Original article

The effects of phytosanitary hot water treatments on West African mangoes infested with *Bactrocera invadens* (Diptera: Tephritidae)

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The effects of phytosanitary hot water treatments on West African mangoes infested with *Bactrocera invadens* (Diptera: Tephritidae).

Abstract – Introduction. Quarantine heat treatments have not yet been introduced in West Africa and no work has been done to determine the treatment conditions needed to eliminate eggs and larvae of West African fruit fly populations, especially of the new species *Bactrocera invadens,* from mangoes produced in the region. The objective of our study was to carry out hot water disinfestation experiments on naturally infested mangoes to determine the exposure parameters required to kill eggs and larvae of *B. invadens* present in commercial-quality fruits. The effects of hot water treatment on fruit quality were also investigated. **Materials and methods**. A tank with a heating element and a water pump equipped with a tank sensor were used. Physiologically mature, hard, green mango fruits (cv. Kent) with potential export quality but infested by *B. invadens* were harvested from plantations in the Bobo-Dioulasso (Burkina Faso) area. The effect of hot water treatment by immersion at 42.0 °C, 46.5 °C or 51.0 °C was evaluated by counting identifiable sites of fruit fly oviposition before and after paring the fruit and, finally, the numbers of live and dead larvae of *B. invadens* were counted in the pulp. The quality of the fruit was evaluated after the hot water immersion. **Results and discussion**. A hot water treatment resulting in a core temperature of 46.5 °C could be the basis of a fruit fly quarantine treatment for West African mangoes produced in Burkina Faso. All of the larvae extracted from the fruits treated at 46.5 °C and 51.0 °C were dead, while, in fruit treated at 42.0 °C, only about one-third of the larvae extracted were dead.

Burkina Faso / *Mangifera indica* / fruits / exports / fruit-damaging insects / Tephritidae / *Bactrocera invadens* / insect control / quarantine / heat treatment

Les effets de traitements phytosanitaires à l'eau chaude sur les mangues d'Afrique de l'Ouest infestées par *Bactrocera invadens* (Diptera: Tephritidae).

Résumé – Introduction. Les traitements thermiques de quarantaine n'ont pas encore été introduits en Afrique de l'Ouest et aucun travail n'a été effectué pour déterminer les conditions de traitement nécessaires à l'élimination des œufs et des larves des populations ouest-africaines de mouches des fruits, en particulier de la nouvelle espèce *Bactrocera invadens*, dans les mangues produites dans la région. L'objectif de notre étude a été d'expérimenter la désinfestation à l'eau chaude de mangues naturellement infestées afin de déterminer les paramètres d'exposition nécessaires pour tuer les œufs et les larves de *B. invadens* présents dans des fruits de qualité commerciale. Les effets du traitement à l'eau chaude sur la qualité des mangues ont également été étudiés. **Matériel et méthodes**. Un réservoir équipé d'un élément chauffant et d'une pompe à eau avec capteur a été utilisé. Des mangues physiologiquement matures, dures et vertes (cv. Kent) de la qualité des fruits d'exportation mais infestées par *B. invadens* ont été récoltées dans des plantations de la région de Bobo-Dioulasso (Burkina Faso). L'effet du traitement à l'eau chaude par immersion à 42,0 °C, 46,5 °C ou 51,0 °C a été évalué par comptage des sites de ponte des mouches des fruits avant et après épluchage des mangues et le nombre de larves vivantes et mortes de *B. invadens* a été déterminé dans la pulpe. La qualité des fruits a été évaluée après immersion dans l'eau chaude. **Résultats et discussion**. Un traitement à l'eau chaude, entraînant une température à cœur de 46,5 °C pourrait être la base d'un traitement de quarantaine pour les mouches des fruits des mangues ouest-africaine produites au Burkina Faso. Toutes les larves extraites des fruits traités à 46,5 °C et 51,0 °C ont été tuées, tandis que, dans les fruits traités à 42,0 °C, environ un tiers seulement des larves extraites ont été trouvées mortes.

Burkina Faso / *Mangifera indica* / fruits / exportation / insecte déprédateur des fruits / Tephritidae / *Bactrocera invadens* / lutte anti-insecte / quarantaine / traitement thermique

1. Introduction

The horticultural sector has quickly become a key component of agricultural development policy in West Africa. Horticultural crops are essential for national consumption, but exports are a source of economic growth for many developing countries. Among tropical fruits, the mango has considerable economic potential to increase export earnings, to provide employment, and to improve food security. In northern Benin, as in other similar agro-ecological zones in neighbouring countries, the mango serves as a subsistence crop for family farms. As it ripens at the end of the dry season and at the start of the rainy season, the mango is a fundamental source of nutrition for rural populations living in the Sudano-Sahelian regions of West Africa. It is rich in potassium, alpha-carotene, vitamin C and calcium [1], covering food needs at this crucial period of the year.

