A REVIEW OF VAPORMATE™ (ETHYL FORMATE & CO2): AN EFFECTIVE POST-HARVEST FUMIGANT

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I. Introduction

The Montreal Protocol's phase out of methyl bromide has left the post-harvest agricultural industry with few viable alternatives. Historical and recent research has shown that ethyl formate is an effective alternative for a variety of post-harvest scenarios. The Linde Group's proprietary VaporMate™ technology uses gaseous carbon dioxide (CO_2) to deliver non-flammable ethyl formate for post-harvest fumigation.

Research highlighting the product's efficacy has been performed for crops which include: grains, oilseeds, fresh and dried fruit, fresh vegetables, tubers, legumes, nuts, and flowers. Treatment schedules for probit-9 security levels of control for pests of concern have been developed. These schedules indicate the ideal dosage rate, exposure time, and conditions required for a successful fumigation.

VaporMate™ has been successfully registered in several countries, where it has been well received by former methyl bromide users for post-harvest applications. The Linde Group is currently in the process of pursuing registration for its use in several countries in the Americas, Asia, and Europe.

II. Background

Ethyl formate (the active ingredient of VaporMate™) is a naturally occurring chemical that appears in a wide range of foods, particularly in fruit, grain, and dairy products. (Desmacerchelier 1999). It holds "generally regarded as safe" (GRAS) status with the US Food and Drug Administration (FDA) for its use as a food additive. It is a low molecular weight volatile compound which can potentially degrade to biogenic levels before treated product reaches the market (T. Simpson 2004). This presents a significant advantage over traditional pesticides, particularly so when considering the plethora of regulatory and financial challenges resulting from maximum residue levels required for exports. In addition to these advantages, ethyl formate fumigations are rapid and comparatively less toxic from a worker safety perspective than methyl bromide and other comparable fumigants.

Ethyl formate is not without its challenges, which historically included its flammability and registration efforts (Armstrong 2014). The flammability aspect has been eliminated

through Linde's VaporMate™ delivery system, which reduces the concentration of the product to below its flammability level in air while still achieving complete mortality of pests.

Despite its effectiveness at fumigation, the potential return on investment for ethyl formate is restricted due to the size of its target market. The cost of development and registration of a pesticide is at historically high levels, and has thus deterred agrochemical companies from investing in the product. However, gradual and continual efforts have led to The Linde Group now successfully having attained registrations and labels for the products in Australia, New Zealand, South Korea, Indonesia, Malaysia, Israel, and the Philippines. Similar registration efforts are underway in various countries in the Americas, Asia, and Europe where market interest has been established.

III. Recent Research

This paper seeks to focus on recent breakthroughs in VaporMate™ efficacy studies; see Table 1 in the Appendix for a full listing of the pests for which VaporMate™ has been found effective at for achieving complete mortality.

While the key strength of VaporMate™ is achieving mortality of external feeding pests, Mitcham et al. (2010) reported complete control of internal feeding bean thrips in commercial scale fumigations performed on navel oranges. Bean thrips were forced into the navels of the oranges by dropping the ambient temperature prior to commencement of the trials. Dosage rates of 7.3 g/m^3 VaporMate™ were found to be 100% effective at temperatures as low as 5°C. Evaluations of the fruit appearance and quality were performed (1) after the fumigation and (2) three weeks after completion of the fumigation, and no significant fruit damage was reported as a result of the fumigation.

Asian citrus psyllid (*Diaphorina citri*) is a pest of major concern for the global citrus industry because it is a vector of the citrus disease Hunglongbing (citrus greening disease). The disease is responsible for the destruction of several citrus industries in Asia and Africa (Manjunath 2008). The effect of citrus greening disease's introduction to the US has also been drastic. The Florida citrus industry reported a 50-year low point in citrus production, with a ~60% reduction in production volume between 1999 and 2015 (USDA-NASS 2010). VaporMate™ has been found to be effective at achieving complete mortality of Asian citrus psyllid at relatively low dosage rates (~5g/m^3) applied over a 1 hour period (Mitcham et al, 2017).

IV. Conclusion

VaporMate™ presents an alternative to methyl bromide for post-harvest applications, which is both effective and safer than traditional pesticides from a worker safety standpoint. Although ethyl formate is a naturally occurring chemical, it has insecticidal properties which makes it very desirable as a post-harvest fumigant. The Linde Group continues its efforts across the world to register VaporMate™ for post-harvest applications.

Appendix I

Table 1: A comprehensive list of commodities and pests for which Vapormate™ fumigation efficacy data has been collected.

Commodity	Insect
Cereal grains and oilseeds	Lesser grain borer, flour beetle, psocids (various), storage moths, saw-toothed grain beetle, flat grain beetle, rice weevil
Leafy vegetables	Aphids (various)
Onions	Onion thrips
Sweet pepper / capsicum	Western flower thrips
Tubers	Detritus moth
Bananas	Mites, mealybugs, scale
Pineapples	Mites, mealybugs, scale, koya, hana, kutu daun
Grapes	Light brown apple moth, redback spiders, long-tailed mealy bug, two-spotted spider mite, western flower thrips, plague thrips, grape mealybug, aphids (various), pacific spider mite
Strawberries	Western flower thrips, two spotted mite
Kiwifruit	Oleander scale, long tailed mealybugs
Blueberries	Light brown apple moth, long tail mealybug
Persimmons	Light brown apple moth, long tail mealybug
Flours, dried fruit, nuts, dates	Lesser grain borer, flour beetle, psocids (various), storage moths, saw-toothed grain beetle, flat grain beetle, rice weevil, nitidulid beetles
Cut flowers	Thrips, white flies
Citrus	Thrips, light brown apple moth, fullers rose weevil, long tailed mealybug, citrus mealy bug, Asian citrus psyllid, red scale, mites
Cocoa	Broad mite, hairy caterpillar, mirid bugs, yellow peach moth adult, cocoa pod borer
Bed bugs	Cimex Spp.

Appendix II – Citations

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