|---|---|---|---|
| | | Small | Medium | Large |
| 21 | 10 | NE*(89,100) | NE (97,100) | NE (152,100) |
| | 30 | NE (93,100) | NE (103,100) | NE (128,100 |
| | 60 | NE (85,100) | NE (99,100) | NE (134,100) |
| | 300 | NE (88,100) | NE (112,100) | NE (169,100) |
| 55 | 10 | NE (9,100) | NE (14,100) | NE (24,100) |
| | 30 | NE (7,100) | NE (6,100) | NE (9,100) |
| | 60 | E (0,100) | E (0,100) | E (0,100) |
| | 300 | NE (0,90) | NE (0,90) | E (0,100) |
| 75 | 10 | E (0,100) | E (0,100) | E (0,100) |
| | 30 | E (0,100) | E (0,100) | E (0,100) |
| | 60 | NE (0,70) | NE (0,90) | E (0,100) |
| | 300 | NE (0,10) | NE (0,70) | E (0,100) |
| 95 | 10 | E (0,100) | E (0,100) | E (0,100) |
| | 30 | E (0,100) | E (0,100) | E (0,100) |
| | 60 | NE (0,60) | NE (0,80) | NE (0,90) |
| | 300 | NE (0,0) | NE (0,20) | NE (0,80) |

*E=Effective (no root mealybugs and 100% survival of enset suckers), NE=Not effective (surviving root mealybugs or less than 100% survival of enset suckers).

for 10 and 30 s and 95°C for 10 and 30 s (Table 2). Weight gain of small enset suckers (compared to the 21C treatment) increased by 100, 90, and 86% for the treatments of 55°C for 60 s, 75°C for 10 s and 95°C for 10 s, respectively (Table 2).

## Effect of hot/boiling water immersion on the growth of medium-sized suckers

Medium-sized enset suckers grew significantly better when treated at 55°C for 60 and 300 s and at 75 and 95°C for both 10 and 30 s (Table 3). As with the small-sized suckers, combinations of 75 and 95°C for 300 s significantly reduced all the above-ground performance parameters. On the other hand, the enset plants treated with water at 21°C (control) for all exposure periods had intermediate performance levels. They were only better than the treatments with the highest temperatures and longest exposure durations (75 and 95°C at 60 and 300 s), which caused very poor growth or mortality of the enset plants. Similar observations were made for the below ground plant growth traits (Table 3). The treated medium-sized suckers also had heavier corms as compared to the control groups treated with water at 21°C (except for the 75 and 95°C with 300 s exposure duration combinations). These corms attained up to around 70 g/plant and about 150 g/plant total dry weight, respectively (Table 3). Higher whole plant weight gains were recorded for the medium-sized suckers with treatments of 55°C for 60 s (70%), 75°C for 10 and 30 s (77%), and 95°C for 10 and 30 s (76 and 78%) (Table 3).

## Effect of hot/boiling water immersion on the growth of large-sized suckers

Similar trends in temperature effects were observed on the above- and below ground plant growth traits of the large-sized enset suckers (Table 4). The large-sized plants grew significantly better when treated at 55°C for 60 and 300 s and at 75 and 95°C for 10 and 30 s (Table 4). As with the small and medium-sized suckers, combinations of 75 and 95°C for 300 s significantly reduced all the above-ground growth traits (Table 4). Similar observations were made as for the medium-sized suckers when comparing the control suckers with the treated ones. The large-sized enset suckers achieved about a 57-58% total plant dry weight gain when treated at 75 and 95°C hot water for 10 and 30 s (Table 4).

## DISCUSSION

This study revealed that enset suckers could tolerate higher temperatures (75 and 95°C) for only shorter

**Table 2.** Effect of hot water treatment on above and below ground plant traits for small-sized enset suckers infested with enset root mealybugs at 120 days post treatment. 10 plants were assessed per water temperature level and immersion time.