Demand for mangoes and their production have increased greatly in recent years. Worldwide production in 2005 was estimated at 28 Mt by the FAO. The mango production area in West Africa has increased slightly since 1999. Exports have also increased slightly, with annual fluctuations. European mango imports reached 174,000 t in 2003, representing a fourfold increase in 10 years [2]. West African origin represents 7% to 10% of this demand. Intense competition and increasingly stringent food quality and safety standards will harm West African exports unless strategies are adopted to address fruit quality and phytosanitary issues.

Previous studies on mango in West Africa revealed numerous quality problems due to physiological disorders and pathogenic or pest attacks, the latter due mainly to fruit flies [3]. Fruit flies (Diptera: Tephritidae) are the pests that cause the most serious damage to mangoes in tropical areas [4, 5]. It is the case in Northern Guinea and the Sudanese savannas, where it remains the major constraint to mango production. As fruit flies attacking mangoes are common to all West African countries [6–8], there is a need to address the problem from a regional perspective.

Several *Ceratitis* species have been detected in West Africa, but a new invasive species, *Bactrocera invadens* Drew Tsuruta & White, has been found heavily attacking mangoes [9, 10], mainly during the rainy season. Preliminary field surveys demonstrated that the new species, thought to have originated in Sri Lanka, has the potential to pose an even greater threat to mango production than native fruit fly species. *Bactrocera invadens* has invaded all of West Africa [11], where it creates increasing problems for mango production. In 2006, in Benin, losses of all mango cultivars due to fruit fly were 17% in early April, but more than 70% by mid-June [1]. By the middle of the production season, losses of more than 50% were recorded over several years. The losses result from direct and indirect damage, the latter due to development of larvae inside the fruit, leading to decay and a reduction in the ability of fruit to withstand transport and storage.

The economic importance of mango fruit flies is due not only to the damage they cause to fruits, but also to their status as quarantine organisms in many countries, including the European Union [Directive CE 2000/29 (Annexe IAI / art. 25)]. Exporters to markets where these pests have quarantine status must guarantee that shipments are free of fruit fly. If not, they risk being refused entry to the market. If fruit flies are detected, shipments are automatically rejected and the mangoes destroyed and, if the problem persists, imports from the offending country may be banned.

A number of methods have been developed and successfully applied to control fruit flies at different stages in the mango production and supply chain. Commercial postharvest heat treatments using either hot water or hot air have been developed and are mandatory for some markets [12]: for example, the Japanese fruit and vegetable market for the fruits from New Caledonia and the Philippines or the USA mango market for the fruits from Brazil, Peru, Ecuador and Mexico. The major problem with postharvest heat treatments is fruit damage caused by high heat loads. Attempts to minimise such damage have included reducing the vapour pressure deficit in hot air methods

[13] and combining insecticidal controlled atmospheres and hot air [14, 15]. Mango is of subtropical origin and thus relatively tolerant to heat. The efficacy of heat as a method for disinfesting fresh fruits of Tephritid has been developed over the last two decades.

Quarantine heat treatments have not yet been introduced in West Africa and only a little work has been done [16] to determine the treatment conditions needed to eliminate eggs and larvae of West African fruit fly populations, especially the new species *B. invadens,* from mangoes produced in the region. The objective of our study was to carry out hot water disinfestation experiments on naturally infested mangoes to determine the exposure parameters required to kill eggs and larvae of fruit flies present in commercial-quality fruits. The effects of hot water treatment on fruit quality were also investigated. Our work was carried out as part of a wider study on the biology and ecology of fruit flies in West Africa, particularly *B. invadens*, which includes laboratory studies to determine lethal temperature thresholds for eggs and different instar larvae of individual species. Quarantine heat treatments generally specify a target temperature that must be achieved at the core of a given fruit for a certain time to ensure that the most temperature-resistant insect stages, normally the first instars [17] and in some cases the third instar larvae [18], experience a lethal temperature exposure wherever they are within the fruit [12, 17].

2. Materials and methods

2.1. Hot water treatment tank

An insulated tank [(stainless steel Z2CND 18/10 (AISI 316 L)] with a heating element (Acim Jouanin - France, total power 4.5 kW) and a water pump (Lowera ref. 2HMS3, 0.3 kW, power 250 W) was constructed at CIRAD, Montpellier, France, with a total volume of 234 dm^3, sufficient to treat a crate of 20 kg to 25 kg of mango fruits in about 160 dm^3 of water. The tank was fitted with a temperature sensor connected to an adaptive set-point temperature control, and two other thermocouples (PT 100 OHMS ref. MA 61501/DG1209130) that could be placed anywhere in the tank. Two other data loggers (Almemo 2890-9, Ahlborn, Germany) and eight thermocouples (PT 100 OHMS ref. SAPS515013) were used to record water and fruit temperatures during the experiments. Data from the tank sensors and the loggers could be downloaded to a laptop (software AMR-control, version 5.13, Almemo) as required. The tank was shipped to Burkina Faso, where field work was carried out at the mango packing station of the *Société de Gestion de Terminaux Fruitiers* (SGTF), Bobo-Dioulasso, in June 2008.

