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ENVIRONMENTAL IMPACTS OF THREE DATE DISINFESTATION TECHNOLOGIES QUANTIFIED BY THEIR CARBON FOOTPRINT

Hagit Navarro*,

Food Technology International Consultancy Ltd., P.O. Box 3300, Beit-Yehoshua, 40591 Israel.

*Corresponding author's e-mail address: *HNavarro@ftic.info*

ABSTRACT

Nitdulid beetles and Phycitidae moths start their infestation in the date orchard, where pest management is insufficient and may continue their infestation in storage. Therefore, to eliminate the insects from the dates and to prevent further damage during storage, disinfestation of the dates should be carried out as they reach the packing stations. Methyl bromide has been very successful fumigant in removing the insects from the fruit, and kills the insects. As alternative to methyl bromide, in accordance with Montréal protocol, fumigation using Vapormate^{TM} and thermal disinfestation have been developed and implemented. Thermal disinfestation technology is based on the principle of transfer of hot air through a channel containing 3 tonnes of dates, where the dates are exposed on trays for 3 h to 50^{o}C. Economic and environmental analyses were done by the carbon footprint assessment which is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity. The analysis was done for three disinfestation methods of dates; fumigation using methyl bromide, fumigation using Vapormate^{TM} and thermal disinfestation using LPG or solar energy. In each disinfestation method, the emissions were converted to carbon equivalents according to its Global Warming Potential values. Then these carbon equivalent values were converted to monetary values according to the update of the 2005 ExternE methodology. Results show that the most effective disinfestation technology both economically and environmentally is the use of solar energy based thermal disinfestation. The lowest carbon footprint values were obtained using solar energy. Thermal disinfestation method was found as a suitable alternative technology to methyl bromide in all biological, environmental and economical aspects. Currently the thermal disinfestation technology is successfully implemented on all major date cultivars including Medjool as an alternative to methyl bromide, in accordance with Montréal protocol in Israel.

Key words: Dates, Medjool, insect control, methyl bromide, ethyl formate, Vapormate^{TM}, thermal disinfestations, carbon footprint, solar energy.

INTRODUCTION

The dates industry in Israel serves as an important portion of Israel's agricultural export. The dry cultivars grown in Israel are Medjool, Deglet-Noor, Hadrawi, Halawi, Zahidi, Derhi and Ameri (Cohen, 2011). Most pests develop in the field, where pest management is insufficient, then brought to the warehouses where some Nitidulidae beetles and Phycitidae moths continue to develop (Blumberg, 2008). Therefore, to prevent further damage during storage within the warehouses and to remove the insects from the dates, insect control should be carried out by disinfesting the dates as they reach the packing stations.

In accordance with Montréal protocol, Israel agreed to decrease the use of methyl bromide (MB) and search for alternatives (TEAP & MBTOC, 2003). After the successful implementation of the thermal disinfestation technology on the major cultivar, Medjool (Navarro, 2006), three field trials were carried out on other date cultivars which resulted in expanding and implementing the thermal disinfestation technology to other dry cultivars in Israel (Navarro, 2011). Thermal disinfestation technology is based on the principle of transfer of hot air through a channel containing 3 tonnes of dates, where the dates are exposed on trays/boxes for 3 h to 50^{o}C (Navarro et al., 2003; 2004).

Along with the implementation of the thermal disinfestation technology, another method was registered in Israel – the use of the fumigant VAPORMATE^{TM} which consists of 16.7% ethyl formate in liquid CO_2. Its registration by the Israeli Plant Protection Services for the date's industry was accomplished in 2009 as an alternative to MB (Lendler, 2009). This fumigant is environmentally friendly and in use in the food industry.

The thermal disinfestation technology could be applied based either on Liquid Petroleum Gas (LPG), solar energy or combined energy. All of the above mentioned disinfestation methods have different impacts on the environment. Nevertheless, the choice of which method should be applied is influenced by its economic feasibility. A means of evaluating the benefit of technology application is by evaluating the costs which takes into account its impact on the environment (e.g., external costs). The present work aims at evaluating the environmental impacts of the disinfestation methods by their "carbon footprint" which is "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" (Wiedmann and Minx, 2008).

