Quarantine Treatments for Pests of Food Plants

EDITED BY
Jennifer L. Sharp
and Guy J. Hallman

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Systems Approaches to Achieving Quarantine Security

Eric B. Jang and Harold R. Moffitt

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The development of quarantine treatments for use against pests that infest food plants arose from the need to protect agricultural interests without prohibiting commerce. Quarantine procedures are necessary to ensure that exotic pests do not enter a geographic location where they do not currently exist. Although the need for establishing quarantine security is practically universal among nations, guidelines for exactly what constitutes quarantine security are not universal. The majority of the quarantine treatments used to ensure that commodities are free from exotic pests have been direct treatments (e.g., heat, cold, fumigants) that assume a high (and frequently unknown) level of pest infestation in the commodity. These treatments are perceived as providing quarantine security if they meet an established mortality level based on laboratory and field efficacy tests. For example, treatments for fruits infested with tephritid fruit flies are usually required to demonstrate mortality of at least 99.9968% (probit 9) or no more than 32 live insects per million of treated insects (Baker 1939). However, many commodities that have been reported as hosts for various pests are at best poor hosts and do not normally sustain high infestation levels in the fruit. In other cases, the host commodity is not infested if certain operational procedures are met (e.g., maintaining fly free areas, harvest at specified maturity, pest-host phenology). In such situations, integrating biological information about the pest, knowledge of the host-pest relationship, and incorporating specific operational factors leading to and including the grading, sorting, and packing of the commodity may be sufficient to meet quarantine security. In some cases, this information alone may provide the
framework for certification without the need for a direct treatment. The integration of such biological and operational factors into a viable system of procedures that will itself meet quarantine security is the topic of this chapter. In it are discussed the concepts that comprise the systems approach, definition of a system, and differentiation of systems approaches from direct quarantine treatments or multiple treatments.

The systems approach to quarantine treatments is a concept that has evolved in response to the need to consider the various preharvest and postharvest biological factors that can influence the level of infestation leading to and including the sorting, packing, shipping, and marketing of commodities. To understand the systems approach and how it differs from other methods used to certify that a commodity is free from a pest, one must define the terms that will be used in this chapter and clarify how the systems approach differs from methods described in other chapters included in this book. The systems approach can be defined as the integration of those preharvest and postharvest practices used in production, harvest, packing, and distribution of a commodity which cumulatively meet the requirements for quarantine security. Systems approaches integrate biological, physical, and operational factors that can affect the incidence, viability, and reproductive potential of a pest into a system of practices and procedures that together provide quarantine security.

**Comparison of Systems Approaches with Other Quarantine Methods**

Systems approaches (hereafter referred to as systems) differ from other methods such as direct treatments in that they integrate biological and operational factors to meet quarantine requirements. Unlike commodities that are considered nonhosts, systems recognize that the commodity in question is a host, the level of infestation in the host being the key component in the design of the overall system. Systems rely on knowledge of the infestation level of the host and measure the impact of the various operational procedures on removing infested hosts, thereby reducing the risk that infested fruits will be shipped. Systems can be differentiated from single quarantine treatments such as fumigation, heat, cold, irradiation, and atmospheric modification (modified or controlled) in which the treatment alone is sufficient to ensure quarantine security. Systems should also be separated from the concept of combination and multiple treatments. Combination and multiple treatments are comprised of two or more direct treatments each of which, if used alone, would not be sufficient to achieve quarantine security (Chapter 16). Each part of
combination and multiple treatments must have a calculated level of security that, when combined, will ensure adequate security. However, a direct treatment can be a systems component if the treatment alone will not provide adequate security, but in combination with other (operational) parts of the system will provide quarantine security. This working definition of how systems are used in providing quarantine security can be better understood within the context of a larger discussion of how specific components of systems work and relate to each other.

Components of Systems

Because systems attempt to integrate biological, physical, and operational factors into coherent practices, the repertoire of techniques which could be considered as part of systems is large and diverse. For the purpose of this discussion we have chosen to identify several key components that can be included in systems. However, it must be emphasized that within each component are several practices that can be combined in different ways with other components to develop systems. A generalized flow chart showing the components of a system is shown in Figure 15.1.

Production Component

Systems should integrate all available production practices that reduce or limit the pest population in the field. Thus, integrated pest management (IPM) practices are frequently part of systems. Normal IPM practices usually rely on inherent knowledge of the biological status of the pest with regard to the host in question. This information is the foundation from which accurate assessments are made regarding the use of other systems components. Pest surveys and sampling are routinely used in IPM programs to define economic thresholds or economic injury levels of the crop being grown. Predictive models are frequently helpful to determine initial and ongoing pest population levels. Results of surveys and samples could trigger the use of pest management practices to reduce population levels in the field.