2.2. Fruit material

For the experiment on fruits infested with fruit flies, physiologically mature, hard, green mango fruits (cv. Kent) of export quality were harvested from plantations in the Bobo-Dioulasso area and transported the same or the next day to the SGTF packing station in plastic crates covered with mango leaves. For a second experiment on fruit quality, Kent mango fruits with export quality and, insofar as possible, free of infestation were harvested at three different maturity stages: immature (hard and green but physiologically mature), "export by sea" (EBS) commercial maturity and "export by air" (EBA) commercial maturity.

EBS mangoes were harvested when they were at the half-maturity stage and EBA mangoes were harvested when they were fully matured.

A Magness-Taylor pressure tester was used to determine the firmness of the sampled fruits. A pressure of more than 2 kg per cm^2 was considered the most optimal for most of the varieties of mangoes. In addition, the sampled fruits were subjected to Brix reading to determine the total soluble sugars (TSS) content with the help of a refractometer. EBS mangoes transported in refrigerated containers were harvested with a TSS content of 7–9 °Brix, as these fruits have a rather long shelf life of 20–25 days. EBA mangoes were harvested with a TSS content of 10–13 °Brix as they have a shorter

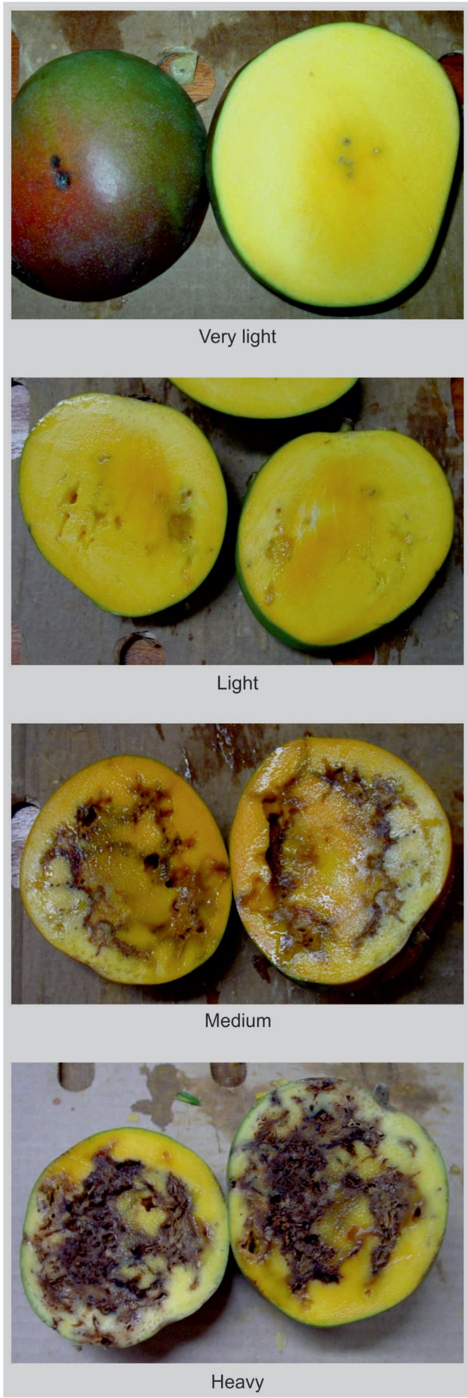

Figure 1.
Typical examples of internal pulp damage caused by fruit fly larvae in Kent mangoes.

shelf life of 17–20 days (Standard Operating Procedures, Packinghouse Facilities for Export of Indian Mangoes to the USA).

2.3. Effect of hot water treatment on fruit fly larvae in infested Kent mango fruit

Most hot water treatment protocols require fruits to be immersed in water at 43 °C to 46 °C [19]. In order to compare the efficacy of the treatments with a good range of variation, the immersion temperatures were (42.0, 46.5 and 51.0) °C. At 42.0 °C, there will be survivors; 46.5 °C represents the typical treatment protocol; 51.0 °C is a temperature which guarantees to kill all eggs and larvae.

