# Postharvest disinfestation treatments for deciduous and citrus fruits of the Western Cape, South Africa: a database analysis

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**EFFECTIVE POSTHARVEST DISINFESTATION of export fruits from the Western Cape province of South Africa would help to reduce rejections due to the presence of insects. However, there is normally only a limited opportunity between controlling the insects and damaging the produce. A widely used agent in disinfestation procedures, methyl bromide, was scheduled to be withdrawn in many countries in 2005 due to its ozone-depleting properties. The main alternatives are irradiation, extreme temperatures, forced air, vapour-heat methods and the use of controlled atmospheres. A literature survey was used to identify postharvest treatments with the highest likelihood of success in killing insect contaminants without damaging the fruit. Data from 284 scientific articles relating to these kinds of disinfestation were entered into a database (PQUAD). Queries were run to determine the most intensively studied fruits and pests. The tolerances of the commodities were compared with those of the pests at family level. Where pest tolerances were lower than those of the fruit, the treatment was regarded as a possible candidate for use. Methyl bromide, controlled atmospheres and irradiation were identified as the most widely used against pests. Irradiation appeared to control insects at doses that did not damage deciduous produce. Citrus appeared to be more susceptible to damage, however, than deciduous fruits. Low temperature also seemed to be less detrimental to deciduous fruit than to citrus. Deciduous fruit is already preserved in cold storage, making this an inexpensive option to combat insects. Cold treatment appeared to control members of the Pseudococcidae, Tephritidae and Tortricidae; more work is required on the other pest families. Controlled atmospheres also had a high chance of success for both citrus and deciduous fruits.**

## Introduction

The Western Cape province of South Africa is the main deciduous fruit producing area of the country. Citrus, particularly oranges and soft citrus, are also grown there, but to a lesser extent. Markets in the European Union and the United States are of particular importance to these fruit industries. A major threat to fruit exports is the risk of consignments being rejected due to the presence of insect contaminants. Postharvest disinfestation treatments can be used to control the presence of insects,[1,2] so that the risk of rejection as a result of insect contamination can thereby be reduced.[2] These treatments need to control the pest species without damaging the crop. However, there is normally only limited opportunity between combating the insects and damaging the fruit.[3]

Methyl bromide is a widely used and relatively inexpensive postharvest pesticide. Owing to its ozone-depleting properties[4] and risks to human health,[5] however, it was to be deregistered in developed countries in 2005 and in poor countries in 2015,[6] meaning that alternative ways of removing insects must be found. The main alternatives are irradiation, temperature (high or low), forced air (hot air blown over the commodity), vapour heat treatments (hot air saturated with water blown over the fruit), and controlled atmospheres (the levels of $O_2$, $CO_2$ and temperature are manipulated).

The most important insect contaminants of deciduous fruits in the Western Cape belong to the families Curculionidae, Pseudococcidae, Tephritidae, Tortricidae, Lygaeidae and Pyrrhocoridae. Lygaeidae and Pyrrhocoridae are not primary pests in the Western Cape, but enter consignments of fruits coincidentally and are thus regarded as phytosanitary pests (G. Hendrikse, Special Export Programmes Manager, Deciduous Fruit Producers Trust and Citrus Growers Association, pers. comm.).

The aim of the study reported here was to determine which postharvest disinfestation methods would be most effective in the Western Cape. To achieve this, a database of published information was compiled to allow comparisons of the tolerances of insects and fruits.

## Methods

CAB Abstracts in the ISI Web of Knowledge (isiknowledge.com) were searched for the literature in English relating to postharvest disinfestation treatments, for both pests and fruits, from 1990 to 2004. Relevant articles were obtained and their reference lists were searched for further studies, which were in turn added to the literature list. This published information formed the basis for a postharvest disinfestation treatment database (PQUAD) for the Western Cape. The relevant data were entered into PQUAD in Microsoft® Access 2002. Information from 284 papers was used (see Appendix 1 in supplementary material online at www.sajs.co.za).