Shipments of Florida-grown grapefruit to California include a field monitoring program and bait sprays as part of the system to ensure that areas are free from Caribbean fruit fly, Anastrepha suspensa (Loew) (Chapter 14). Apple growers in the Pacific Northwest area of the United States (U.S.) monitor codling moth, Cydia pomonella (L.), field population levels and integrate this information to determine an appropriate use of selective chemical sprays when a certain economic threshold is reached.
FIGURE 15.1. Components of the systems approach to achieving quarantine security. Movement to a subsequent level is dependent on meeting pest incidence thresholds (PIT) or appropriate control measures must be initiated.
Systems should rely on production estimates of field populations at harvest. More importantly, there is a need to improve correlations between field populations and resulting in-field infestation levels at harvest that impact systems.

**Preharvest Component**

The preharvest component of systems uses information on the pest’s interactions with the host commodity at or about the time of harvest to further reduce the risk that a commodity entering the postharvest chain will be infested. Accurate knowledge of the infestation biology of the pest and the commodity at the time of harvest along with knowledge of the fruiting phenology and ripening of the host commodity may reveal specific seasonal periods where infestation would not occur or would be light. Components showing pest-host asynchrony in certain geographic locations, the use of specific fruit selection criteria such as ripeness, hardness, and color, or specific harvesting techniques meant to reduce or alleviate infestation, all have been included as parts of proposed systems for different commodities. Progress in these areas has been made in the use of this component in systems. Emphasis on better knowledge of the infestation levels and biologies of quarantine pests should continue in the development of systems. Yokoyama et al. (1992) suggested that California-grown nectarines shipped to New Zealand would not be infested with walnut husk fly, *Rhagoletis completa* Cresson, due to early season asynchrony between the emergence of the pest in walnuts and the presence of early-season nectarine fruits in the San Joaquin Valley. Curtis et al. (1991) surveyed codling moth levels in the field as well as in culled and packed nectarines to determine the incidence of codling moth infestation at harvest. Cousey & Hayes (1986) recommended a fruit selection procedure based on fruit color as part of the double hot water dip system for fruit flies in Hawaii-grown papayas based on the work of Seo et al. (1982) who reported that mature green fruits were seldom infested. This was highly correlated with levels of the chemical benzyl isothiocyanate in green fruit (Seo & Tang 1982, Seo et al. 1983). Armstrong et al. (1983) showed that ‘Sharwil’ avocados while on the tree were not normally a host of fruit flies in Hawaii.

**Postharvest Component**

Historically, most quarantine treatments have focused on the postharvest component of systems as the starting point in the development of direct treatments. The lack of specific knowledge of how the production and preharvest components impact field infestation levels
has hindered the development of true systems, leading to treatments where maximum infestation levels were assumed. Central to the success of any systems to quarantine treatments is the determination of an initial threshold or tolerance level of infested fruit upon arrival at the packing house. This assessment is the key to determining the effectiveness of any subsequent operational procedures (including direct treatments) aimed at removing remaining infested fruit. The initial tolerance level upon arrival at the packing house should be low enough to ensure that subsequent procedures will remove remaining infested fruit sufficient to provide quarantine security. Specific packing house procedures can include but are not limited to culling, grading, sorting, and packing. Knight & Moffitt (1991) found that several factors including the degree of injury in the fruit upon arrival at the packing house, volume of apples sorted per worker second, and the appearance and size of injury all affected the culling procedure. A mean 84% of codling moth-injured fruits were removed by culling, with initial injury levels of 0.2 – 35% to the fruit upon arrival at the packing house. Direct treatments used as a component of systems would be those not providing quarantine security when used alone. However, when used in conjunction with production and/or postharvest components, these direct treatments contribute to systems that provide quarantine security. Packaging of the commodity to ensure that reinfestation does not occur could include methods such as shrink wrapping (Jang 1990) or the use of specially designed boxes to prevent possible reinfestation.

Final Inspection and Certification

Final inspection of the packed product is necessary to ensure that the product to be shipped has gone through the proper inspections/treatments. Certification, normally carried out by the importing country, can be included as part of the final inspection. Although most of the final inspection certification is currently done prior to shipment (e.g., security was determined prior to shipment), certification at destination is another option that needs to be considered as part of systems to quarantine treatments. Couey et al. (1984) developed a system for Hawaii-grown papayas that included an in-transit cold treatment that would be certified at destination.