Twenty crates of hard, green, physiologically mature Kent mango fruits infested with *B. invadens* were harvested on June 12 and delivered to the SGTF on June 13. The fruits were sorted by two experienced staff to select those most likely to be infested. This was done twice and nine full crates of fruit likely to be infested were harvested. All the adults (100%) that emerged from mangoes in June 2007 and June 2008 near Bobo-Dioulasso were *B. invadens.*

Eight crates of about 30 fruits each were then prepared for the experiment. Crates were treated by immersion in hot water at 42.0 °C, 46.5 °C or 51.0 °C. It was executed until the core temperatures of four fruits encompassing the range of fruit sizes in the crate and measured continuously with thermocouples reached the target temperature. Three crates, one at each temperature, were treated on Day 1, and the remaining three crates on Day 3. Two untreated crates were designated as controls.

After treatment, the fruit were kept in cool conditions for about an hour and then placed on damp sand in a crate covered with mosquito netting to prevent re-infestation. The 30 fruits in each repetition were divided into three crates. One of them was then examined to determine infestation levels (Day 5). Two further evaluations were carried out for the remaining repetitions over the next ten days (Day 10 and Day 14). Identifiable sites of fruit fly oviposition were counted and, after paring the fruit peel or cutting the pulp, they were classified as "surface", "typical" or "major" sites. The pulp was then further cut to assess internal damage caused by larvae. This was classified as "none", "light", "medium" or "heavy" (*figure 1*). Finally, the numbers of live and dead larvae were counted. Counting stopped at 20 larvae per fruit with the count noted as "> 20" and a value of 20 used in calculations.

2.4. Effect of hot water treatment on fruit quality

To study the effect of hot water treatment on fruit quality, fruits were harvested at the immature stage, and at "export by air" (EBA) maturity. Crates of each maturity were treated as described above at 42.0 °C, 46.5 °C and 51.0 °C for 75 min. Control fruits were not treated. Treated fruits were then dried and cooled to ambient temperature and packed in 4-kg capacity export boxes and palletised. The fruit was stored for 3 days at 12 °C and then transported by road to the airport and by air to Montpellier, France (like fruits routinely exported by air). On arrival, the boxes were put in a ripening room at 22 °C for 1 week before analysis of fruit quality. Fruits were visually assessed for the presence of external pitting and shrivelling, and the presence of internal cavities, gelatinous pulp, white pulp inclusions and dark pulp discolouration. Pulp colour was measured with a Minolta Chromameter (CR 300, Ramsey, N.J., USA) on a non-affected portion of pulp. Four measurements per fruit were made: total soluble solids with a refractometer [0–32 g·100 g^{-1} (ATAGO, ACT-1)] and acidity by titration [titratable acidity (TA) was determined by titration with NaOH and expressed as mEq of citric acid per 100 g of mango pulp]. This was done on composite blended fruit samples consisting of 20 fruits.

2.5. Data analysis

As indicated above, the fruits used in the experiment were verified as infested with *B. invadens*, but 40 of the 235 fruit used in the experiment were found to be not infested. Data for the non-infested fruits were removed before further analysis of the results, leaving 195 infested fruits in the experiment. Count data (numbers of oviposition sites and of larvae per fruit) were square-root transformed before variance analysis, because of the high number of zero values in the data sets, using the following formula: $y' = \sqrt{(y + 0.5)}$.

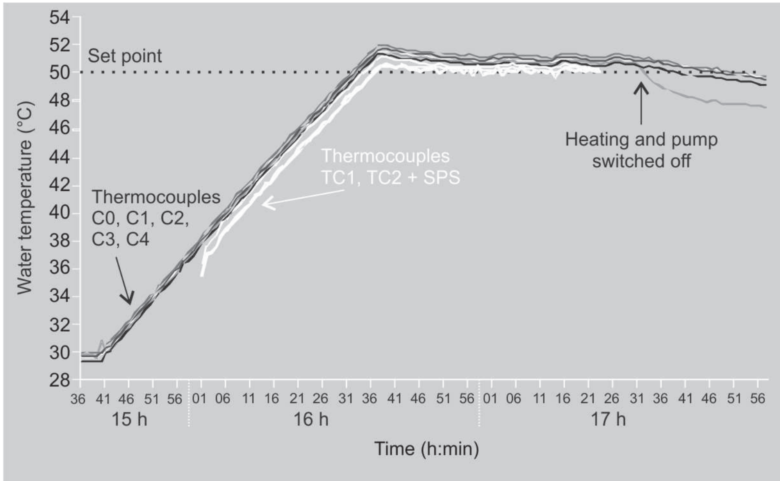

Figure 2.
Water temperatures recorded during a pilot tank heating test by different thermocouples placed throughout the tank and by the set-point thermocouple.