PQUAD is a relational database and consists of 17 tables. The fields of these tables can be linked to access information from multiple tables when queries are run.[7] Table structure and a brief explanation of the field contents are given in Table 1.

Queries were run to determine what the most studied commodities, insect families and insect species were for each treatment. The range between the most susceptible and the most tolerant cultivars was regarded as the range of cultivar tolerance for a particular commodity. The range between the most susceptible and the most tolerant species was regarded as the range of species tolerance for a particular insect family. These results were recorded as those treatments that would achieve 100% mortality or reproductive sterilization of each pest for its most tolerant life stage. The results for each commodity and its cultivars were then compared with those for each insect species in its family. Where the most tolerant species was controlled using a less intensive treatment than that which damaged the most susceptible fruit cultivar, that treatment was regarded as a possible postharvest disinfestation method for that particular fruit against that family of insects. Confidence levels could not be calculated due to the lack of replicated studies.

## Results and discussion

### PQUAD summary

The effect of disinfestation of fruits using controlled atmosphere and methyl bromide was the subject of most of the studies (Table 2). Methyl bromide was used in the most treatments, and vapour heat in the smallest number (Table 3). Controlled atmospheres and irradiation were also included in many studies involving pests (Table 3). From the small number of authors who published on controlled atmosphere and irradiation, it was assumed that this work was conducted by specialist groups. Few studies on high and low temperature treatments were reported, (as was the case with forced air and vapour heat), and were usually

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restricted to tropical fruits. Low temperature studies were limited to deciduous produce.

Investigations involving high temperature, irradiation, and methyl bromide have been conducted in similar proportions on both fruits and pests, suggesting an equal interest in their respective effects. There have been more studies on the effects of controlled atmospheres on commodities than on pests, probably because this form of treatment is also used to improve the quality and shelf-life these products. The few studies at low temperatures was probably because fruits are stored in the cold to preserve them before contamination becomes a concern, so that the effect of cold storage on fruit is well known. The effect of cold storage on insect contaminants was not initially researched. The reason for the disproportionately high number of studies on the effect of vapour heat and forced air on insects relative to fruit products is probably that these treatments are predominantly used on tropical fruits; their insect pests are not found in temperate regions like the Western Cape.

Apples and nectarines were the most studied fruits, followed by oranges, grapes, grapefruits, pears and mandarins. These are the most important fruits exported globally, especially from wealthy countries that can afford research on postharvest disinfestation.[8] Persimmons, tangerines and lemons were included in only a few studies.

In total, 45 pest species were recorded, Tephritidae and Tortricidae were the two most frequently studied families (featuring in 48% and 39% of the publications, respectively) (Tables 3 and 4). They also represent the two most important families in terms of insect pest risk globally.[9,10] The nine most studied species were members of either the Tortricidae or Tephritidae; among the 16 most studied pests, five and seven belonged to these families, respectively (Table 4). Pseudococcidae and Curculionidae, including Brentidae,[11] were also comparatively well studied (6.6% and 5.1%, respectively), whereas Tenebrionidae, Diaspididae and Bostrichidae were referred to in only one publication each.[12–14]

## Methyl bromide

Methyl bromide did not appear to be successful against two Coleoptera families (Curculionidae and Bostrichidae) as these insects were able to survive doses that would damage all fruits included in PQUAD (Fig. 1). Members of the Pseudococcidae can be controlled only on certain