The "carbon footprint" serves as a common denominator that allows comparing between similar products of different processes that are generated due to their contributions to understanding the impact of the product on global warming. This concept has become popular in recent years and is used for comparison. In contrast to Life Cycle Analysis (LCA) which compares the entire environmental impacts, it is actually more complicated analysis for different products that might skip the concept of the common denominator of a products' influence on the environment, since the carbon footprint is popular, has attractive marketing advantage, and thus has the potential to increase the green environmental awareness of consumers when greenhouse gases emission is the main reference on global warming (Weidema et al., 2008).

MATERIALS AND METHODS

The main differences resulting from different disinfestation methods depend on the way disinfestation is applied. Therefore, comparison of costs served as basis for the different disinfestation methods:

A. Fumigation using MB.

In this method, dates are placed into plastic enclosures of different sizes (200 or 400 kg vats or factory boxes that contain about 13 kg dates) in fumigation chambers where the gas is distributed and circulated during an exposure of 4 to 6 h. The MB fumigation is no longer in use in Israel after the approval of the thermal disinfestation technology by the Israel Ministry of Environmental Protection in 2010. In the present work MB was used as a reference (TEAP, 2009), to compare with alternative methods at a dosage of 30 g/m^3.

B. Fumigation using VAPORMATE™.

In 2008 the product VAPORMATE™ was registered by the Israel Ministry of Agriculture for disinfestation of dates (Finkelman, 2010). This fumigant is particularly useful for fumigating vats containing 400-450 kg fruit or half vats (50 cm height) containing about 200-220 kg of fruit that are not suitable for the thermal disinfestations due to resistance of hot air flow through the bulk of dates. This method is a complete alternative to thermal disinfestation technology when dates are handled in vats. Technically, the application of the fumigant is as with MB in fumigation chambers. For disinfestation of dates VAPORMATE™ is applied at 420 g m-3 for 12 h exposure time, at 30°C.

C. Thermal disinfestation using LPG, solar energy or combined as an energy source.

The common thermal disinfestation method is based on solar radiation, in case of a cloudy day it is backed up by additional energy. The disinfestation facility is built as a greenhouse structure which is covered with polyethylene sheets and has concrete floor.

Theoretical energy consumption calculations required for thermal disinfestation using different energy sources when compared to solar energy:

Calculations for disinfestation process of 1 tonne of dates were considered in two scenarios:

1- On cloudy days when active heating is required constantly, the heating unit is operated during the whole disinfestation process.

2- On sunny hot days, the heating unit is operated intermittently during the whole process.

The heating units were LPG based. To reach the target temperature of 50°C, pre-heating of 1-4 h is required. The calculations were based on pre-heating duration time, disinfestations exposure time to 50°C (3 h) in accordance with the facilities tested and their capacities. Calculations were based on the price of kg LPG in 2009 which was $US 0.026 and electricity price (0.34 $US per kW/h) needed to circulate the hot air through the dates by the electric fans (GEA, 2011).

Comparative environmental analysis of the disinfestation methods:

Environmental impacts resulting from the different disinfestation methods were quantified by converting the emissions resulting from the processes into metric tonnes of carbon dioxide equivalents (MTCE). Each calculation was determined by its Global Warming Potential factor (GWP) (Forster et al., 2007). According to the equation:

[MTCE (Tg of gas) x (GWP) x (12/44)] (ICBE, 2000)

Where: Tg is Terra gram of gas and 12/44 by weight is 12/44^{ths} of carbon dioxide.

The data gathered in the present work is from emissions that resulted from:

a.) Fumigation using MB- GWP factor is 5 for 100 years (Forster et al., 2007).
b.) Fumigation using VAPORMATE™, since the product VAPORMATE™ consist 83.3% carbon dioxide, the emissions are based on this factor. The rest is the active ingredient ethyl formate which hydrolyses to formic acid therefore has no impact on the environment. Therefore its GWP factor is 1.
c.) Thermal disinfestation on cloudy days when heating units were operated constantly.

d.) Thermal disinfestation on hot and sunny days when heating units were operated intermittently.

For the above conditions described in items c and d, the GWP factor is 3.65 (Forster et al., 2007) derived from the use of LPG which consists of 50% propane and 50% butane (EPPO, 2011). The amount of carbon was quantified by the calories needed for the disinfestation process for 1 tonne of dates.

