行政院及所屬各機關出國報告
（出國類別：研習）

國際農業合作計畫(植物有害生物風險評估與風險溝通機制及邊境檢疫管理措施決策-澳大利亞)

服務機關：行政院農業委員會動植物防疫檢疫局
出 國 人　職稱：技士　　　　姓名：楊世綵
出國地區：澳大利亞
出國期間：民國 108 年 9 月 22 日至 9 月 27 日
報告日期：民國 108 年 12 月 5 日

目次

摘要

近年來國際貿易活動頻繁，我國亦推動新南向等國際化相關政策，外國農產品市場進入議題及風險評估案件逐日增加。為提升檢疫作業效能，兼顧有效風險管理，受訓人員於 108 年 9 月 22 日至 27 日赴澳大利亞農業部 (Department of Agriculture, DA) 瞭解該國針對有害生物及農產品風險評估之作業方式、風險管理措施之決策過程與風險溝通機制等，藉以強化國內現行植物產品及有害生物風險評估作業模式。研習內容包括：澳大利亞輸入生物安全風險分析作業程序及其負責部門、其與利害關係者之風險溝通架構與實務、針對果實蠅之防檢疫政策、該國檢疫規定線上資訊平台 Australian Biosecurity Import Conditions (BICON) 及 Atlas of living Australia 生物系統資料庫之建構、操作、概念及維護、出口檢疫作業流程等，並參訪 Plant Health Australia (PHA)、The Commonwealth Scientific and Industrial Research Organization (CSIRO) 等相關研究執行單位及隔離檢疫 (PEQ) 實務操作設施。本次研習囊括生物安全制度、政策及實務課程，藉由參考他國生物安全體系架構，有助於調整我國邊境植物檢疫管理措施之決策模式及實際應用，提升檢疫效率。對於精進我國現行對於特定植物、植物產品以及特定物品之檢疫規定、植物病蟲害監測、首次輸入風險評估、有害生物風險評估等做法，以及進一步協助我國農產品輸往澳大利亞有所助益。

前言

由於近年來國際貿易日益頻繁，我國亦推動新南向等國際化相關政策，外國農產品市場進入議題及風險評估案件日漸增加，生物安全政策之制定、系統架構之建立成為植物檢疫作業中重點一環。本局目前執行農產品市場進入申請案及風險評估案件，部分係透過科技計畫委請大學院校及試驗單位專家協作，與美澳等檢疫高度發展國家之作業流程有相異之處。為向檢疫發展先進國家學習，瞭解其針對有害生物及農產品風險評估之作業方式、風險管理措施之決策過程與風險溝通機制等，以強化國內現行植物產品及有害生物風險評估作業模式，提升我國檢疫作業效能，兼顧有效風險管理，並將相關風險評估案件之有害生物疫情資料與分析評估資料進行系統性整合及運用，本局以行政院農業委員會 108 年國際農業合作計畫項下之「植物有害生物風險評估與風險溝通機制及邊境檢疫管理措施決策(澳洲)」計畫，辦理赴澳大利亞研習其有害生物及農產品風險評估之作業方式，及其風險管理措施之決策過程與風險溝通機制等課程，冀藉由實地前往學習觀摩及瞭解澳國植物防疫檢疫規定及措施、有害生物檢查監測及輸入貨品風險評估機制、風險管理措施決策機制、風險評估最新工具及實際應用於邊境檢疫管理措施之決策模式，提升我國於制定與執行植物有害生物風險評估、風險管理及溝通等政策及邊境檢疫管理實務之技能及效率，並強化檢疫政策制定及執行實務間之連結。此外亦藉本研習深化臺澳雙邊植物檢疫技術措施之合作交流與暢通食品衛生檢驗及動植物檢疫 (Sanitary and Phytosanitary, SPS) 議題溝通管道。

行程紀要

日期	行程
9 月 22 日	23:25 自桃園國際機場搭乘中華航空 CI-057 班機出發飛往澳大利亞墨爾本機場轉機。
9 月 23 日	10:45 抵達澳大利亞墨爾本機場，12:20 搭乘澳大利亞航空 QF-2130 班機赴坎培拉機場，於 13:30 抵達坎培拉。下午與澳洲農業部（Department of Agriculture, DA） Plant Systems and Strategies Branch (PSaS), Technical Capacity Building Assistant Director Ms. Wendy Lee 確認研習行程並進行課程內容初步討論。晚間入住 QT Canberra 旅館。
9 月 24 日	由 DA PSaS, Technical Capacity Building Director Dr. Ian Naumann 於該部位於坎培拉之辦公室介紹本次研習，該部 PSaS Assistant Secretary Mr. Peter Creaser 介紹生物安全議題負責部門。本日課程及討論包括由 Dr. Ian Naumann 講授澳大利亞生物安全風險分析概略；與該部 Stakeholder Engagement Team 成員討論該國風險溝通架構與實務；與該部 Mr. Lyall Grieve 討論該國針對果實蠅之防檢疫政策；由 Ms. Sophie Cools 及 Mr. Darren Pass 講授 Australian Biosecurity Import Conditions (BICON)系統之建構、操作、概念及維護；由 Mr. David Burns 講授該國出口檢疫流程；以及由 Mr. Douglas Kerruish 講授該國風險評估實務等。
9 月 25 日	與 Dr. Ian Naumann、Ms. Wendy Lee 討論風險評估議題後前往 Plant Health Australia (PHA) 機構參訪，並由該機構 General Manager Mr. Rodney Turner 等人介紹該機構負責之風險溝通相關工作，包括產業溝通計畫、緊急防疫措施及果實蠅分類研究。後至 Commonwealth Scientific and Industrial Research Organization (CSIRO) 參訪，由 Dr. Mike Hodda 等人介紹高影響物種之入侵途徑分析計畫及 Atlas of living Australia 系統

	資料庫，並參訪該機構位於澳大利亞國立大學之昆蟲標本館，與昆蟲各類群之分類學家交換意見。18:05 自坎培拉機場搭乘澳大利亞航空 QF-833 班機赴墨爾本機場，晚間入住 Ciloms Airport Lodge。
9 月 26-27 日	由 PSaS, Technical Capacity Building Policy Officer Ms. Anjuni Peiris 陪同參訪澳大利亞 Post-Entry Quarantine (PEQ)設施，後自墨爾本機場搭乘澳大利亞航空 QF-460 班機赴雪梨機場轉機，19:55 抵達雪梨，22:10 搭乘中華航空 CI-052 班機自雪梨返回桃園國際機場，9 月 27 日 05:40 抵臺。

研習內容

本次研習由澳洲農業部（Department of Agriculture, DA）安排課程及參訪行程，主要研習項目及內容如下：

一、澳國生物安全風險評估流程、實務及負責部門：由 DA 之 Plant Systems and Strategies Branch (PSaS) Assistant Secretary Mr. Peter Creaser 介紹 DA 之架構及生物安全議題負責部門。DA 架構下分為農林漁業政策、生物安全、輸出貿易與市場進入及水資源、財政法律等四個部門，其中植物及其產品輸入之風險評估由生物安全部門 (Biosecurity) 下之植物生物安全部門負責，該部門又分為科學及風險評估、植物輸入檢疫、植物健康政策、植物輸出檢疫、系統及策略五個組別，分別負責植物檢疫之不同環節。

有關該國生物安全風險分析概況由 PSaS Technical Capacity Building Director Dr. Ian Naumann 講解，並由 Plant Operations Program, Plant Import Operations 之 Mr. Douglas Kerruish 介紹實務作業情形。在 WTO Sanitary and Phytosanitary (SPS) 協定中之適當保護等級 (Appropriate Level of Protection, ALOP) 為有害生物風險分析的基礎。該等級界定入侵有害生物之風險是否可被接受，若不可被接受，則應透過檢疫處理措施，降低有害生物入侵風險至可接受等級。ALOP 為一可由 WTO 各成員國自行訂定之等級，惟該等級一旦訂定後應維持一致性。風險分析流程即為界定有害生物隨貨品入侵風險、估計風險入侵之可能性及入侵後果、並建立可能降低風險措施之一系列程序。

澳國之有害生物風險分析依循國際植物保護公約 (International Plant Protection Convention, IPPC)，包括國際植物防疫檢疫措施標準 (International Standards for Phytosanitary Measures (ISPM) 2 及 11 等之規

範。並可分為例行性生物安全輸入風險分析 Biosecurity Import Risk Analysis (BIRA) ，及非例行性風險分析(Non-regulated Risk Analysis)。BIRA 流程包括執行步驟、時間、出版及諮詢要件、科學諮詢成員參與、發布暫時性報告以與相關人士溝通、獨立人員監察生物安全資料及程序終止等。整個分析流程又可概略分為啟始階段、風險評估及風險管理三階段。值得一提的是，各階段中除進行分析作業外，與任何相關單位或人士之溝通情形皆可能左右分析作業結果，故風險溝通為風險分析中極其重要之環節。