3. Results and discussion

3.1. Performance of the hot water treatment tank

Initial experiments to optimise the water circulation configuration of the tank showed that its operational characteristics were within the specifications stipulated by the USDA for hot water treatment of mangoes for import into the USA [16]. Water temperature increased at 0.4 °C·min^{-1} and was uniform throughout the tank with temperatures recorded by individual thermocouples not differing by more than 1 °C (1.8 °F), which is the maximum difference allowed by USDA regulations [20] (*figure 2*). Water temperature decreased by about 1 °C as a crate of fruit was lowered into the tank, but then increased again to the set-point temperature in less than 5 min. Heating times for fruits between grade 6 [(675–800) g] and grade 9 [(460–510) g] [*Société de Gestion de Terminaux Fruitiers* (SGTF) export size classes] varied between (90 and 120) min (*figure 3*). These times are in accordance with those stipulated by the USDA for round mango varieties, such as Kent, of similar size classes. Pulp temperature near the seed continued to increase for (10 to 15) min after

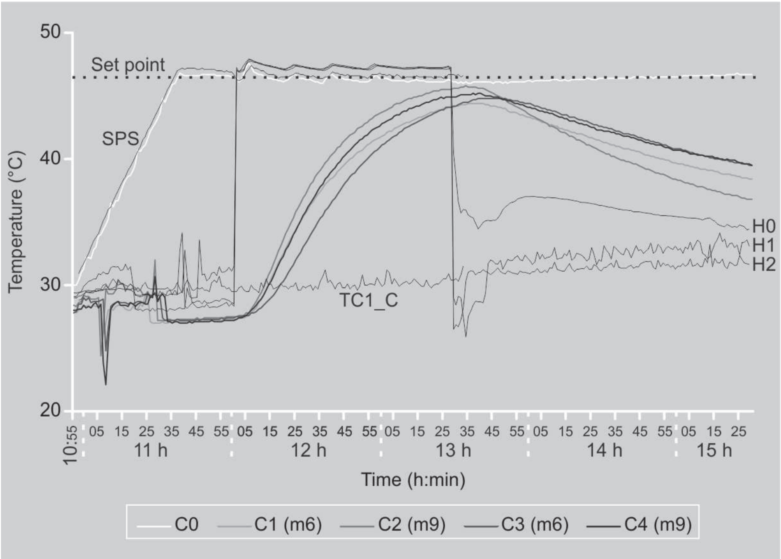

Figure 3.
Water and fruit core temperatures during a fruit heating test. C1 to C4 refer to thermocouples inserted through the pulp to the seed of four Kent mango fruits of *Société de Gestion de Terminaux Fruitiers* (SGTF) size classes 6 (m6: 675–800 g) and 9 (m9: 460–510 g). The other codes refer to various thermocouples placed throughout the tank and the set-point thermocouple.

fruits were removed from the tank. Final temperature differences among fruits of similar grade were generally about 0.5 °C (0.9 °F). After removal from the tank, core temperatures decreased to 42–43 °C within 30–45 min depending on fruit position within the crate, and to less than 42 °C in 45–60 min.

3.2. Oviposition sites

The numbers of 'surface' and 'typical' fruit fly oviposition sites per fruit were similar regardless of treatment and not statistically different (*figure 4*). This would be expected as they were pre-existing features of the fruit before treatment. In contrast, fruits treated at 46.5 °C and 51.0 °C had significantly fewer 'major' sites than control fruits, whereas fruits treated at 42.0 °C had the same number (*figure 4*). This suggests that some of the damage associated with the 'major' sites was caused by larvae after hot water treatment at 42.0 °C [18].

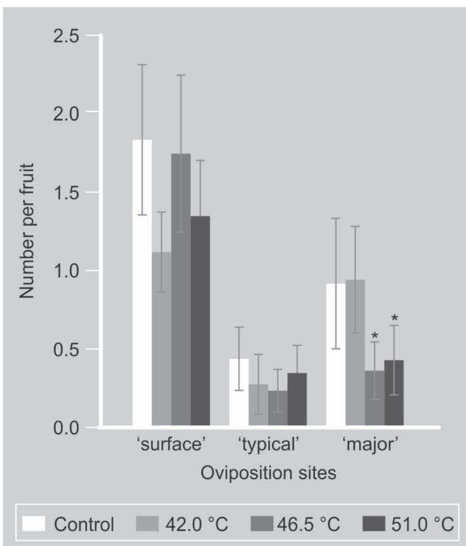

Figure 4.
Number per fruit of identifiable oviposition sites of *B. invadens*, classified as "surface", "typical" or "major" in Kent mangoes after hot water treatment at 42.0 °C, 46.5 °C or 51.0 °C. Control fruits were not treated with hot water. * Indicates a significant difference from the control (p = 0.05). Bars are 95% confidence intervals.