**Table 1**. PQUAD field names and descriptions.

| Fields | Description |
|---|---|
| *Fields shared by all tables* | |
| Reference number | Unique number for article |
| Reference | Reference for article |
| *Fields shared by all pest tables* | |
| Genus | Taxonomic genus of insect pest |
| Species | Taxonomic species of insect pest |
| Commodity | Fruit on which study was conducted |
| Cultivar | Cultivar on which study was conducted |
| *Fields in the overall pest table only* | |
| Family | Taxonomic family of insect pest |
| Treatment | Treatment tested |
| *Fields in the pest treatment tables* | |
| Life stage | Life stage of insect tested |
| Effect on pest | Effect of treatment on the insect pest |
| Temperature (°C) | Temperature at which treatment was conducted |
| Duration (h) | Duration of treatment |
| *Fields shared by all commodity tables* | |
| Commodity | Fruit studied |
| Cultivar | Cultivar studied |
| *Field in the overall commodity table* | |
| Treatment | Treatment tested |
| *Fields in the overall commodity table* | |
| Effect on the commodity | Effect of treatment on fruit |
| Temperature (°C) | Temperature of treatment |
| Duration (h) | Duration of treatment |
| *Fields specific to the treatment tables* | |
| Controlled atmosphere—$O_2$ and $CO_2$ composition (kPa) | $O_2$ and $CO_2$ levels of treatment |
| Forced air—flow rate ($m^3/s$) | Flow rate of treatment |
| High temperature – medium | Treatment medium |
| Irradiation – dose (Gy) | Irradiation dose |
| Methyl bromide – dose ($g/m^3$) | Dose of methyl bromide used |
| *Fields in the reference table only* | |
| Authors | Author(s) of article |
| Year | Year of publication |
| Title | Title of article |
| Source | Source of article |

**Table 2**. Number of studies per fruit type for the various postharvest treatments.

| Commodity | Con. atmos* | Forced air | High temp. | Irrad. | Low temp. | Methyl bromide | Vapour heat | Total |
|---|---|---|---|---|---|---|---|---|
| Apple | 25 | 0 | 9 | 7 | 1 | 13 | 0 | 55 |
| Nectarine | 15 | 1 | 9 | 0 | 4 | 14 | 0 | 43 |
| Orange | 1 | 2 | 6 | 8 | 0 | 5 | 1 | 23 |
| Grape | 6 | 0 | 0 | 8 | 0 | 4 | 1 | 19 |
| Grapefruit | 1 | 1 | 2 | 4 | 2 | 6 | 2 | 18 |
| Pear | 6 | 0 | 2 | 2 | 0 | 4 | 0 | 14 |
| Mandarin | 0 | 0 | 0 | 7 | 0 | 5 | 0 | 12 |
| Persimmon | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 4 |
| Tangerine | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 4 |
| Lemon | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 3 |
| Total | 54 | 4 | 29 | 40 | 9 | 54 | 5 | 195 |

*Con. atmos. = controlled atmosphere, temp. = temperature, Irrad. = irradiation.

**Table 3**. Number of studies per insect family for the various postharvest treatments.

| Family | Con. atmos* | Forced air | High temp. | Irrad. | Low temp. | Methyl bromide | Vapour heat | Total |
|---|---|---|---|---|---|---|---|---|
| Bostrichidae | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Curculionidae | 1 | 0 | 0 | 6 | 0 | 4 | 0 | 11 |
| Diaspididae | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Pseudococcidae | 2 | 0 | 4 | 2 | 4 | 2 | 0 | 14 |
| Tenebrionidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Tephritidae | 6 | 11 | 17 | 24 | 14 | 21 | 9 | 102 |
| Tortricidae | 24 | 0 | 13 | 6 | 7 | 31 | 1 | 82 |
| Total | 33 | 11 | 35 | 39 | 25 | 59 | 10 | 212 |

*Con. atmos. = controlled atmosphere, temp. = temperature, Irrad. = irradiation.

apple, grape and nectarine cultivars without the product being damaged. The tolerances of these fruits were similar to the dose that is required, so further research is needed to verify the use of this form of quarantine on Pseudococcidae. Some Tortricidae and Tephritidae could be controlled on all the fruits (Fig. 1), although the tolerances of the commodities and the pests were similar. These results indicate that the phasing out of methyl bromide need not be of concern as it is not particularly effective against the insect pests of the Western Cape.

### Irradiation

Doses of 250–600 Gy appeared able to control (either by sterilization or by killing) Tortricidae, Curculionidae, Tephritidae and Pseudococcidae without adversely affecting the three kinds of deciduous fruit kinds included in Fig. 2. The two fruits featured in the figure tolerated irradiation doses of 150 Gy, which only just controlled Curculionidae, Tephritidae and Pseudococcidae. Irradiation as a means of postharvest disinfestation has great potential for deciduous fruits, as it appeared to contain insect contaminants without damaging the fruits.