Marketing and Distribution

Perhaps the least studied area in systems is the marketing and distribution of the commodity and its impact on pest risk assessment. Most commodities are divided into smaller units upon arrival at the
destination and then further divided as they enter retail marketing channels. The impact of such further divisions, and the determination of exactly what makes up a unit for the purpose of risk assessment at destination, has not been well defined. Lacking such a consensus, the ability to realistically factor this information into systems will be limited. Including biological factors into systems requires knowledge of the postharvest biology of the pest in question to determine the probability of a mating pair arriving at the same destination or location in the importing country. Vail et al. (1993) studied the biological factors as well as postharvest packaging and distribution practices that would normally be a part of the marketing system in Japan in assessing quarantine security against codling moth inside in-shell walnuts shipped from California. Better knowledge of such systems would serve to further identify how operational factors and biological factors could be integrated into more comprehensive systems.

There are many ways in which each of the above components could be integrated to form a system providing quarantine security. The ability of any one of the components to impact the pest population and subsequent infestation will usually be dependent on that component alone. However, the success of that component will impact the success of subsequent components that make up a system. At each step, assessment of the pest incidence threshold allows for the determination of how subsequent components of a system will impact infestation levels. For example, the success of a system that uses culling, sorting, and packing of a commodity in lieu of a direct treatment would be dependent on a low tolerance level for the pest upon arrival at the packing house (i.e., production and preharvest methods combining to reduce initial infestation) as well as a calculated efficiency in removing damaged fruit on the packing line.

**Systems to Achieve Quarantine Security**

Systems to achieve quarantine security have been used in the past although perhaps not widely recognized. Specific examples of systems and how systems are integrated to provide quarantine security are discussed for apple, cherry, papaya, in-shell walnut, and watermelon.

**Export of Pacific Northwest Apples and Cherries**

The Pacific Northwest currently ships apples and cherries to several Pacific Rim countries using systems to ensure that these fruits are not infested with codling moth. Apples are a preferred host of codling moth
while cherries are a rare or sporadic host in the U.S. (Moffitt 1990). The system used for apples includes control of codling moth in the orchard (production); inspection of harvested fruit on arrival at the packing house with rejection of those lots not meeting the packing house’s established standards; grading, sorting, and packing emphasizing removal of codling moth injured fruit (postharvest); and a final inspection and certification that quarantine security has been achieved. In his study of a system used for export over a two year period, Moffitt (1990) found that only 10 out of 171,448 culled apples were infested with codling moth. None of the 501,537 apples examined from boxes packed for export were infested. Also, data from the Washington State Department of Agriculture showed that only 33 of 41,397,020 apples inspected for export over a five year period were infested. These data strongly support the use of systems for quarantine security for apples without need for a specific single treatment. Similar systems without the orchard control program are currently used for cherries shipped to Japan and Korea (Moffitt, 1990). Data gathered from the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (USDA-APHIS-PPQ), and the Pacific Northwest cherry industry on the incidence of codling moth larvae in shipments to Japan and Korea over an 11 year period showed that only two larvae in an estimated 316 million cherries have been found. Japan, however, continues to require a direct treatment such as methyl bromide as part of their certification of imported cherries. Both systems would meet or exceed the standard probit 9 (99.9968% mortality) level of security without the need for a specific postharvest treatment.

**Shipment of Hawaii-Grown Papaya to the Mainland U.S.**

Papaya grown in Hawaii can be infested with tephritid fruit flies such as Mediterranean fruit fly, Ceratitis capitata (Wiedemann), oriental fruit fly, Bactrocera dorsalis (Hendel), and melon fly, Bactrocera cucurbitae (Coquillet). For the past several years, papayas were allowed to enter the U.S. based on a system developed by Couey & Hayes (1986). Their system was composed of a preharvest fruit selection procedure based on an objective measurement of fruit color and a two stage hot water treatment to ensure that immature insects in the fruit would be killed. Then fruit was inspected visually prior to packing and certification. In developing this system, the authors referred to work by Couey et al. (1984) which reported that fruit less than one-quarter ripe was rarely infested in the field and showed that the two stage hot water treatment was sufficient to kill eggs near the surface of the fruit. The subsequent discovery of a blossom end defect in some fruits that allowed larvae to
migrate deep inside the seed cavity (Zee et al. 1989) resulted in an additional visual inspection requirement to remove blossom end defective fruit prior to packing. This system used information on the infestation biology of the insects (Seo et al. 1982) as well as knowledge of the chemistry of the fruit (Seo et al. 1983) to minimize the chance of infested fruit arriving at the packing house. The two-stage hot water dip incorporated the standard dip for disease control with a second dip required for insect control.