啟始階段係指當新的農產品申請市場進入而鑑定出新的有害生物風險，或重新檢視目前作法時，均可啟動有害生物風險分析。風險評估階段則應界定有害生物可能入侵的地區、植物產品出口地區、有害生物可能入侵途徑及有害生物的種類、入侵的可能性、在有害生物風險分析區域立足與擴散的可能性，對有害生物風險分析區域造成之經濟層面影響等。再依序將評定的結果以評估表格綜合判斷此有害生物是否需進行有害生物風險後續評估及管理。

在評估有害生物立足可能性時，需由相關領域專家比較來源地區與有害生物風險分析地區之生物及環境因子。評估項目包括在目標地區是否具有害生物之適當寄主或替代寄主，以及媒介生物；是否具適合的環境條件；是否已具防治措施；有害生物之繁殖、存活策略，及適應能力，可立足族群數量之最小值等。若專家有意見歧異之情形，須充分溝通並以群體決議之方式做出最後決定。惟澳方亦表示，在評估時通常傾向較為嚴格之評估標準。而因擴散相關研究報告不足，評估擴散可能性則更加困難。目前澳國發展數個模擬程式以評估有害生物之擴散情形，並據實際發生之生物擴散案例所累積之數據反饋以修正模擬程式。

評估有害生物造成之經濟影響，需考慮其對經濟、環境造成之直接、間接影響。直接影響包含有害生物對已知或潛在寄主植物造成危害之方

式、總量與頻率，及對作物收穫量與品質的損失，防治措施的效益與成本等；間接影響包括對國內及國際間市場的影響及對環境造成的風險等。

風險評估獲得之結論，如確認其風險等級高於 ALOP，則需進行第三階段之風險管理。包括禁止輸入或有條件輸入，以檢疫處理降低有害生物風險，如化學燻蒸處理、低溫、高溫、放射線等物理方式處理等。另依據 ISPM 31 規範進行貨品輸入檢疫檢查。

二、澳國風險溝通架構與實務：風險溝通為整個風險分析作業中極其重要一環，利害關係成員間及主政單位與各利害關係成員間皆應積極溝通以交換意見及資訊，達成作業流程透明化，如此方能使風險分析作業順暢及達到降低風險入侵之目的。目前 DA 設有專門之 Stakeholder Engagement Team，負責與所有可能之利害關係成員風險溝通之架構與實務；依據目前該溝通小組之作業程序，於風險分析啟動後，應確定利害關係成員身分，可能包括政府部門、個人、社區組織、產業組織、貿易商、國內外申請者等，建立成員資料庫及相關溝通管道，包括會議、網站、電子郵件、產業的組織或其他通訊軟體等，於分析過程充分提供利害關係成員相關資訊，並確保成員提供意見之管道暢通 (至少每四個月一次)。在風險分析各階段並訂有應與利害關係成員工溝通之明確時段、方式，於最後確定發部檢疫條件前，多次藉各種會議、網站發布等管道讓利害關係成員得以知曉分析進度及表達意見。風險溝通需花費長時間及需要人力參與，惟其在風險分析過程中極為重要，實應建立完善管道及流程。

三、果實蠅之防檢疫政策及執行：與 DA Plant Health Policy Branch, National Policy and Implementation 之 Mr. Lyall Grieve 討論該國針對果實蠅之防檢疫政策，包括依照 ISPM 26 規範建立及維持非疫區；中央 (DA) 與地方單位防檢疫業務之合作；召開集合產官學之會議以確保執行果實蠅之防檢疫等。藉由強力之邊境檢疫加上非疫區域之高度防治管理，確

保維持果實蠅非疫區之狀態，並發展昆蟲不孕技術 (sterile insect technique, SIT) 等方式以維持非疫區狀態或撲滅非疫區爆發之果實蠅疫情，並於發生疫情後通盤檢討可能入侵管道等。目前另發展分子標記技術，未來可望以分子方式確認入侵非疫區之果實蠅來源，以更加確實防堵果實蠅入侵及爆發可能。另澳國農業亦發展農產品可追溯流程，除病蟲害防檢疫目的外，亦為食品安全把關。

四、生物安全相關線上資訊平台資料庫及之建構、操作、概念及維護：由 PSaS Content Change Team 之 Ms. Sophie Cools 及 Mr. Darren Pass 介紹澳國之檢疫條件公告系統 Australian Biosecurity Import Conditions (BICON) 之建構、操作方式、概念及維護，包含網頁後臺管理模式、檢核系統、使用者操作頁面方式、新增資料之時機及程序等。另由 Commonwealth Scientific and Industrial Research Organization (CSIRO) 之 Dr. Mike Hodda 等人介紹 Atlas of living Australia 系統資料庫，此為澳洲生物資料之開放資訊集合介面，可搜尋該國各種生物資料庫之資訊，並可自由上傳及下載該國生物之物種及標本相關資訊，有利於風險分析流程中有害生物及相關生物因子資料之蒐集分析。

五、出口檢疫作業：由 DA Plant Export Operations, Horticulture Exports Program 之 Assistant Director Mr. David Burns 介紹該國出口檢疫流程。澳國為農業出口大國，出口農產品約佔總產量之 70%，每年出口產值可達 500 億澳幣 (約合 1 兆臺幣)，其中園藝作物出口比例約佔總產量之 20%。如此龐大之植物產品出口量，需要一系列完整之規範以確保輸出之農產品能符合輸入國之檢疫及食安要求。澳洲之出口植物安全檢疫流程包含五部分：認證屬性、註冊機構、檢疫檢查、發證、設施查證等，藉系統化管理達成出口檢疫程序。認證屬性指依據輸入國要求，澳洲農產品之生產田區或園區及包裝場皆經政府認證並查證，且由 DA 建立認證設施清單。註冊機構指出口農產品之檢疫檢查應於經政府認證

登記註冊之機構執行。檢疫檢查則由授權檢疫人員 (Authorized Officers, AO) 負責執行。AO 可能是第三方之獨立人員或包裝場、生產點員工，經政府訓練並認證後授權予檢疫執行權力，負責植物輸出產品檢疫檢查。檢查之數量、方式、檢查區域及檢查檯之要求皆有一定規範。澳國並建構輸入國檢疫規定查詢系統 Manual of Importing Country Requirements (MICoR)，使輸出人及檢疫相關人員皆可直接確認輸入國之檢疫規定，確保輸出植物產品之檢疫狀態皆符合要求。發證程序由 DA 負責執行，確認 AO 之檢疫結果及相關文件符合輸入國檢疫要求後製發輸出植物檢疫證明書。

六、參訪 Plant Health Australia (PHA)：由該機構 General Manager Mr. Rodney Turner 等人介紹該機構負責之風險溝通及其他工作，包括產業溝通計畫、緊急防疫措施及果實蠅分類研究。PHA 為非營利組織，負責協調政府與產業成員間植物生物安全議題，使產業及組織可達永續經營。其宗旨為將植物有害生物影響最小化、提升澳洲植物健康狀態、協助澳洲農產品貿易及保障生產者生計等。PHA 目前執行之產業溝通計畫核心包括與產界溝通及教育產界有關植物檢疫及生物安全之重要性，及其對產業之可能影響。另 PHA 亦統合植物病蟲害緊急防治措施，除監測外來有害生物是否入侵，亦於進行緊急防治作業時，協調中央、地方政府與產業界之經費、權責等議題。PHA 並有數個與海外合作之研究計畫，包括果實蠅鑑定圖鑑計畫，本次參訪亦介紹該計畫之書面成果。

七、參訪 CSIRO：CSIRO 為澳大利亞國家級科技研究機構，由 Dr. Mike Hodda 等人介紹高風險物種之入侵途徑分析計畫 (Pathways and Risk Assessment Framework for High Impact Species, PHAFHIS)，該計畫主要以澳洲及紐西蘭過往曾造成高度經濟影響之入侵有害生物為基礎，分析該類有害生物之生物學、入侵路徑、傳播率、可預測性等，以建立其他可能入侵有害生物之風險評估系統。Dr. Hodda 另介紹 Atlas of living

Australia 系統資料庫之架構，並帶領參訪該機構位於澳大利亞國立大學之 The Australian National Insect Collection (ANIC) 昆蟲標本館，與鱗翅目、雙翅目、鞘翅目各昆蟲類群及蟎蜱、線蟲等分類學家交換意見。