External environmental cost calculations were based on the update values in the monitories of ExternE methodology for 2005 which shows a value of 19 €/tonne of carbon dioxide emitted. This methodology is based on a published FUND model by the environmental protection air quality division in cooperation with the department of economics and the matched price tonnes of carbon dioxide, according to the costs of prevention (cost of saving emissions according to international standards) and per capita compared to the EU-designated GDP (Gross Domestic Product) on € 14.83 (Kadmi et al., 2008). The environmental report published by the Israel Electric Corporation revealed that in 2009 the specific emission of carbon dioxide per kW h-1 was 707 g (Israel Electric Corporation, 2009).

RESULTS

Fumigation using MB

Methyl bromide 2009 cost in Israel was 11.84 $US/kg. Israel ministry of Environmental Protection recommends a dose of 300 g/tonne MB to fumigate dates. Although a dosage of 30 g m-3 is sufficient to control date insects, in practice 300 g/tonne is calculated because of the volume factor that varies often, the fumigation chamber is not full with commodity. Therefore, the direct cost of MB fumigation resulted in 3.55 $US/tonne fora full 95 m^3 fumigation chamber that contains 14 tonnes of fruits.

Fumigation using VAPORMATE™

VAPORMATE™ 2009 cost in Israel was 31.57 $US/kg. The manufacturer recommendation was to use a dose of 420 g m-3, equivalent to 2850 g/tonne. Therefore, the direct cost of VAPORMATE™ fumigation was 90 $US/tonne fora full 95 m^3 fumigation chamber that contains 14 tonnes of fruits.

Thermal disinfestation

Table 1 represents the energy and direct costs of different energy sources for thermal disinfestation based on the above data and on the caloric value (12.73 kW) obtained from 1 kg of LPG (propane butane ratio 1:1). Two disinfestation facilities were investigated; "Tzemach" facility is able to disinfest in a single batch maximum 21,840 kg of dates (28 pallets). In "Tzemach" there were two heating units which consume 33 kg LPG/h with capacity of 418.68 kW. Therefore, 7.5 kg LPG were needed to disinfest 1 tonne dates (95.6 kW/tonne). During the disinfestation process both heating units and axial fans (Termotecnica Pericoli, Italy) consumed electricity of 1.1 kW/h. There were 7 fans and two heating unit fans (4 and 6 kW/h each). Therefore, for a 5 h disinfestation process 88.5 kW/h was needed, this accounted for 4.05 kW/h per tonne. Considering the price of kW/h in Israel ($US 0.14) and LPG price ($US 0.026) continuous heating costed 3.05 $US/tonne.

Table 1. Energy (kW) needed to thermal disinfest a tonne of dates and their direct costs based on different energy sources.

Type of thermal disinfestation	kW	Direct cost ($US/tonne)
LPG based, constantly heating ("Tzemach")	99.52	3.05
Combined solar & LPG, alternately heating ("Tzemach")	29.58	0.91
LPG based, constantly heating ("Timura")	40.84	1.89
Combined solar & LPG, alternately heating ("Timura")	21.75	1.39
Solar based ("Timura")	1.99	0.67

In another scenario, on hot sunny days the energy consumption at "Tzemach" facility stands on 30%. Therefore, when the heating units were operated intermittently the cost was 0.91 $US/tonne.

"Timura" facility contained a single batch, maximum 60 tonnes dates. Therefore, 3 kg LPG were needed to disinfest 1 tonne dates (38.19 kW/h/tonne). In "Timura" there was one main heating unit fan (5 kW) with 20 fans (0.7457 kW/h each) for each channel. Since this facility was much bigger than that of Tzemach, 4 h preheating were needed to reach the target temperature of 50^{o}C. Therefore, the disinfestation process in "Timura" required 8 h in total where the energy consumption was 2.65 kW/h/tonne derived from electricity and 38.19 kW/h/tonne derived from LPG consumption. Therefore, when installation heaters were continuously in operation, the total disinfestation cost was 1.89 $US/tonne.

On hot sunny days when the heating units were operated intermittently, the energy costs were for moving air by fans using 21.75 kW/h/tonne (1.39 $US/tonne).

The least energy needed, hence, the cheapest thermal disinfestation method was solar based disinfestation in "Timura" which needs 1.99kW and costs 0.67 $US/tonne derived only from the fans.