### Low temperature

The low temperatures currently used to store deciduous fruit prior to and during export appeared to control both Pseudococcidae and Tephritidae (Fig. 3). Cold regimes also appeared to be effective against pests of grapefruit (Fig. 3). However, it was uncertain whether this treatment can combat all members of the Tortricidae. Some tortricids (e.g. *Cydia pomonella* (Linnaeus), codling moth) diapause in their larval stage and thus are able to tolerate low temperatures.[15] Others, however, like *Thaumatotibia leucotreta* (Meyrick) (= *Cryptophlebia leucotreta* (Meyrick), false codling moth), did not survive low temperatures.[16,17] This major pest of Western Cape fruit is controlled in 17 days at –0.6°C,[16,17] which is a shorter time than apples, pears and grapes currently undergo at –0.5°C. Cold storage is already used for a disinfestation treatment against Tephritidae in the Western Cape, for both grapes and apples.[18] Because this is a relatively simple and inexpensive procedure, research into the use of low temperatures to control other insect families, such as Curculionidae, is recommended.

### Heat, vapour heat and forced-air treatments

Fruits exposed to hot air were damaged long before the pests were killed or incapacitated. Hot water was more successful, with grapefruit and persimmons being tolerant of treatments that achieved 100% mortality of Pseudococcidae, Tenebrionidae, Tephritidae and Tortricidae. Apples and oranges suffered too much damage for this treatment to be viable. Research on the effects of hot water on other fruits and pests is required to determine whether or not this is a viable means of disinfecting fruits in the Western Cape.

Vapour heat treatment was unsuccessful against Tephritidae in grapes. However, vapour heat applied at 44°C or 46°C for 3.5 hours controlled Tortricidae without

**Table 4**. Sixteen species of insects, most commonly tested in postharvest disinfestation treatments, recorded in PQUAD. An additional 29 species recorded are not included.

| Species | Family* | Common name | No. of studies |
|---|---|---|---|
| *Cydia pomonella* (Linnaeus) | Tort. | Codling moth | 33 |
| *Anastrepha suspensa* (Loew) | Teph. | Caribbean fruit fly | 30 |
| *Ceratitis capitata* (Wiedemann) | Teph. | Mediterranean fruit fly | 23 |
| *Epiphyas postvittana* (Walker) | Tort. | Light brown apple moth | 17 |
| *Anastrepha ludens* (Loew) | Teph. | Mexican fruit fly | 14 |
| *Ctenopseustis obliquana* (Walker) | Tort. | Brownheaded leafroller | 11 |
| *Cydia molesta* (Busck) | Tort. | Oriental fruit moth | 7 |
| *Planotortrix octo* Dugdale | Tort. | Greenheaded leafroller | 7 |
| *Bactrocera tryoni* (Froggatt) | Teph. | Queensland fruit fly | 6 |
| *Pseudococcus longispinus* (Targioni-Tozzetti) | Pseudo. | Long-tailed mealybug | 6 |
| *Anastrepha obliqua* (Macquart) | Teph. | West Indian fruit fly | 5 |
| *Cylas formicarius* (Fabricius) | Brentidae | Sweet potato weevil | 4 |
| *Bactrocera dorsalis* (Hendel) | Teph. | Oriental fruit fly | 3 |
| *Pseudococcus viburni* (Signoret) | Pseudo. | Obscure mealybug | 3 |
| *Rhagoletis pomonella* (Walsh) | Teph. | Apple maggot fly | 3 |
| *Sitophilus granarius* (Linnaeus) | Curc. | Granary weevil | 3 |

*Tort. = Tortricidae, Teph. = Tephritidae, Pseudo. = Pseudococcidae, Curc. = Curculionidae.