八、參訪 DA 位於墨爾本之 Post-Entry Quarantine (PEQ) 設施，該設施隸屬生物安全部門之 Post Entry Quarantine Group，為澳國輸入後隔離檢疫之總園區，自 2015 年後所有澳洲活體動植物輸入後之隔離檢疫皆集中於該設施進行，由中央單位 (DA) 負責執行檢疫。各種動植物類群 (犬貓、馬、禽鳥、蜜蜂、植物等) 皆於獨棟並具不同層級生物安全管理之隔離設施執行隔離檢疫，並設有實驗室，配置檢測人員以確認病蟲害隔離情形。各設施人員進出皆需管制並視不同層級進行消毒、清潔。

心得與建議

一、本次研習，對澳國生物安全風險分析系統之架構及實務有一定了解，其風險分析過程各環節皆有充足人力及經費挹注，使其架構完善，得落實生物安全規範，執行風險評估及輸出入之植物檢疫檢查相關作業，保護該國農業及生物體系。農產品輸出入亦為我國主要經濟活動之一，生物安全對我國農業重要性不言而喻。澳國之風險分析架構值得我國學習。

二、了解風險分析中不可或缺的風險溝通執行方式，為本次研習最大收穫之一。由於生物安全不僅限於邊境檢疫作業，更關係到整體農業及經濟發展。風險評估並非單由政府單位獨立執行即可達成，實需仰賴產業界甚至民眾個人之自覺及理解。因此，政府進行風險分析過程中，有必要充分與利害關係者溝通，使其理解各種分析過程及訂定降低風險措施之理由，最終目的皆在於保護本土農業，實有利於本國經濟，而非無理之限制行為。為確保利害關係者可完全了解此訊息，整個風險分析過程之透明化是不可或缺的。惟有過程透明公開，並可使相關人士皆能充分表示自己的意見，才能達成風險溝通，使各利害關係人能達成一致共識，兼能完成生物安全之保護。

三、風險分析除過程透明化外，另首重科學之客觀證據。澳國之風險分析有強大之研究機構及非營利組織協助提供相關科學證據，並發展科學方法以加強風險分析之準確度及可信度，以及同步建立科學證據資料庫，供風險分析之資料需求。風險分析科學證據之取得方式，包括研究團隊及資料庫等，為我國風險評估作業應強化之一環。

四、澳國將各種生物安全相關計畫委託 PHA 執行，提升執行效率。我國是否有以非營利組織協助執行風險管理作業之可能性，亦為未來可討論之議題。

五、澳國經由充分之風險溝通，使產業界、生產者皆能意識到生物安全管理之重要，防檢疫成為所有相關人士之共識，故得發展農產品授權檢疫檢查之系統，以由產業界支付薪水之授權檢疫人員執行出口檢疫，讓檢疫回歸產業界之自行管理，形成一良好循環；另產界亦願意提供經費於生物安全相關研究及防檢疫措施執行，並長期挹注經費於 PHA 等生物安全作業執行組織，產官學界間有共同目標及良好互動，方能真正落實生物安全，此點非常值得作為我國借鑑學習。

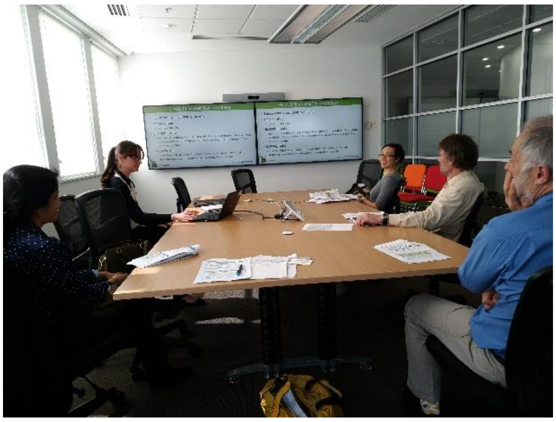
六、感謝 DA PSaS Technical Capacity Building 之 Dr. Ian Naumann、Ms. Wendy Lee 及 Ms. Anjuni Peiris 協助安排本次訓練及陪同參訪行程。

圖片

圖一、與 Mr. Lachlan Parsons (左起)、Ms. Wendy Lee、Ms. Anjuni Peiris 及 Dr. Ian Naumann 合影。

圖二、Ms. Sophie Cools 及 Mr. Darren Pass 講解 BICON 系統。

圖三、參訪 PHA，Mr. Rodney Turner 及其團隊介紹該組織業務。



圖四、參訪 CSIRO，由 Dr. Mike Hodda 等研究人員介紹執行計畫。

圖五、參訪 ANIC 昆蟲標本館。　　圖六、PEQ 園區及隔離檢疫設施。

DEPARTMENT OF AGRICULTURE ORGANISATIONAL CHART

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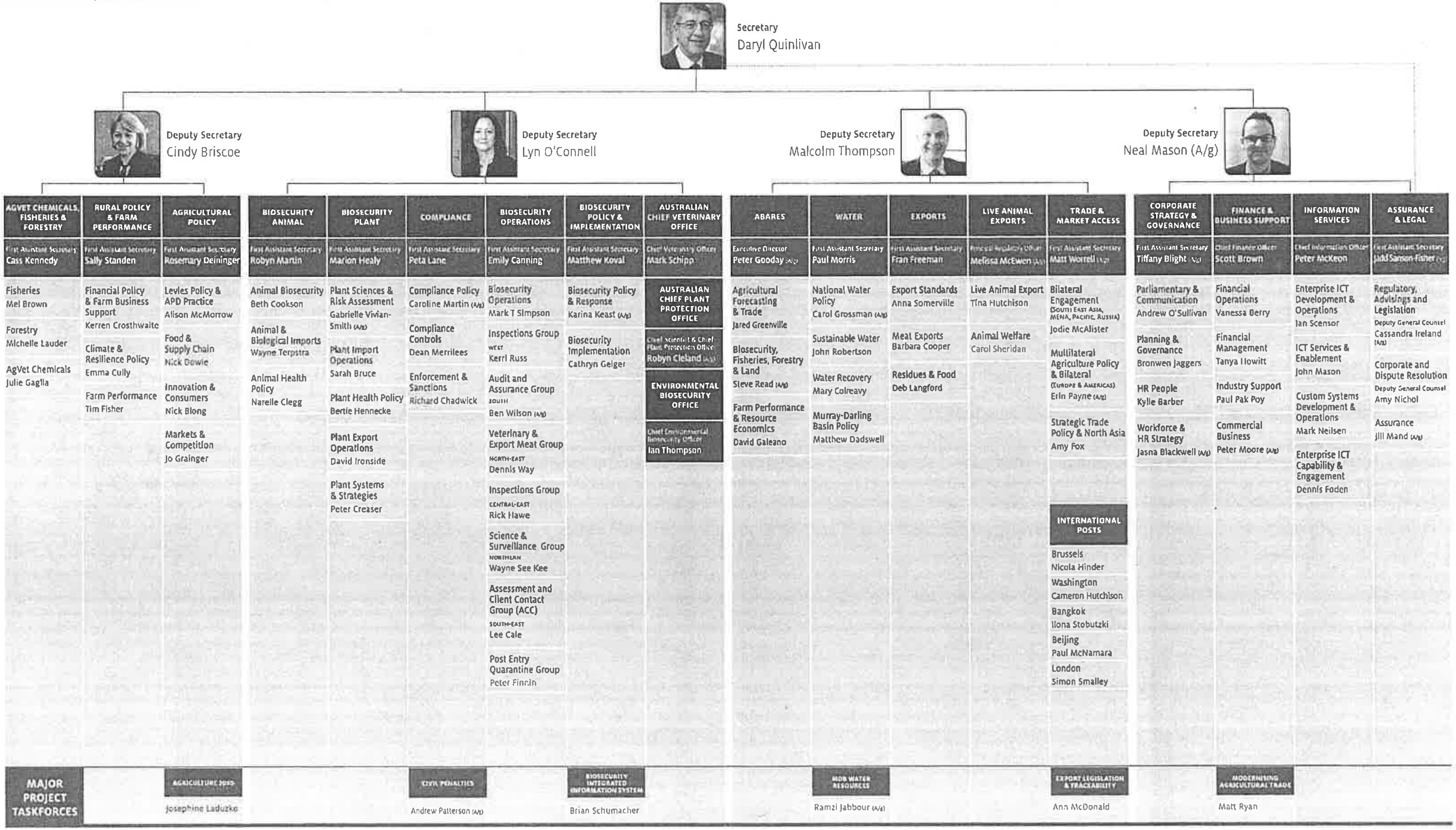
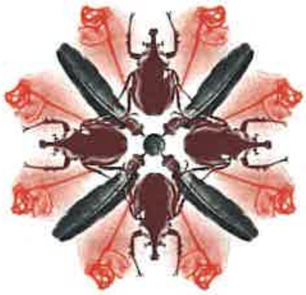


Australian Government
Department of Agriculture

Overview of Pest Risk Analysis (PRA)

Ian Naumann
Technical Capacity Building Section
Plant Systems & Strategies Branch

September 2019
Canberra, Australia



Structure of Presentation

- Purpose of pest risk analysis (PRA)
  - Why conduct a PRA?
- Principles of pest risk analysis
- Components of pest risk analysis
  - Stage 1: Initiation of a PRA
  - Stage 2: Risk assessment
  - Stage 3: Risk management

Purpose of Pest Risk Analysis (PRA)

Increasing trade is generally accepted as good for economies **BUT** more movement of goods **INCREASES** chance of importing a pest

- **Analysis of risk of successful invasion by pests**
  - **Identify risks**
  - **Estimate likelihood and consequences**
  - **Options for mitigation of risks**
- **Justify phytosanitary measures on traded goods**

Principles of Pest Risk Analysis

- **Based on sound science**
- **Structured and transparent**
- **Consistent and repeatable**

- **Guidelines & International Standards**
  - Framework for pest risk analysis (ISPM 2)
  - Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms (ISPM 11)

Terminology

- **Pest:** "Any species, strain or biotype of plant, animal or pathogenic agent, injurious to plants or plant products"
- **Endangered area:** "An area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss"
- **Quarantine pest:** "A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled"

Level of Risk

The SPS Agreement introduces the concept of *Appropriate Level of Protection* (ALOP)

....the level of protection considered appropriate ...to protect human, animal or plant health...