Table 2 summarizes the external costs derived from their carbon equivalent emissions for disinfestation of 1 tonne of dates in two thermal disinfestation facilities compared to fumigation with MB and VAPORMATE^{TM}. It is clear that the larger the amount of carbon equivalent was emitted (e.g., the carbon footprint), the higher was the external cost. The cheapest total cost was obtained for thermal disinfestation derived from solar energy (0.67 $US/tonne with $0.38*10^{-3}$ carbon equivalents/tonne) and surprisingly fumigation with MB gave carbon emission ($0.40*10^{-3}$ carbon equivalents/tonne) close to solar energy system but at a higher total cost (3.553 $US/tonne).

DISCUSSION

Results indicated that the most effective disinfestation technology both economically and environmentally was the use of solar energy. Similarly, in the analyzed thermal disinfestation method, the lowest carbon footprint ($0.38*10^{-3}$ carbon equivalents/tonne), was obtained using solar energy. Thermal disinfestation method was found as an appropriate alternative technology to MB in all senses; biologically to achieve complete disinfestation including the egg stage, environmentally and economically (Navarro, 2011).

Table 2. External and total costs, carbon equivalent (tonne) emitted from each disinfestation method for disinfesting dates.

Type of disinfestation	**Carbon equivalent (tonne) / tonne dates disinfestation**	**External Cost ($US/tonne)**	**Total cost ($US/tonne)**
Thermal-LPG based, constantly heating ("Tzemach")	$8.05*10^{-3}$	0.157	3.207
Thermal-Combined solar & LPG, alternately heating ("Tzemach")	$2.41*10^{-3}$	0.047	0.957
Thermal-LPG based, constantly heating ("Timura")	$3.45*10^{-3}$	0.067	1.957
Thermal-Combiend solar & LPG, intermittently heating ("Timura")	$1.85*10^{-3}$	0.036	1.426
Thermal-Solar based ("Timura")	$0.38*10^{-3}$	0.007	0.677
Fumigation using MB at 300 g/tonne	$0.40*10^{-3}$	0.008	3.553
Fumigation using VAPORMATE™ at 2850 g/tonne	$0.64*10^{-3}$	0.012	90.012

The carbon footprint includes activities of individuals, populations, governments, companies, organizations, processes, and various industry sectors. Analyzed products include goods and services. In any case, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream and downstream) need to be taken into account (Weidema *et al.,* 2008). To simplify the calculations and to provide a clear solution, the stable/constant variants in this work, since they were the same for each disinfestation method, were not taken into account (e.g., 1- Check in and check out of dates from the disinfestation facility, 2- management, general and professional supervision on the process and 3- packing containers of dates (i.e., costs of Medjool trays), and 4- factory boxes (used in handling and disinfestation of other date varieties than Medjool and vats).

In boxes where the airflow through the bulk of dates was above 1.4 m/s the target temperature of 50^oC was achieved within 3 h from the start of the heating of the chamber, and at higher airflow rates same results were achieved within 1 to 2 h (Navarro, 2011). Although actions were made to prevent energy loss by achieving adequate sealing and improving circulation with fans to achieve homogenous air distribution, Table 1 shows that solar energy absorbed by "Timura" facility is greater than "Tzemach" facility, where the disinfestation process lasted longer time.

According to Montréal protocol an alternative would be implemented and accepted if it is proven to be economically feasible. The above suggested alternatives to MB have been approved and are in use in Israel. In spite of the high price of VAPORMATE™, due to shipping and handling, efforts are being made currently to reduce its price (personal information). Although VAPORMATE™ according to Montréal protocol is environmentally user friendly, there is no consideration on its impact on the environment as an alternative to MB. It seems that when the thermal disinfestation alternative is improperly used, it has a much harmful impact on the environment than MB or VAPORMATE™. However, one must not be mistaken by the carbon footprint only, since the carbon equivalent emitted by the MB fumigation has much more harmful impact on the environment, since the damage caused to the ozone layer is irreversible compared to the pure carbon emitted to the environment (Walter, 2009).

CONCLUSIONS

Thermal disinfestation method of dates was found as a suitable alternative technology to the methyl bromide fumigation both from environmental and economical aspects. To reduce the carbon footprint impact of thermal disinfestation process, solar energy absorbing ability of the disinfestation installations must be maximized by providing a transparent cover of the unit, sealing the disinfestation facility, and by providing appropriate circulation of the hot air at recommended rates.

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