3.3. Effects of hot water treatment on larvae

All of the larvae extracted from the fruits treated at 46.5 °C and 51.0 °C were dead (except for one live larva of *B. invadens* found in the 47 infested fruits treated at 46.5 °C), while, in fruit treated at 42.0 °C, only about one-third of the larvae extracted were dead (*figure 5*). No dead larvae were found in untreated fruit. Comparatively, mortality rates in excess of 99% were obtained for *Bactrocera tryoni* (Frogatt) exposed to temperatures of 44.0 °C to 46.0 °C, depending on the developmental stage [21]. Temperatures lower than 43.0 °C may be lethal for some fruit fly species, but only when exposure is prolonged. A mortality rate of 97.9% was obtained for third-instar Caribbean fruit fly, *Anastrepha suspensa* (Loew), exposed to 40.0 °C for 110 min [20]. The mortality rate of 97.9% observed here at 46.5 °C would not be considered adequate for control purposes, for which rates in excess of 99.99% are required [17]. The possibility that the surviving larva of *B. invadens* resulted from reinfestation cannot be completely ruled out, although the experiment was designed to prevent it. This issue need to be addressed in laboratory experiments where conditions can be more closely controlled.

The total number of *B. invadens* larvae (live and dead) extracted per fruit was significantly reduced in hot water treatment at 46.5 °C and 51.0 °C, but not in treatment at 42.0 °C (*figure 5*). However, the number of dead larvae extracted per fruit was affected by the time of treatment. The experiment was in effect repeated with a gap of two days between repetitions, during which time the

Table I.
Numbers of live and dead larvae of *B. invadens* found in Kent mango fruits after hot water treatment at 42.0 °C, 46.5 °C or 51.0 °C on day 1, or two days later on day 3. Control fruit were not treated with hot water.

Hot water treatment	Day 1			Day 3		
	Total	Live	Dead	Total	Live	Dead
Control	4.84	4.84	None counted	3.43	3.43	None counted
42.0 °C	3.69	3.52	0.17	3.39	1.50	1.89
46.5 °C	None counted	None counted	None counted	3.00	0.05	2.95
51.0 °C	0.33	None counted	0.33	1.45	None counted	1.45

fruits were kept at ambient temperatures. Virtually no *B. invadens* larvae (live or dead) were extracted from fruits treated at 46.5 °C and 51.0 °C on June 14 (Day 1) (*table I*). In contrast, larvae (all dead but one) were extracted from fruits treated at these temperatures on June 16 (Day 3) (*table I*). Whereas similar total numbers of larvae were extracted from fruits treated at 42.0 °C on Day 1 and Day 3, nearly all of the larvae extracted from fruits treated on Day 1 were alive, while, of those extracted from fruits treated on Day 3, about half were alive and half dead (*table I*).

These observations could be explained by the fact that, on June 14 (Day 1), the fruits contained mainly *B. invadens* eggs that had then hatched into larvae by June 16 (Day 3). The results therefore suggest that eggs are killed by temperatures of 46.5 °C and above, but are largely resistant at 42.0 °C. Furthermore, while some larvae appear to be sensitive to 42.0 °C, some are also resistant. This is consistent with the lack of an effect on the number of oviposition sites classed as 'major' in fruits treated at 42.0 °C. In a previous work on *Bactrocera tryoni* (Frogatt), eggs and third instars were found to be more tolerant to high temperatures than first and second instars [21].

3.4. Pulp damage

The damage observed in treated fruits was consistent with the observed effects of the hot water treatments on larvae. The proportion of fruits with 'heavy' pulp damage caused by larvae was significantly reduced by hot water treatment at 46.5 °C and 51.0 °C compared with untreated fruits (*figure 6*). The

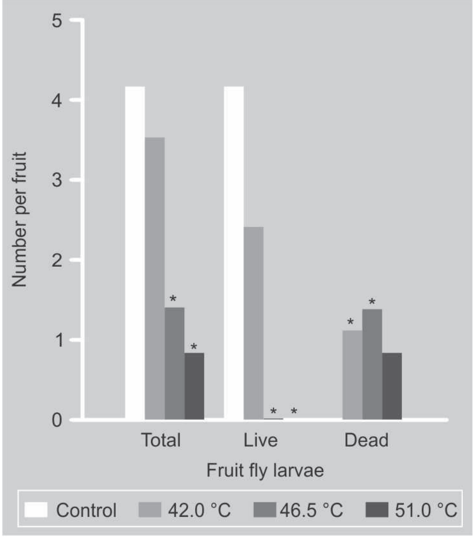

Figure 5.
Total number, number of live and number of dead larvae of *B. invadens* per fruit found in Kent mango fruits after hot water treatment at 42.0 °C, 46.5 °C or 51.0 °C. Control fruits were not treated with hot water. * Indicates a significant difference from the control ($p = 0.05$).