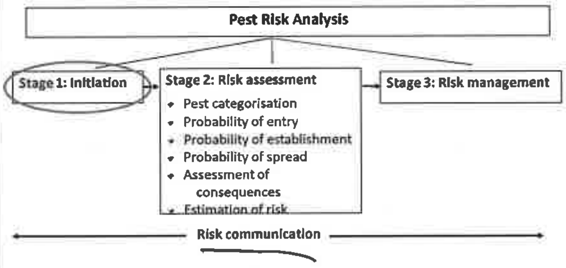
ALOP is the basis in a PRA for determining if the risk is acceptable and, <u>**if not**</u>, what mitigation measures are necessary to bring the risk to an acceptable level

ALOP is a policy setting that each country may set as it chooses

– **ALOP must be applied consistently**

Components of Pest Risk Analysis

IPPC approach to PRA



Components of PRA: Stage 1. Initiation of a PRA

Purpose of the initiation stage is to:

➢ Identify the pest(s) and pathway(s) which are of quarantine concern and should to be considered for risk analysis in relation to the identified PRA area

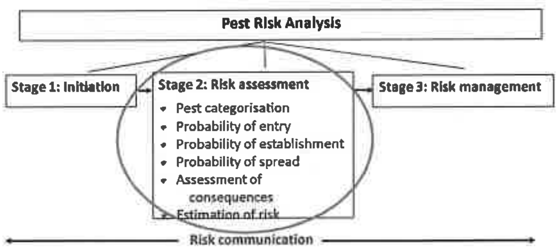
PRA may be initiated by:

- **Identification of a pathway that presents a potential pest hazard**
  e.g. proposal to import a commodity
- **Identification of pest that may require phytosanitary measures**
  e.g. an outbreak of a new pest within an area
- **Review or revision of existing policies and practices**
  e.g. new information or a treatment impacting on an earlier decision

PRAs are most often initiated following a request for market access

Components of Pest Risk Analysis

IPPC approach to PRA



Components of PRA: Stage 2. Risk assessment

Step 1. Pest categorisation

What is pest categorisation?

- Process of determining whether a pest meets the criteria for a quarantine pest

Determining pest status

- Identity of the pest
- Presence or absence in the PRA area
- Regulatory status
- Association with pathway
- Potential for establishment and spread in PRA area
- Potential for economic consequences (including environmental consequences) in the PRA area

Pest	Present in exporting country?	Present in importing country?	Potential to be on pathway	Potential for establishment and spread	Potential for economic consequences	Pest risk assessment required
Order Species Synonyms Family Common names	Yes	No – pest is absent Yes – pest is present and under official control	Yes	Yes	Yes	Yes
	Yes	Yes – pest is present and not under official control	Assessment not required	Assessment not required	Assessment not required	No

Determining pest status

- Identity of the pest
- Presence or absence in the PRA area
- Regulatory status
- Association with pathway
- Potential for establishment and spread in PRA area
- Potential for economic consequences (including environmental consequences) in the PRA area

Components of PRA: Stage 2. Risk assessment

Step 2. Probability of entry

Determine the likelihood of:

- Pest arriving in a country as a result of trade in a given commodity
- Distribution of pest in a viable state to the endangered area

Factors to consider are:

- Probability of pest being associated with pathway at origin (e.g. *orchard – source fruit infested*)
- Probability of survival during transport or storage (e.g. *pest survives packing house procedures*)
- Probability of pest surviving existing pest management procedures (e.g. *pest not detected during on-arrival inspection*)
- Probability of transfer to a suitable host (e.g. *dispersal mechanisms*)

Components of PRA: Stage 2. Risk assessment

Step 3. Probability of establishment

Probability of establishment reflects an expert opinion

- Different to analysis used in deriving probability of entry
  – data often scarce

Factors to consider are:

- Availability of suitable hosts, alternate hosts and vectors in PRA area
- Suitability of environment
- Cultural practices and control measures
- Reproductive strategy of pest and method of pest survival
- Genetic adaptability
- Minimum population for establishment

Components of PRA: Stage 2. Risk assessment

Step 3. Probability of establishment

Probability of establishment reflects an expert opinion

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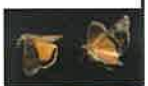
- Cultural practices and control measures
- Reproductive strategy of pest and method of pest survival
- Genetic adaptability
- Minimum population for establishment

Components of PRA: Stage 2. Risk assessment

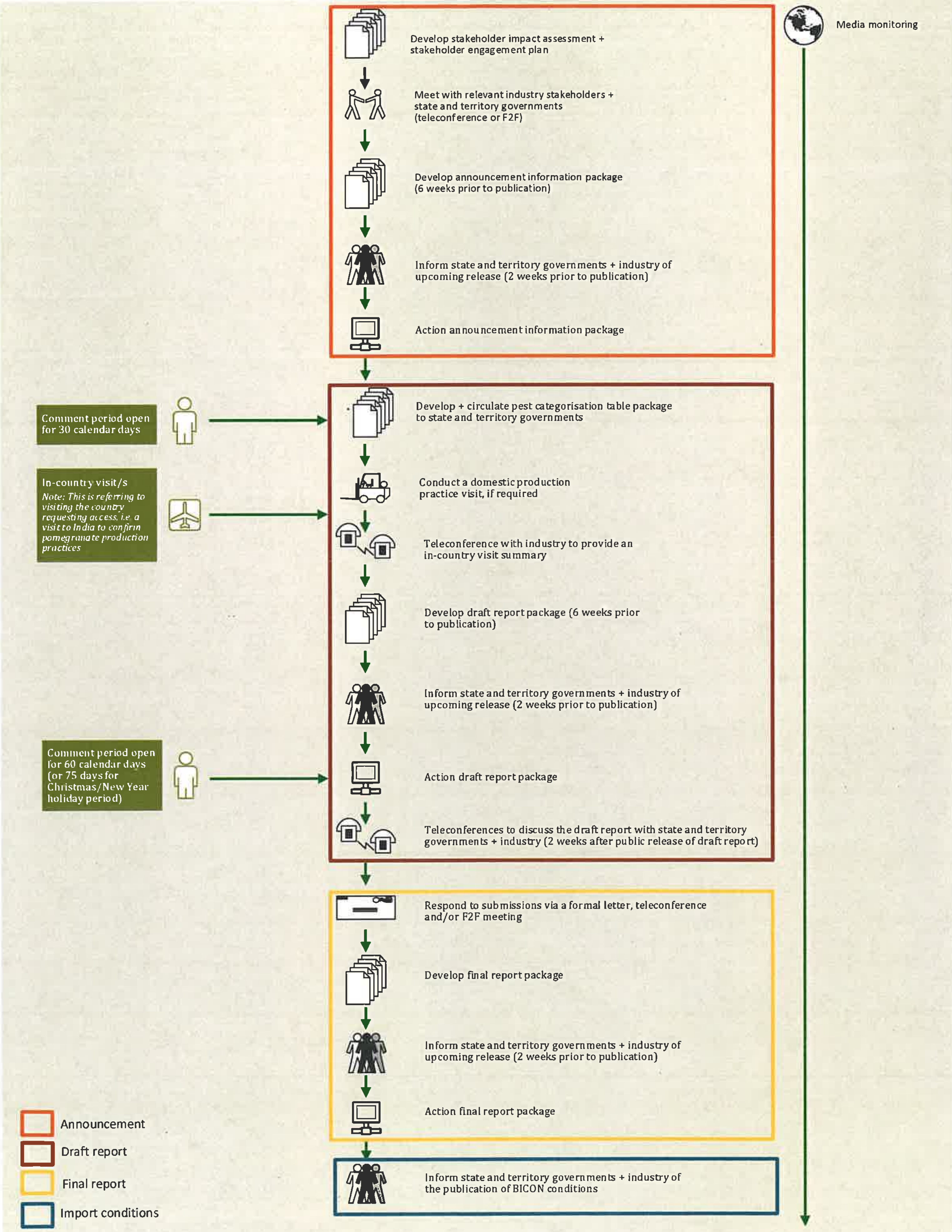
Step 4. Probability of spread

❖ Dispersal characteristics of pest



Stakeholder engagement process

Regular engagement with domestic stakeholders (state and territory governments and industry) is to occur. Stakeholders are to be contacted at least every four months.