| Water temperature (°C) | Exposure time (seconds) | Plant height (cm) | Leaf DW# (g) | Pseudostem DW (g) | N° of cord roots | Corm DW (g) | Root DW (g) | Total plant DW (g) | Whole plant dry weight gain compared to the 21°C treatment (%) |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 10 | 23.3$^{b}$* | 12.1$^{a}$ | 13.5$^{a}$ | 6.3$^{a}$ | 22.2$^{a}$ | 5.4$^{a}$ | 53.2$^{d}$e | |
| | 30 | 23.2$^{b}$ | 12.0$^{a}$ | 13.6$^{a}$ | 6.4$^{a}$ | 22.1$^{a}$ | 5.4$^{a}$ | 53.1$^{d}$e | |
| | 60 | 23.3$^{b}$ | 12.1$^{a}$ | 13.5$^{a}$ | 6.2$^{a}$ | 22.2$^{a}$ | 5.4$^{a}$ | 53.2$^{d}$e | |
| | 300 | 23.4$^{b}$ | 12.2$^{a}$ | 13.6$^{a}$ | 6.3$^{a}$ | 22.2$^{a}$ | 5.3$^{a}$ | 53.3$^{d}$e | |
| 55 | 10 | 24.2$^{b}$ | 13.5$^{a}$ | 20.4$^{c}$ | 8.8$^{a}$ | 31.9$^{c}$ | 6.4$^{a}$ | 72.2$^{abcd}$ | 35.7 |
| | 30 | 25.7$^{ab}$ | 16.0$^{b}$ | 24.7$^{c}$ | 10.9$^{a}$ | 35.0$^{c}$ | 7.2$^{a}$ | 82.9$^{abcd}$ | 55.8 |
| | 60 | 29.3$^{ab}$ | 22.1$^{b}$ | 31.7$^{b}$ | 13.1$^{b}$ | 44.6$^{b}$ | 8.2$^{a}$ | 106.6$^{a}$ | 100.4 |
| | 300 | 26.8$^{ab}$ | 18.1$^{b}$ | 23.1$^{b}$ | 11.5$^{b}$ | 32.3$^{c}$ | 6.5$^{a}$ | 80.0$^{abcd}$ | 50.4 |
| 75 | 10 | 38.8$^{a}$ | 20.0$^{b}$ | 28.60 | 12.8$^{b}$ | 44.8$^{b}$ | 7.8$^{a}$ | 101.2$^{ab}$ | 90.2 |
| | 30 | 39.1$^{a}$ | 19.4$^{b}$ | 27.9$^{b}$ | 12.2$^{b}$ | 43.4$^{b}$ | 7.7$^{a}$ | 98.4$^{abc}$ | 85.0 |
| | 60 | 22.9$^{b}$ | 15.2$^{b}$ | 17.9$^{b}$ | 8.6$^{a}$ | 24.2$^{d}$ | 4.8$^{a}$ | 62.1$^{bcd}$ | 16.7 |
| | 300 | 2.7$^{c}$ | 2.2$^{c}$ | 3.1$^{d}$ | 1.2$^{c}$ | 3.6$^{e}$ | 0.7$^{b}$ | 9.6$^{ef}$ | -82.0 |
| 95 | 10 | 38.9$^{a}$ | 19.8$^{b}$ | 27.7$^{b}$ | 12.4$^{b}$ | 43.6$^{b}$ | 7.7$^{a}$ | 98.8$^{abc}$ | 85.7 |
| | 30 | 38.4$^{a}$ | 19.2$^{b}$ | 27.2$^{b}$ | 12.6$^{b}$ | 43.9$^{b}$ | 7.6$^{a}$ | 97.9$^{abc}$ | 84.0 |
| | 60 | 21.4$^{b}$ | 11.4$^{a}$ | 16.8$^{b}$ | 7.7$^{a}$ | 22.7$^{d}$ | 4.5$^{a}$ | 55.4$^{cd}$ | 4.1 |
| | 300 | 0.0$^{c}$ | 0.0$^{c}$ | 0.0$^{d}$ | 0.0$^{c}$ | 0.0$^{e}$ | 0.0$^{b}$ | 0.0$^{f}$ | -100 |
| Fpr | | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | |

#: DW: dry weight
*: means followed by the same letter are not significantly different according to Tukey's HSD test (p<0.05).

durations (<30 s) irrespective of their sizes. However, the larger sized suckers tolerated higher temperatures and exposure durations better than the smaller ones. Immersion of the enset suckers in tap water at a temperature of 21°C did not kill the mealybugs on suckers of all sizes (Table 1). However, few mealybugs survived on suckers treated at 55°C for 10 and 30 s. On the other hand, the 75 and 95°C hot water treatments killed all the mealybugs within 10 s.

Insects feeding on plants vary in their ability to survive thermal treatments. Water temperatures of 49°C and above have been shown to kill external insect pests in less than 10 minutes (Sharp, 1994). Researchers in Hawaii found that a 10 min immersion of cut flowers in 49°C achieved 100% mortality of all stages of *Pseudulacaspis cockerli* (Cooley) and *Coccus viridis* (Green) (Hara et al., 1997). They also found that a 12 min immersion in 49°C water eliminated 95% of ants, aphids, and mealybugs on red ginger flowers, *Alpinia purpurata* (Vielli). In another study, a hot water immersion treatment of 20 min at 49°C was effective in killing mealybugs and all other arthropods found externally on limes, or under the calyx of the fruit, and there were no surviving insects or mites (Gould and McGurie, 2000). For the long tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozetti), an estimated 19 minutes was required to reach 99% mortality on persimmons (*Diospyros kaki* L.) dipped in 49°C hot water (Lester et al., 1995). Researchers in New Zealand found that two-spotted spider-mites were more resistant to heat and required 40 min at 48°C to reach 99% mortality (Lester et al., 1995). In this study, the enset root mealybug was not able to survive a 55°C water treatment for one minute, while at 75 and 95°C complete mortality of mealybugs was obtained within 10 s. This study showed that certain combinations of water temperature and exposure duration can completely kill the insect pest without causing any damage to the plant. Hot water temperatures at 55°C for one minute, and at 75 and 95°C for 10 or 30 s can be used on small, medium and large-sized enset suckers without causing any plant damage. Large-sized plants could also be treated for 60 s at 75°C.