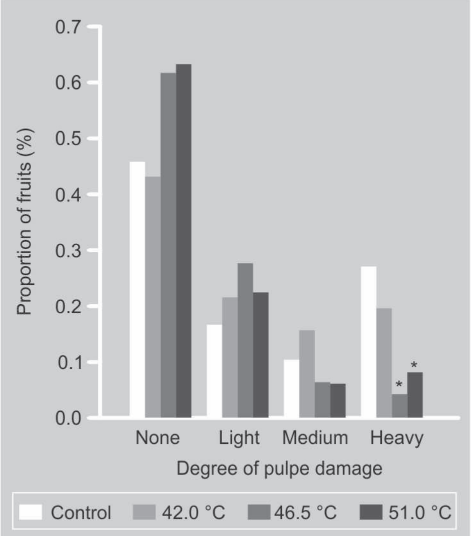

Figure 6.
Proportion of Kent mango fruits with none or different levels of internal damage caused by larvae of *B. invadens* after hot water treatment at different temperatures. Control fruits were not treated with hot water. * Indicates a significant difference from the control ($p = 0.05$).

Table II.
Proportions of immature, ship- and air-mature Kent mango fruits not treated or treated with hot water at (42.0, 46.5 or 51.0) °C for 75 min showing different external defects after ripening.

• Pitting

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	0.0	0.0	0.0
46.5 °C	6.3	18.8	0.0
50.1 °C	88.2	77.8	100.0
Significance	*	*	*

• Shrivelling

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	5.6	38.9	0.0
46.5 °C	6.3	18.8	0.0
Significance	Not significant	*	Test unreliable

*: Significant at $p = 0.05$.

proportions of fruits with 'medium' damage also tended to be lower, while the proportions with 'no' or 'light' damage to the pulp were correspondingly greater in these fruits. Internal damage in fruits treated at 42.0 °C was not significantly different from that in control fruits (*figure 6*).

3.5. Effects of hot water treatment on fruit quality

Immersion in hot water at 42.0 °C to 49.0 °C is reported to induce external and internal defects in a range of mango cultivars [19]. Treatment at 51.0 °C caused surface pitting in more than 80% of mangoes irrespective of their harvest maturity, but a low level of pitting (< 20%) was observed in immature and ship-mature fruits treated at 46.5 °C (*table II*). Surface shrivelling was observed in treated immature and ship-mature fruits, but not in control fruits or in air-mature fruits (*table II*). Internal defects also only occurred in treated fruits, their incidence again being generally greater in immature fruits (*table III*). Immature fruits are frequently found to be less resistant to hot water treatments [19, 22] and this was the case here for Kent mangoes. The exception was for localised dark discolouration of the pulp, which occurred equally in fruits irrespective of harvest maturity (*table III*).

Hot water treatment had no effect on the total soluble solids of ship-mature and air-mature fruits, but may have impaired the ripening of immature fruits, leading to lower soluble solids (*figure 4*). Sudden heat damage has been linked to the disruption of starch metabolism in mangoes, with affected tissues having higher concentrations of starch [18]. It might be expected that this would result in lower soluble solids. There was an indication that treatment at 46.5 °C and 51.0 °C resulted in lower acidity in ship-mature and air-mature fruits, which could indicate that ripening was accelerated in these fruits (*figure 6*). This is consistent with lower hue values for these fruits, indicating a more orange pulp colour (*figure 6*). While heat treatments have been reported to accelerate skin colour changes, internal physicochemical parameters including acidity are frequently reported to be unchanged [16]. Further work is needed to confirm the physiological and biochemical effects of heat treatment of West African mangoes.

Adverse effects of hot water treatments were largely confined to fruits treated at 46.5 °C and 51.0 °C. Where effects occurred in fruits treated at 42.0 °C, they were largely confined to immature fruits. While fruits treated at 51.0 °C were rendered inedible, the prevalence of internal defects in fruits treated at 46.5 °C, even in air-mature fruits, is of concern. Paull and Chen give a threshold of 45.0 °C at which cells' ability to recover from heat shock is generally lost [22]. Preharvest conditions, variety, maturity, the method of heat application, temperature dose and time are modifying factors [19, 22] and need to be investigated in determining a hot water quarantine treatment for West African mangoes.

We have recent data about heat tolerance *in vitro* of *B. invadens* compared with other fruit fly species [23] including the medfly. At 44.7 °C, failure of pupariation of third instars of *B. invadens* was achieved after a 50-min exposure in the hot water bath [23]. However, with larvae in mangoes the heat tolerance for immature stages of *B. invadens* should be higher.