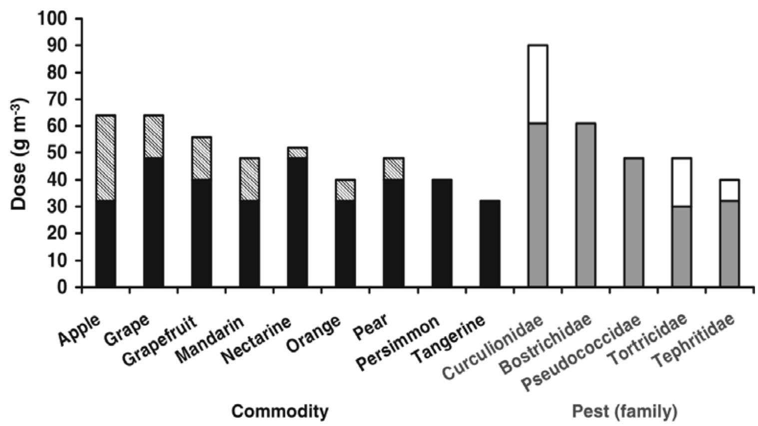


**Fig. 1**. Highest doses of methyl bromide that did not cause damage to fruits (solid black represents doses that all cultivars tolerated; diagonal lines signify the range of cultivar tolerance) and the doses required to control all pests (solid grey represents doses all species tolerated; clear is the range of species tolerance) during a two-hour fumigation period.

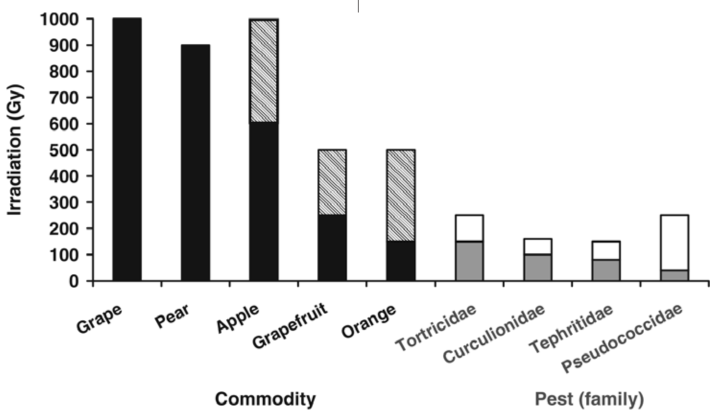


**Fig. 2**. Highest irradiation doses that did not cause damage to fruits (solid black represents doses all cultivars tolerated; diagonal lines indicate the range of cultivar tolerance) and the doses that were required to control pests (solid grey represents doses all species tolerated; clear is the range of species tolerance).

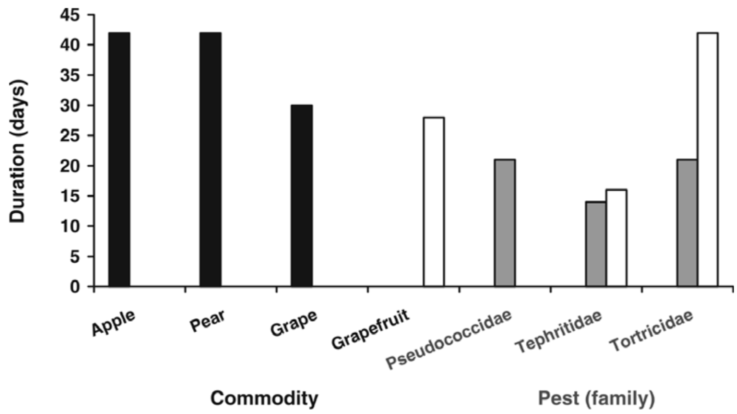


**Fig. 3**. Cold storage temperatures used for preserving export fruit and the maximum duration at these temperatures before fruit quality deteriorates. Apples, pears and grapes are currently stored at –0.5°C, whereas grapefruit is chilled optimally at 1°C before quality starts to decline. Also shown is the shortest exposure to low temperatures that would cause 100% mortality in all pest species per family. Key to bars: Solid black = –0.5°C, solid grey = 0°C, clear = 1°C.

damaging grapefruit, oranges or tangerines. These procedures could be successful for citrus contaminated with Tortricidae, but we do not know how other fruits or pest families would be affected.