Australian horticulture exports

- Around 70% of agricultural production is exported worth about $50 billion annually
- Export almost 20% of horticulture production
- Horticulture exports are forecast to exceed $3 billion in 2018-19, an increase of over $1b since 2014-15

What we do

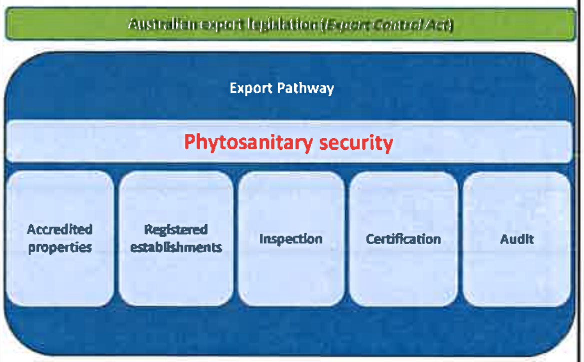
Department of Agriculture:

- Certify documents presented by Australian exporters to ensure compliance with:
  - the *Export Control Act 1982* and subordinate legislation
  - importing country requirements
  - Australia's biosecurity obligations under the International Plant Protection Convention

Export activities

- Provide phytosanitary certification to meet importing country requirements
- Accreditation of growers and packhouses
- Registration of export establishments
- Audit, verification and inspection
- Specified export activities including the issuance of certification are undertaken on a cost-recovered basis

Export Certification System



Key horticulture exports

– 68% of fresh horticulture goes to Asia
– Top horticulture export commodities:

	Commodity	Volume (t)	Value ($m)
Fresh fruit			
1	Citrus	258,196	$427.8
2	Table grapes	110,280	$384.1
3	Melons	20,271	$31.6
4	Summerfruit	17,769	$65.1
Fresh vegetables			
1	Carrots	108,175	$94.6
2	Potatoes	36,529	$28.0
3	Onions	30,516	$21.7
4	Broccoli	5,861	$16.0

Protocol markets

- Protocol markets are countries that have an agreement with Australia prescribing the export requirements for a particular commodity

Manual of Importing Country Requirements (MICoR)

- Provides information about:
  - import permits
  - phytosanitary certificates
  - additional declarations and treatments
  - any other relevant export information and documentation, such as protocols

Growers and packhouses

Accredited properties

- Farms and packhouses need to be accredited
  - if the importing country requires it
  - properties must meet the relevant standards and any importing country requirements
- Properties are audited
- List of accredited farms, packhouses and provided to (some) importing countries

Registered Establishments

Registered establishments

- Goods must be inspected at a registered establishment
- This may be your own establishment, or someone else's

Registered establishments

- To be registered premises must be constructed, equipped and operate in an effective and hygienic manner
- Premises audited at least once a year to assess compliance

Inspection

Inspection of goods

- Prescribed goods must be inspected and certified by an Authorised Officer at a registered establishment
- It is the exporter's responsibility to make sure goods presented for inspection are export compliant
- Live insects and infested goods will not be permitted to leave Australia

Authorised officers (AOs)

- Specifically trained individuals authorised to perform export inspection functions in accordance with Australian export legislation
- Authorised officers
  - are regarded as Australian Government officials
  - may conduct a range of duties depending on the commodity and their training qualification
  - are subject to rigorous verification and audit

Inspection

- Undertaken in registered establishment
  - Clean, lighting, inspection area, no contamination
- Standard 600 unit inspection (statistically robust)
- Confirm packaging and labelling
- Accredited grower / pack house
- Product security sufficient
- Confirm any other requirements

Certification – permits and phytosanitary certificates

Supporting documentation

- Supporting documentation may need to be submitted if the importing country requires an information to be certified on the phytosanitary certificate
- Evidence to be presented to the Authorised Officer at the time of inspection may include:
  - crop, field or orchard inspections records
  - treatment certification
  - area or production freedom declarations

Phytosanitary certificate

- Official government-to-government certificates certifying that horticulture products:
  - have been inspected and/or tested using appropriate procedures
  - are sourced from pest free areas
  - are considered to be free from the quarantine pests or diseases specified by the importing country

Pathways and Risk Assessment Framework for High Impact Species (PRAFHIS)

NATIONAL Science Exchange 2018

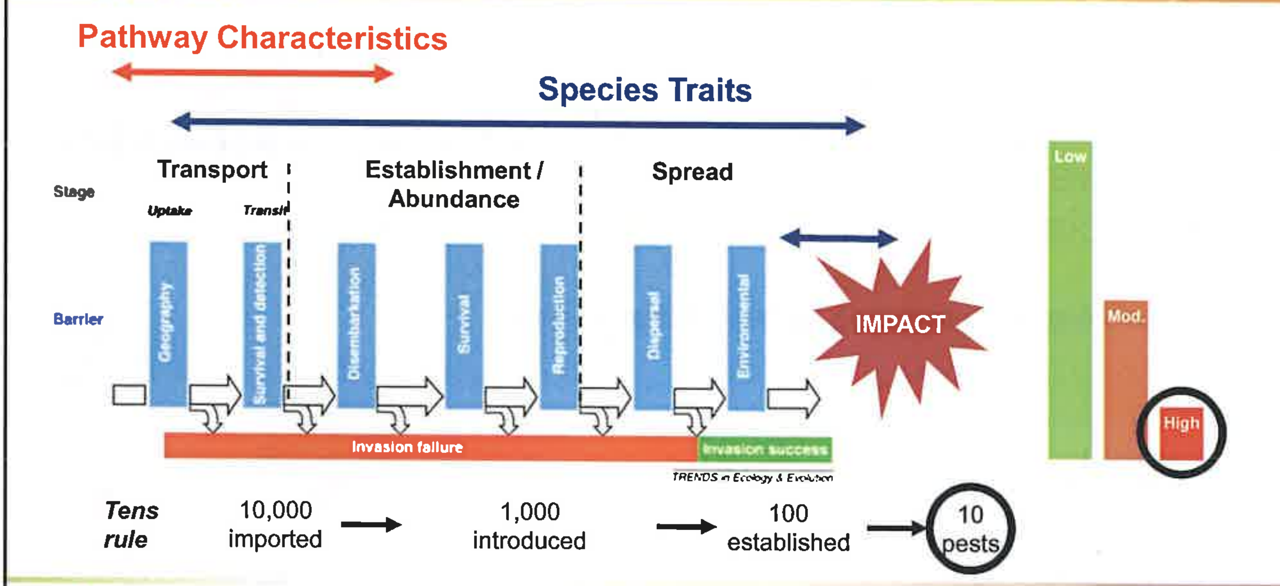
Prioritising and predicting high impact plant pests

Kylie Ireland
Postdoctoral fellow

CRC PLANTbiosecurity

PLANT BIOSECURITY COOPERATIVE RESEARCH CENTRE

Karnal bunt
European canker
Cotton aphid
Guava rust (exotic strain)
Tomato leaf miner
Tarnished plant bug
Apple maggot
Japanese beetle
Brown marmorated stink bug
Huanglongbing
Pierce's disease
Texas root rot
Sudden Oak Death
Oriental Fruit Fly
Khapra beetle
Plum curculio
Asian Gypsy Moth
Peach X disease
Brown rot
Verticillium wilt
Asian citrus psyllid
Vegetable leaf miner
Tomato ringspot virus



Blackburn et al. (2011). Trends in Ecology & Evolution 26(7): 333-339.
Chapple et al. (2012). Trends in Ecology & Evolution 27(1): 57-64.

CRC PLANT biosecurity — biosecurity built on science

1. Understand & define "Impact" ➡ Impact metric system

Literature review, expert input/ validation, decision tool

2. Understand past pests & impacts ➡ Database & summary

Impact, pathways and biological data of exotic pests

3. Priority pathways & pest traits ➡ Decision tree analysis

Machine learning, choose your own adventure….

Pathways and Risk Assessment Framework for High-Impact Species (PRAFHIS)

CRC PLANT biosecurity — biosecurity built on science

1. Understand & define "Impact"

What is "Impact"?