Hot water immersion treatments at 55°C for 60 s, 75°C for 10 to 30 s, and 95°C for 10 to 30 s on small, medium and large-sized suckers were effective. In addition, the water treatments at 55°C for 300 s, and 60 and 300 s at 75°C were also effective. The remaining combinations of

**Table 3.** Effect of hot water treatment on above and below ground plant traits for medium-sized enset suckers infested with enset root mealybugs at 120 days post treatment. 10 plants were assessed per water temperature level and immersion time.

| Water temperature (°C) | Exposure time (seconds) | Plant height (cm) | Leaf DW# (g) | Pseudo stem DW (g) | N° of cord roots | Corm DW (g) | Root DW (g) | Total plant DW (g) | Whole plant dry weight gain compared to the 21°C treatment (%) |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 10 | 26.9[a]* | 14.1[a] | 22.7[c] | 8.3[a] | 44.3[a] | 7.5[a] | 88.6[c] | |
| | 30 | 27.0[a] | 14.1[a] | 22.7[c] | 8.5[a] | 44.1[a] | 7.4[a] | 88.3[c] | |
| | 60 | 27.1[a] | 14.1[a] | 22.6[b] | 8.6[a] | 44.6[a] | 7.4[a] | 88.7[c] | |
| | 300 | 27.2[a] | 14.1[a] | 22.2[c] | 8.4[a] | 44.8[a] | 7.3[a] | 88.4[c] | |
| 55 | 10 | 31.6[c] | 15.4[c] | 33.2[b] | 12.3[c] | 57.5[b] | 9.5[b] | 115.6[abc] | 30.6 |
| | 30 | 35.7[c] | 19.5[c] | 36.2[b] | 13.5[c] | 61.5[b] | 10.3[b] | 127.5[abc] | 44.1 |
| | 60 | 43.4[b] | 21.6[c] | 47.2[c] | 16.2[b] | 69.8[b] | 11.5[b] | 150.1[ab] | 69.6 |
| | 300 | 43.5[b] | 19.9[c] | 35.9[d] | 16.0[b] | 63.9[b] | 10.4[b] | 130.1[abc] | 47.0 |
| 75 | 10 | 43.8[b] | 24.2[b] | 48.8[b] | 16.7[b] | 72.0[d] | 11.6[b] | 156.6[a] | 76.9 |
| | 30 | 43.6[b] | 24.4[b] | 49.4[b] | 16.4[b] | 71.1[d] | 11.5[b] | 156.4[a] | 76.7 |
| | 60 | 32.4[c] | 20.8[c] | 37.3[c] | 13.7[c] | 53.5[b] | 9.6[b] | 121.2[abc] | 36.9 |
| | 300 | 14.2[d] | 15.5[d] | 25.7[d] | 6.4[d] | 28.6[c] | 5.4[d] | 75.2[cd] | -15.0 |
| 95 | 10 | 43.7[b] | 23.8[b] | 49.1[b] | 16.4[b] | 71.7[d] | 11.5[b] | 156.1[a] | 76.4 |
| | 30 | 43.9[b] | 24.9[b] | 48.5[b] | 16.7[b] | 72.8[d] | 11.6[b] | 157.8[a] | 78.3 |
| | 60 | 25.8[f] | 17.6[d] | 30.6[e] | 11.5[c] | 36.8[c] | 7.0[c] | 92.0[bc] | 4.0 |
| | 300 | 4.7[e] | 4.2[e] | 8.0[f] | 2.1[e] | 13.0[c] | 2.0[e] | 27.2[d] | -69.3 |
| Fpr | | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | |

#: DW: dry weight
*: means followed by the same letter are not significantly different according to Tukey's HSD test (p<0.05).

temperature and exposure periods were either not enough to kill all the mealybugs or killed some proportion of the enset plants. The lower growth of the control plants (21°C water immersion) might have been caused by the presence of mealybugs which were not affected by the water temperature.