Earlier, Couey et al. (1984) developed another quarantine treatment system based on the fruit selection criteria discussed above. With this system, the fruit selection procedure was followed by the standard hot water dip for disease control (49°C for 20 min) followed by an in transit cold treatment (8 - 9°C for 10 d). Final inspection and certification occurred at destination using information from temperature monitors within the shipping container.

**Shipments of 'Sharwil' Avocados to the U.S. Mainland**

A system has been used to meet quarantine requirements for the export of Hawaii-grown 'Sharwil' avocados to the mainland U.S. (Armstrong 1991). It consisted of harvesting only 'Sharwil' avocados with the stem attached, shipping to a certified fruit fly-free packing house within 12 h, sorting and culling procedures to remove damaged fruit prior to packing, final inspection, and certification. This approach was based on the fact that 'Sharwil' avocado is not a host of fruit flies as long as the fruit is attached to the tree (Armstrong et al. 1983, Armstrong 1991).

Several other examples of systems used to satisfy quarantine security have been reported. Yokoyama et al. (1992) recommended a system for the shipment of stone fruits to New Zealand which would ensure that fruits would not be infested with walnut husk fly. The system incorporates a fly free period during which early-season stone fruits could be harvested and exported prior to adult emergence. A methyl bromide fumigation would be used to ensure that no flies exist in fruit packed later in the season. Final inspection and certification would follow fumigation.

Curtis et al. (1991) reported that codling moth is rarely found in California-grown nectarines (based on preharvest trap surveys and postharvest monitoring of culled and packed fruits) and has calculated worst case estimates. The estimates show that the highest number of codling moth larvae that might be present in a given transoceanic van shipment (27,500 - 81,500 fruit per container) are 0.65 - 1.94 larvae per
shipment. Based on these data, <24 codling moth would be found per one million nectarines 95% of the time, which would exceed the probit 9 level of quarantine security. They suggested a system for nectarines aimed at providing quarantine security without the need for a direct postharvest treatment. Their system included integrating inspection of harvested fruit on arrival at the packing house, with rejection of those lots not meeting established standards, grading, sorting, and packing procedures emphasizing removal of fruits damaged by codling moth, and final inspection/certification of nectarines in the box as packed for export.

Vail et al. (1993) proposed a system for ensuring quarantine security for codling moth inside in-shell walnuts. Their system incorporated information on infestation levels at harvest and thoroughly analyzed the postharvest biology and survival of the insect in relationship to the movement of the walnuts through normal marketing channels. Specific parameters studied for their impact on the probability of eventual survival of a mating pair of adults at a location included population of codling moth at harvest, age distribution and survival on harvested nuts, emergence patterns of male and female moths, mating behavior, and the myriad marketing factors that are involved in shipping walnuts. Each factor could impact the probability of insect survival for quarantine security.

Cowley et al. (1991) described a system that included a direct methyl bromide fumigation treatment to disinfest Tongan watermelons infested with Bactrocera xanthides (Broun) for export to New Zealand. Their system incorporated biological information regarding the probable infestation level of export quality melons with a treatment sufficient to meet New Zealand’s quarantine security level (Baker et al. 1990). Baker (1990) also discussed the use of systems practices as part of New Zealand’s bilateral quarantine agreements with countries importing fruit fly host material into that country. Systems practices are used to reduce the risk that a particular shipment of commodities arriving at a specific location on a given day does not exceed New Zealand’s maximum pest limit (Baker et al. 1990).

Future Technology Using Systems

It is apparent from the above discussion that systems are complex and rely on sound information on the pest biology and how preharvest and postharvest operational parameters affect pest infestation levels to ensure that quarantine security can be achieved. Systems are being incorporated into the quarantine treatment programs as successful examples of systems and their use emerge. For systems to gain greater
acceptance by regulatory decision makers, industry, and the public, progress must be made towards improving and quantifying knowledge of the complex interactions between the pests and their hosts. A realistic goal must be established to determine how these interactions integrate into the complex packing, shipping, and marketing channels that most commodities enter. This integration of information makes systems useful and unique.

Until recently, research focused on the uses of direct treatments having the ability to kill insects at any level of infestation. However, the narrow margin that separates the efficacy of many of these treatments against insects and the potential of damage to the commodity requires new analysis of conventional paradigms that rely solely on the use of direct quarantine treatments. Increased concern over the use of toxic compounds should serve to additionally focus attention on meaningful and effective alternatives. All available knowledge on the pest in question must be incorporated to develop viable alternatives to achieve quarantine security. What constitutes a quarantine risk should rely heavily on our knowledge of the biological interactions between the pest and its host rather than "perceived risk." The use of this knowledge will better define quarantine security through knowledge of the complex interactions that impact production, shipment, and marketing of commodities.

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