- Impacts / Consequences / Effects
  - Small -> Medium -> Large
  - Minor -> Major (5%) -> Massive
  - Low -> Moderate -> High
- Important, Severe, Serious, Extreme
- Nationally Significant / National Interest

 # ?

Proportion?

% ?

Ratio ?

CRC PLANTbiosecurity

biosecurity **built on science**

1. DAWR PRA - Consequences

Indiscernible, Minor significance, Significant, Major significance

Indiscernible:	pest impact unlikely to be noticeable.
Minor significance:	expected to lead to a minor increase in mortality/morbidity of hosts or a minor decrease in production but not expected to threaten the economic viability of production. Expected to decrease the value of non-commercial criteria but not threaten the criterion's intrinsic value. Effects would generally be **reversible**.
Significant:	expected to threaten the economic viability of production through a moderate increase in mortality/morbidity of hosts, or a moderate decrease in production. Expected to significantly diminish or threaten the intrinsic value of non-commercial criteria. Effects **may not be reversible**.
Major significance:	expected to threaten the economic viability through a large increase in mortality/morbidity of hosts, or a large decrease in production. Expected to **severely or irreversibly** damage the intrinsic 'value' of non-commercial criteria.

CRC PLANTbiosecurity

→ A common set of impact metrics

Considerations:

- Plant-production specific
- *Measurable*
- Cross-taxa
- Spatio-temporal variability
- Alien & native

Application:

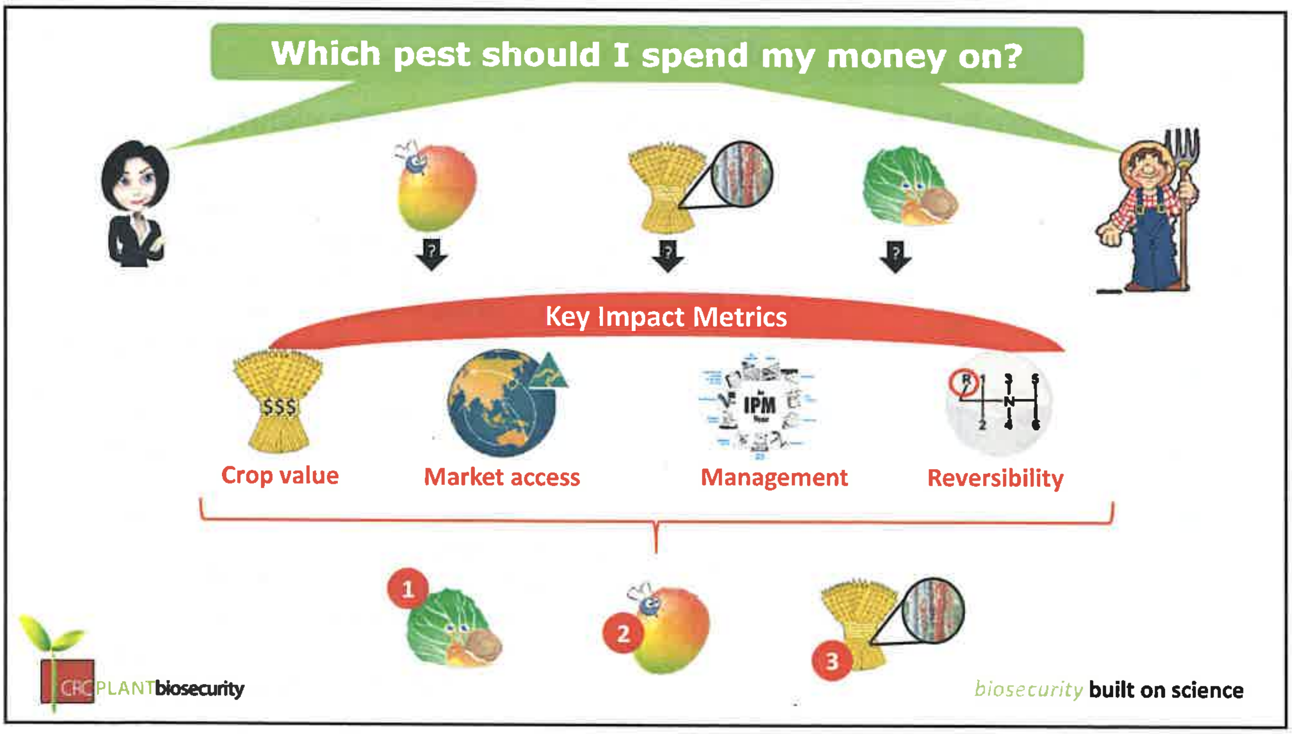
- Prioritisation
- Pest Risk Assessment

Assessment of potential consequences

The objective of the consequence assessment is to provide a structured assessment of the consequences if a disease or pest were to enter, establish and spread in Australian territory. The assessment considers direct and indirect disease or pest effects and their economic and environmental consequences.

Direct disease or pest effects are considered in the context of the effects on plant, animal and/or human life/health and other aspects of the environment. Indirect disease or pest effects are considered in the context of the effects on eradication and control, domestic trade, international trade and the environment. Consequences are estimated over four geographical levels: local, district, regional and national.

CRC PLANT biosecurity — *biosecurity* **built on science**



Plant Pest Impact Metric System (PPIMS) 20 Metrics

Spatio-temporal
- Distribution
- Maximum area affected
- Frequency
- *Reversibility

Primary response
- Investment
- Yield loss
- Success

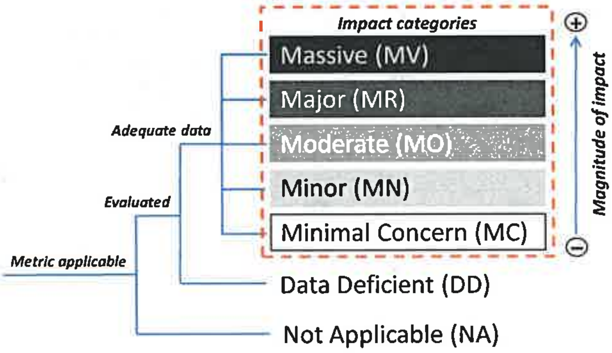
Mid to long term response
- Economic injury level
  - Control costs
  - Yield reduction
- *Feas. of Management
  - Cultivar loss
  - Cultivar recovery

Market-driven
- *Host crop value
- *Market access
  - Alternate market avail.
  - Loss of pest free status
  - Treatments
- Price discount
  - Quality loss

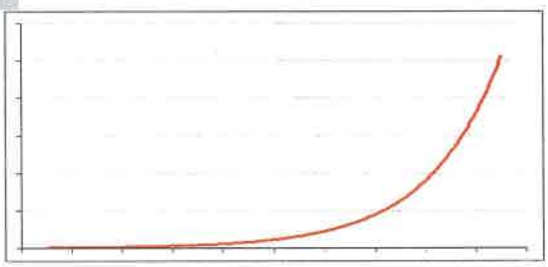
CRC PLANT biosecurity

biosecurity built on science

Impact Categories



Metric	Minimal Concern (MC = 0)	Minor (MN = 1)	Moderate (MO = 2)	Major (MR = 3)	Massive (MV = 4)
Maximum area affected	≤ 1 %	> 1 - 10 %	> 10 - 50%	> 50 - 90 %	> 90 %



- Each category for each metric is incrementally scaled exponentially/stepwise
  - Smooth differences due to uncertainty (epistemic, linguistic…)
  - Quicker assessment

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Modified from Hawkins, C. L. *et al.* (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity and Distributions*, 21(11), 1360-1363.

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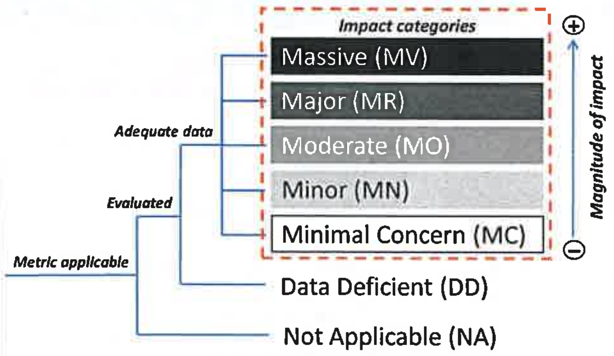
Impact Categories



Not Applicable

Metrics which are not deemed applicable to the current assessment.

e.g. assessing primary response costs may not be relevant to native or long-established pests

Data Deficient

Metrics for which current information is insufficient to assess a level of impact.

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"Disruptor" Metrics & Impact Categories

Metric	Min. Conc. (MC = 0)	Minor (MN = 1)	Moderate (MO = 2)	Major (MR = 3)	Massive (MV = 4)
Market-driven					
Host crop value (% total plant industry)	≤ 0.01 %	>0.01 - 0.1 %	> 0.1 - 1 %	> 1 – 10 %	> 10 %

NZ

Metric	Min. Conc. (MC = 0)	Minor (MN = 1)	Moderate (MO = 2)	Major (MR = 3)	Massive (MV = 4)
Market access change (loss/change of market share)	No change	Minor < 5 %	Moderate > 5 - 20 %	Major > 20 - 50 %	All Major > 50 %

e.g. *Rhizoctonia* sp.