In this way, other experiments should be implemented in order to have accurate data about all immature stages (from eggs to L3) of *B. invadens* in mangoes but also in citrus under the following four temperatures: 42.0 °C, 44.0 °C, 46.0 °C and 48.0 °C. With these narrower intervals, it should be possible to define the heat tolerance of the different immature stages of *B. invadens.*

4. Conclusions

A hot water treatment resulting in a core temperature of 46.5 °C could be the basis of a fruit fly quarantine treatment for West African mangoes produced in Burkina Faso. This treatment was effective in killing fruit fly eggs and larvae in Kent mangoes, but the Probit level was not reached. It means that we recommended adding 10 min of immersion in the hot water. A lower temperature between 42.0 °C and 46.5 °C might be equally effective and would be attractive in terms of reduced energy consumption and damage to fruits, but in these conditions the treatment required a longer time. Field studies such as that carried out here should be combined with laboratory studies to define the lethal temperatures for the different developmental stages of *B. invadens* in order to define the survival probability [24]. Particular attention is needed regarding the deleterious effects of heat treatments on fruit quality and their impact on enzymatic changes involved in maturation. The viability of any quarantine treatment depends ultimately on the capacity of the fruit to withstand it. One practice recommended to improve the effects of heat treatment is to pre-condition fruits before treatment by exposing them to a high but non-damaging temperature or series of temperatures [25]. However, the capacity of eggs from *Bactrocera tryoni* (Frogatt) to withstand heat treatments has also been shown to increase with temperature pre-conditioning, potentially complicating the development of an effective protocol [26]. Another possibility is

Table III.
Proportions (%) of immature, "ship" and "air" mature Kent mango fruits not treated or treated with hot water at (42.0, 46.5 or 51.0) °C for 75 min showing different internal defects after ripening.

• Internal cavities

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	50.0	0.0	0.0
46.5 °C	18.1	12.5	21.4
51.0 °C	24.3	11.1	5.6
Significance	*	Test unreliable	Test unreliable

• Gelatinous pulp

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	50.0	11.1	0.0
46.5 °C	41.0	43.8	25.9
51.0 °C	6.3	22.2	0.0
Significance	*	*	Test unreliable

• White pulp inclusions

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	16.7	0.0	0.0
46.5 °C	0.0	12.5	6.3
51.0 °C	24.3	33.3	13.9
Significance	*	*	Test unreliable

• Dark pulp discolouration

Hot water treatment	Immature	Ship-mature	Air-mature
Control	0.0	0.0	0.0
42.0 °C	27.8	0.0	0.0
46.5 °C	22.9	25.0	46.4
51.0 °C	42.4	50.0	41.7
Significance	*	*	*

*: Significant at $p = 0.05$.

hydro-cooling fruits after heat treatment, which may reduce subsequent heat-induced damage, and other forms of treatment such as vapour heat, microwave heating and irradiation, which may induce fewer negative effects [12].

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Los efectos de tratamientos fitosanitarios en agua caliente en mangos de África occidental infestados por *Bactrocera invadens* (Diptera: Tephritidae).

Resumen – Introducción. En África occidental, aún no se han introducido los tratamientos térmicos de cuarentena ni tampoco se ha llevado a cabo hasta el momento ningún trabajo para determinar las condiciones necesarias para el tratamiento de la eliminación de huevos y larvas de las poblaciones de moscas de las frutas al oeste de África, en particular las de la nueva especie *Bactrocera invadens*, en los mangos producidos en la región. El objetivo de nuestro estudio fue la experimentación de la desinsectación en agua caliente de mangos naturalmente infestados para poder determinar los parámetros de exposición necesarios para extinguir los huevos y las larvas de *B. invadens*, presentes en los frutos de calidad comercial. Asimismo, se estudiaron los efectos del tratamiento en agua caliente en la calidad de los mangos. **Material y métodos**. Se empleó un depósito equipado de un elemento de calentamiento y de una bomba de agua con captador. En plantaciones de la región de Bobo-Dioulasso (Burkina Faso), se cosecharon mangos fisiológicamente maduros, duros y verdes (cv. Kent) de la calidad de los frutos de exportación, aunque infestados por *B. invadens*. Se evaluó el efecto del tratamiento en agua caliente por inmersión a 42,0 °C, 46,5 °C ó 51,0 °C, por cada lugar de puesta de las moscas de las frutas, antes y después de pelar los mangos, y se determinó el número de larvas en vida y extinguidas de *B. invadens* en la pulpa. Se evaluó la calidad de los frutos tras inmersión en agua caliente. **Resultados y discusión**. El tratamiento en agua caliente a una temperatura interna de 46,5 °C podría ser la base de un tratamiento de cuarentena para las moscas de las frutas de los mangos del África occidental producidos en Burkina Faso. A 46,5 °C y a 51,0 °C se extinguieron todas las larvas extraídas de los frutos tratados, mientras que, en los frutos tratados a 42,0 °C, únicamente se extinguieron cerca de un tercio de las larvas extraídas.

Burkina Faso / *Mangifera indica* / frutas / exportaciones / insectos depredadores de los frutos / Tephritidae / *Bactrocera invadens* / control de insectos / cuarentena / tratamiento térmico