The only forced-air methods reported were against Tephritidae in citrus fruits. Treatments of 43°C with a flow rate of 0.4 $m^3/s$ for 2 hours effectively controlled all Tephritidae in grapefruit without damaging the produce,[19] oranges tolerated treatments of 48°C with flow rates of 0.75 $m^3/s$ for 2 hours.[20] This method appeared promising for citrus, however, but so few studies have been conducted to know whether this form of disinfestation would be successful for other fruits or pests.

### Controlled atmospheres

Controlled atmospheres are widely used for extending the storage life of deciduous fruits.

However, we found no studies that directly compared the effects of various atmospheres on fruits and insects. A trend suggested that enhanced temperature and $CO_2$ levels and reduced $O_2$ concentration accelerated damage to fruit and killed insects more quickly, but at different rates. It appeared that controlled atmospheres at high temperature were more successful in controlling pests than at low temperature, probably because the increased metabolic rates of insects when heated resulted in higher demands for oxygen.[3]

Controlled atmospheres are the most complex of the treatments to analyse. They seem to control pests without damaging the commercial product. However, much more data and research on these practices are still required to learn how effective they will be against the pests of the Western Cape.

### Other postharvest disinfestation treatments

Other postharvest disinfestation treatments were reported in the literature, although none was sufficiently well represented to be included in the PQUAD analysis. These methods, although not considered as an important means of disinfestation should not be ignored as they may yet prove effective after further research. *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) and *Platynota stultana* Walsingham (Lepidoptera: Tortricidae) were successfully controlled using a combination of slow-releasing sulphur dioxide pads and cold storage.[21] High-pressure washing reduced the number of *Pseudococcus viburni* (Signoret) (Hemiptera: Pseudococcidae) and *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) found on apples.[22] Ultrasound has recently been shown to be lethal to *F. occidentalis* and the mite *Tetranychus urticae* Koch,[23] but its effectiveness on fresh produce still needs to be established.

## Conclusions

PQUAD is not yet sufficiently developed to provide more than broad research directions thereby reducing research time and costs. The gaps in the data may represent areas which have been researched but not published due to negative results. Thus, PQUAD ought to be extended to include as many preliminary and unpublished results as possible to indicate which treatments could be successful and warrant further investigation. Furthermore, in this study the insects were considered only at the family level, but the pest species themselves should be individually tested to verify the results from PQUAD. As quarantine data are analysed in South Africa, they should be included in database, as should other fruits grown outside the Western Cape.

Lygaeidae and Pyrrhocoridae, although important phytosanitary pest families in the Western Cape, are not represented in PQUAD. Insects from all families studied were controlled at radiation doses that deciduous fruit tolerates. It appears that Pseudococcidae and Tephritidae are controlled by current cold storage regimes as well as the tortricid *T. leucotreta.* Low temperatures are already used to preserve deciduous fruit for export. These disinfestation treatments will not result in extra costs. Further research into controlled atmospheres may also prove to be successful for combatting insect contaminants while not damaging valuable produce. The control of Tortricidae, however, is complicated because some species diapause, hence are able to tolerate low temperatures. The thermal limits of contaminants in the families Curculionidae, Lygaeidae and Pyrrhocoridae still need to be determined.

Heat treatments against insect pests of citrus seem promising, especially the use of hot water.

In addition, controlled atmospheres and low temperature appear to be potential means of disinfestation for these fruits. Another possibility is combine treatments that showed a high degree of efficacy, but this also needs to be more fully researched.

It is desirable that the database be updated regularly, so researches have the most recent data available before deciding which disinfestation treatments to explore. PQUAD could also be expanded for the benefit of those working on other export produce or phytosanitary pests (such as mites or fungi).

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**The entries currently in the PQUAD database are available as on online supplement at www.sajs.co.za**

# Supplementary material to:

Pryke J.S. and Pringle K.L. (2008). Postharvest disinfestation treatments for deciduous and citrus fruits of the Western Cape, South Africa: a database analysis. *S. Afr. J. Sci.* **104**, 85–89.

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