Karnal bunt, wheat, AU/NZ **potential*

Fruit flies, hort, AU/NZ

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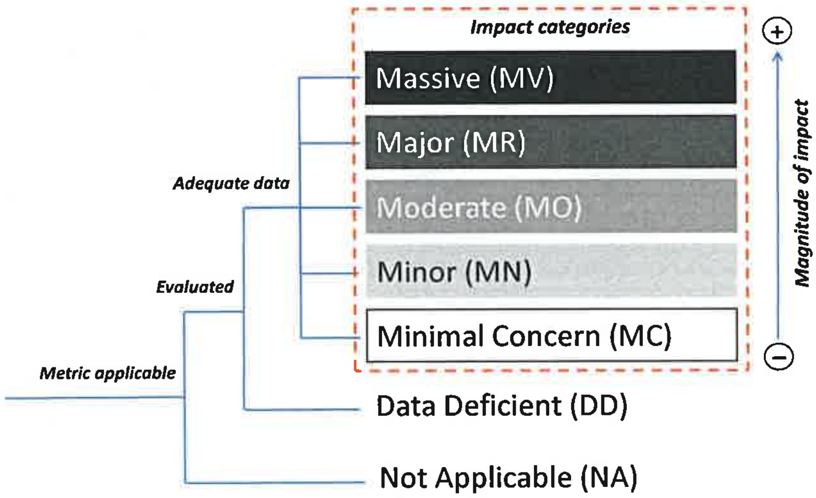
Step 1. Enter event/assessment details

Event details	
Pest:	Kiwifruit canker; *Pseudomonas syringae* pv. *actinidiae* (Psa) (Bacteria) – Exotic
Host(s):	Kiwifruit
Location:	New Zealand
Time period:	2010-2015
Assessor(s):	Joy Tyson, David Logan, Lisa Jamieson – Plant and Food Research New Zealand
Notes:	This assessment focuses on the primary response period

- Set the limitations of your assessment
- Scale all metrics appropriately
  - Allows for comparisons with across spatial (e.g. Qld vs AU), temporal (e.g. incursion period vs. 10 yrs after) and political (e.g. industry vs. govt.) boundaries

Step 2. Assign a classification for each metric

Spatio-temporal	Distribution
	Maximum area affected
	Frequency
	*Reversibility
Market-driven	*Host crop value
	*Market access
	Alternate market
	Loss of pest free status
	Treatments
	Price discount
	Quality loss
Primary response	Investment
	Yield loss
	Success
Mid to long term response	Economic injury level (EIL)
	Control costs
	Yield reduction
	*Feasibility of management
	Cultivar loss
	Cultivar recovery



Modified from Hawkins, C. L. *et al.* (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity and Distributions*, 21(11), 1360-1363.

Event details			HIGH (0.705; DD = 0.00; MEDIUM)
Pest:	Kiwifruit canker; *Pseudomonas syringae pv. actinidiae* (Psa) (Bacteria) – Exotic		
Host(s):	Kiwifruit		
Location:	New Zealand		
Time period:	2010-2015		
Assessor(s):	Joy Tyson, David Logan, Lisa Jamieson – Plant and Food Research New Zealand		
Notes:	This assessment focuses on the primary response period		
Metric	**Class***	**Decision notes**	**Score**
Disruptor			0.625
Crop value	MR	245 M, 2-3%	3
Management	MR		3
Market access	MN	Immediate loss of access to all countries for *Actinidia* nursery stock from New Zealand. Psa was already present in major growing regions of Italy, France, China and Chile	1
Reversibility	MR	Impact ongoing	3
Spatiotemporal			0.938
Distribution	MV		4
Max. area	MV		4
Frequency	MV		4
Reversibility	*MR*	*Disruptor*	3
Market-driven			0.458
Crop value	*MR*	*Disruptor*	3
Market access	*MO*	*Disruptor*	2
Alt. market	MO	? Capture initial closing markets	2
Area freedom	MV		4
Treatments	MO	More change needed initially?	2
Price discount	MC		0
Quality loss	MC		0
Primary response			0.917
Investment	MV	Containment measures. Destruction of heavily infected vines. Large investment in research.	4
Yield loss	MR	? Expect more loss as gold pushed out. Likely higher than this in those first two years	3
Success	MV	MPI and the kiwifruit industry tried to contain Psa to the incursion site/area (Te Puke); these containment measures failed. Spread to all growing regions by 2012	4
Mid to long-term management			0.750
EIL	N/A		-
Control costs	N/A	Removal of heavily infected vines. Large amounts of copper applied.	-
Yield reduc.	N/A		-
Management	*MR*	*Disruptor*	3
Cv loss	MR		3
Cv recovery	MR		3

Step 3. Review, score & final assessment

- Not every metric needs to be assessed
  - NA: Modify assessment to your needs
  - DD: Identify knowledge gaps
- Be as clear as possible in your event details & decision notes
  - "back of the envelope" calculations
  - Logic behind proxies
  - Ensure your assessment is within the limits of your event details
    - e.g. use crop value data averaged over that period of time
  - References

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Event details		
Pest	*Pseudomonas syringae* pv. *actinidiae*, Psa (Bacteria)	
Host(s)	*Actinidia deliciosa*, Green kiwifruit, less susceptible; *A. chinensis* 'Hort16A', Gold kiwifruit, highly susceptible	
Location	North Island, New Zealand	
Time period	2010-2012	2010-2015
Impact class (score)	High (0.705)	High (0.674)
Uncertainty (DD)	0.00	0.05
Confidence	Medium	Medium
Disruptor	0.625	0.625
Crop value	3	3
Management	3	3
Market access	1	1
Reversibility	3	3
Spatiotemporal	0.938	0.938
Distribution	4	4
Max. area	4	4
Frequency	4	4
*Reversibility	3	3
Market-driven	0.458	0.396
*Crop value	3	3
*Market access	2	1
Alt. market	2	1
Area freedom	4	4
Treatments	2	1
Price discount	0	0
Quality loss	0	0
Primary response	0.917	0.750
Investment	4	3
Yield loss	3	2
Success	4	4
Mid to long-term management	0.750	0.750
EIL	N/A	DD
Control costs	N/A	2
Yield reduction	N/A	4
*Management	3	3
Cv loss	3	3
Cv recovery	3	3

Step 4. Compare/Prioritise

- Relative assessment
- Can be continually improved with increased knowledge/data
- Discrimination
  - Spatial
  - Temporal
  - High/low impact
- Scoring
  - Weighting, decision making
    - DCME (Liu & Cook)
  - Conditional probabilities
  - Thresholds....

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2. Understand past pests & impacts

- Exotic species introductions only
- 18 economically significant crops – AU & NZ
  - Fruit: apples, citrus, grapes, kiwifruit, pear
  - Forestry: pines
  - Grains: barley, maize, wheat
  - Vegetables: avocados, brassicas, capsicums, carrots, cucurbits, onions, peas, potatoes, tomatoes
- 586 pests and pathogens
  - Arthropods, bacteria, fungi and oomycetes, nematodes, viruses and viroids

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→ ANZ Plant Pest Trait Database

- Full taxonomy, including synonymy
- Impact rating
  - Low, moderate or high
- Biological traits
  - Host crops & industries, where & how they affect host plant, current pest distribution range, climate suitability, modes of reproduction & dispersal, ability to vector other pests/diseases or requiring a vector
- Pathway traits
  - Australian quarantine interception data; arrival method (air/sea etc), arrival mode (post/baggage/cargo etc.), detection point, commodity, country of origin

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ANZ Plant Pest Trait Database

Table 1. Plant Pest Trait Database – example excerpt

Organism	Common Name	Organism Type	Impact AU	Impact NZ	Crops Affected	Pest Range	Dispersal	Preferred climate (Koppen)
Eutypa lata	Grapevine dieback	Fungus	Low	Low	apple, citrus, grape, peas, pear	NS, SA, TS, VI, WA, N-NZ, S-NZ	Wind, water, plant-to-plant	A, C
Frankliniella occidentalis	Western flower thrips	Arthropod	Low	High	brassica, capsicum, carrot, citrus, cucurbit, grape, onion, peas, potato, tomato, wheat	NS, QL, SA, VI, WA, TS, N-NZ, S-NZ	Flight, wind, soil, human-assisted	C
Potato virus S	PVS	Virus	Low	Low	potato	NS, QL, TS, VI, WA, N-NZ, S-NZ	Plant-to-plant, seeds/bulbs, human-assisted, vectored by aphids	C
Aphis spiraecola	Spirea aphid, apple aphid, green citrus aphid	Arthropod	High	Low	apple, citrus	NS, QL, SA, TS, VI, WA, N-NZ, S-NZ	Flight, crawl, wind, plant-to-plant	A, C
Pseudomonas viridiflava	Bacterial leaf blight, blossom blight	Bacteria	Moderate	Low	apple, brassica, citrus, cucurbit, grape, kiwifruit, onion, peas, tomato	NS, QL, TS, WA, N-NZ, S-NZ	Water, human-assisted, seeds/bulbs, crop debris	C
Phytophthora syringae	Fruit rot, root rot, crown rot...	Fungus	Moderate	Moderate	apple, citrus, peas, pear, pine	NS, SA, N-NZ, S-NZ	Water, soil, human-assisted	C