## Conclusion

This study showed that the immersion of enset corms of all sizes in water at 95°C for at least 10 and up to 30 s prior to planting could be used for the elimination of all enset root mealybugs. In addition, these boiling water treatments significantly enhanced whole plant weight gain of the small, medium and large-sized enset suckers by as much as 100, 78 and 58% as a result of eliminating enset root mealybugs and probably plant-parasitic nematodes and other pathogens. The water treatments at 55 and 75°C are difficult to apply by small-scale subsistence farmers who do not have thermometers and may not have knowledge of temperature measurements. The immersion of enset suckers in boiling water for at least 10 and up to 30 s can be easily demonstrated, with a much higher envisaged adoption rate by farmers. This method could be applied by farmers when adult mealybugs are observed on corms and roots during transplanting and during preparation of corms for macro-propagation in order to obtain mealybug free suckers or planting material. It can also be applied by private seed businesses/entrepreneurs and at development project macro-propagation sites during corm preparation and before sale/distribution of suckers to farmers. Additional detailed socio-economic studies including a cost-benefit analysis and adoption research would be crucial to support out-scaling efforts. In addition, it is envisaged that immersion of banana suckers in boiling water for at least 10 and up to 30 s, e.g. in Kerala, India where the root mealybug *Geococcus* spp. is present on banana, could be highly effective and would warrant further research/confirmation.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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**Table 4.** Effect of hot water treatment on above and below ground plant traits for large-sized enset suckers infested with enset root mealybugs at 120 days post treatment. 10 plants were assessed per water temperature level and immersion time.

| Water temperature (°C) | Exposure time (second) | Plant height (cm) | Leaf DW# (g) | Pseudo stem DW (g) | N° of cord roots | Corm DW (g) | Root DW (g) | Total plant DW (g) | Whole dry plant weight gain compared to the 21°C treatment (%) |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 10 | 35.3[a]* | 19.7[a] | 44.8[a] | 11.4[a] | 77.9[a] | 11.8[a] | 154.2[de] | |
| | 30 | 35.4[a] | 19.7[a] | 44.8[a] | 11.8[a] | 77.9[a] | 11.9[a] | 154.4[de] | |
| | 60 | 35.4[a] | 19.8[a] | 44.8[a] | 11.2[a] | 77.9[a] | 11.9[a] | 154.3[de] | |
| | 300 | 35.5[a] | 19.8[a] | 44.9[a] | 11.3[a] | 77.6[a] | 11.8[a] | 154.1[de] | |
| 55 | 10 | 36.4[a] | 27.5[ba] | 50.1[c] | 15.5[a] | 82.2[a] | 13.2[a] | 173.0[abcde] | 12.2 |
| | 30 | 43.2[c] | 30.5[b] | 61.4[c] | 16.2[a] | 84.5[a] | 14.9[a] | 191.3[abcde] | 24.0 |
| | 60 | 52.4[b] | 33.1[b] | 74.5[b] | 18.3[b] | 104.7[b] | 16.9[b] | 229.2[abcd] | 48.6 |
| | 300 | 52.7[b] | 31.7[b] | 72.1[b] | 18.2[b] | 101.3[b] | 16.7[b] | 221.8[abcd] | 43.8 |
| 75 | 10 | 52.6[b] | 38.0[b] | 79.7[b] | 19.0[b] | 109.0[b] | 17.4[b] | 244.1[a] | 58.2 |
| | 30 | 53.4[b] | 37.7[b] | 77.6[b] | 18.4[b] | 109.1[b] | 17.3[b] | 241.7[ab] | 56.7 |
| | 60 | 45.8[a] | 32.4[b] | 68.4[c] | 16.8[b] | 94.5[bc] | 15.7[bc] | 211.0[abcd] | 36.8 |
| | 300 | 27.1[c] | 29.5[bc] | 43.2[d] | 11.5[c] | 71.5[bc] | 11.7[bc] | 155.9[cde] | 1.1 |
| 95 | 10 | 52.9[b] | 38.2[b] | 77.3[b] | 18.1[b] | 108.7[b] | 17.2[b] | 241.4[abc] | 56.5 |
| | 30 | 51.8[b] | 38.8[b] | 78.2[b] | 18.4[b] | 108.1[b] | 17.7[b] | 242.8[a] | 57.4 |
| | 60 | 35.3[a] | 24.5[c] | 43.1[d] | 12.4[c] | 76.4[c] | 12.4[c] | 156.4[bcde] | 1.4 |
| | 300 | 25.8[c] | 18.2[c] | 40.3[d] | 9.0[c] | 55.9[c] | 9.2[c] | 123.6[e] | -19.9 |
| Fpr | | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | |

#: DW: dry weight

*: means followed by the same letter are not significantly different according to Tukey's HSD test (p<0.05).

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