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ANZ Plant Pest Trait Database

Country	Impact class	Arthropod	Bacteria	Fungus	Nematode	Virus	Total
Australia (n=485/555) 83% rated	Low	102	4	72	6	20	204
	Moderate	17	16	62	10	31	136
	High	76	5	44	10	10	145
	Total	195	25	178	26	61	485
New Zealand (n=302/393) 77% rated	Low	124	6	35	10	39	214
	Moderate	14	0	19	8	2	43
	High	10	4	22	9	0	45
	Total	148	10	76	27	41	302

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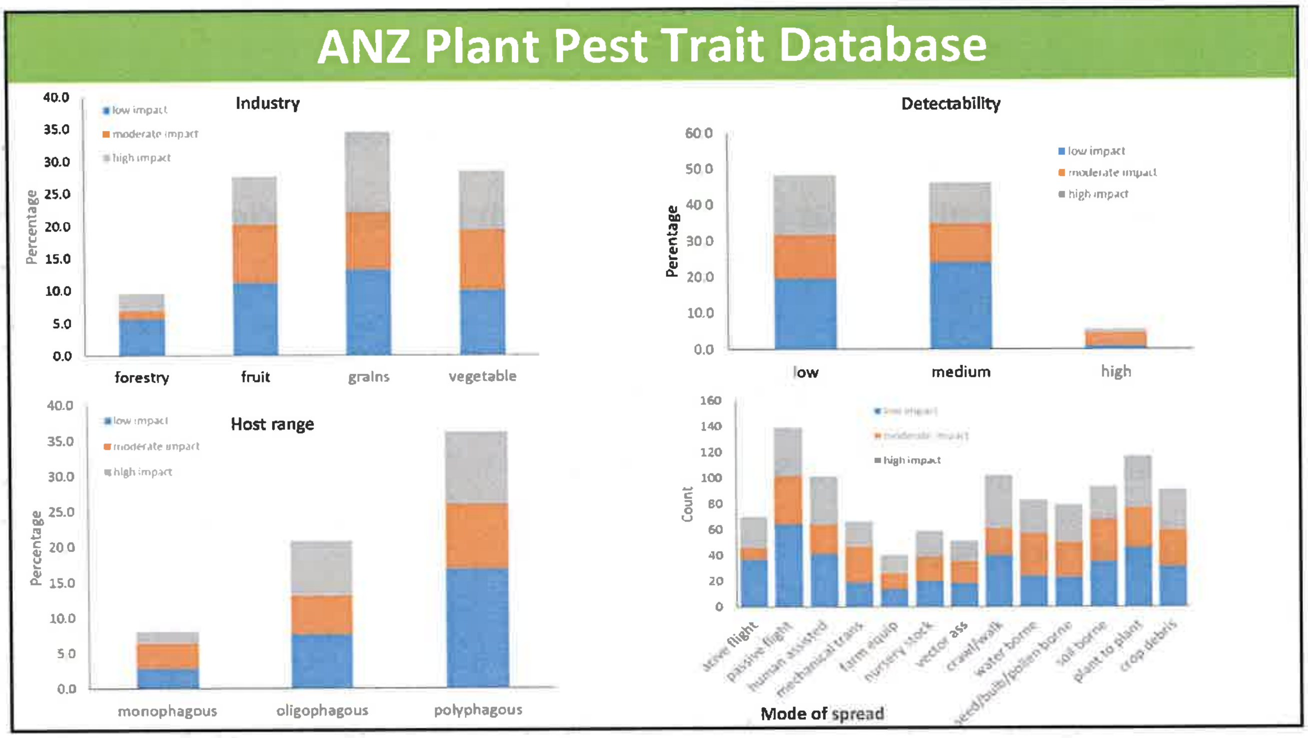
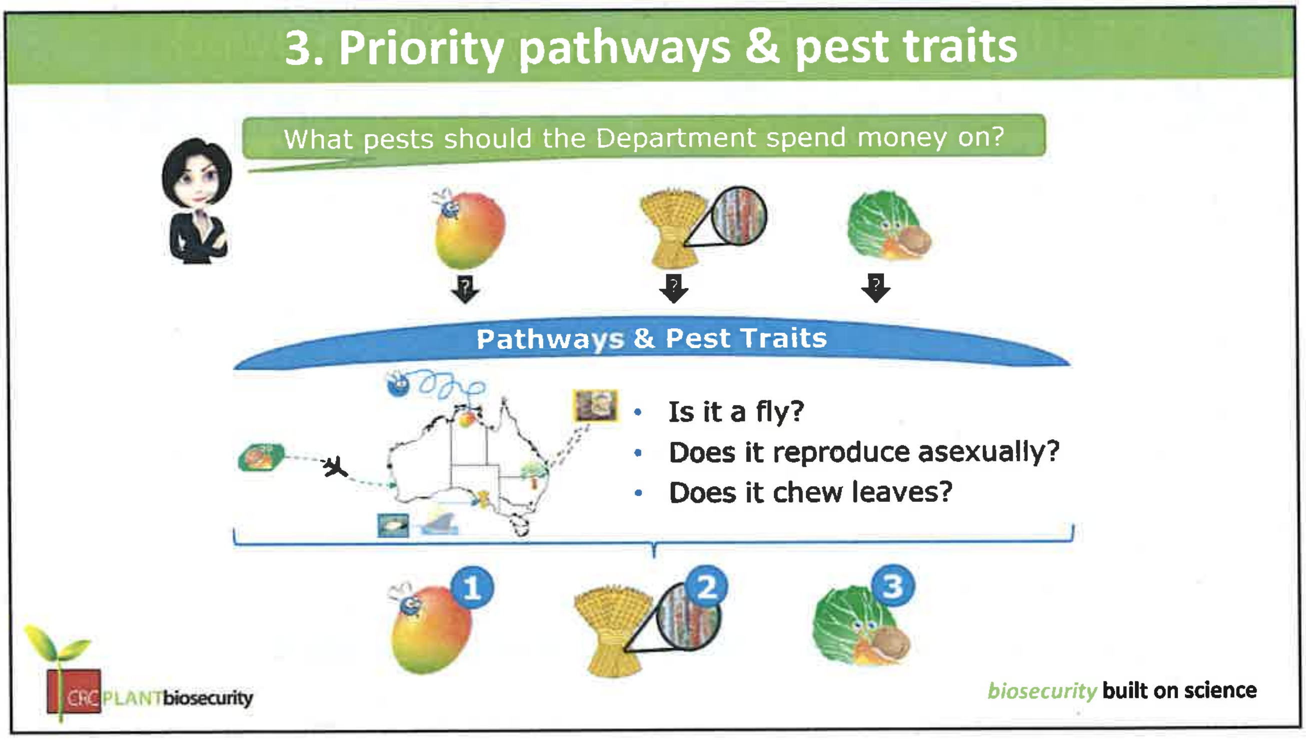

ANZ Plant Pest Trait Database
Industry
low impact
moderate impact
high impact
Percentage
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
forestry
fruit
grains
vegetable
Detectability
low impact
moderate impact
high impact
Perentage
60.0
50.0
40.0
30.0
20.0
10.0
0.0
low
medium
high
Host range
low impact
moderate impact
high impact
Percentage
monophagous
oligophagous
polyphagous
Count
160
140
120
100
80
60
40
20
0
high impact
active flight
passive flight
human assisted
mechanical trans
farm equip
nursery stock
vector ass
crawl/walk
water borne
seed/bulb/pollen borne
soil borne
plant to plant
crop debris
Mode of spread


3. Priority pathways & pest traits
What pests should the Department spend money on?
Pathways & Pest Traits
Is it a fly?
Does it reproduce asexually?
Does it chew leaves?
1
2
3
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→ Decision Tree Analysis

- CART (Classification And Regression Tree) analyses
- Unable to identify clear predictors of high impact species ☹

May be possible with:

- Improvements in the dataset (ANZ-PPTD)
  - Plant Pest Impact Metric System (PPIMS)
- Further analyses

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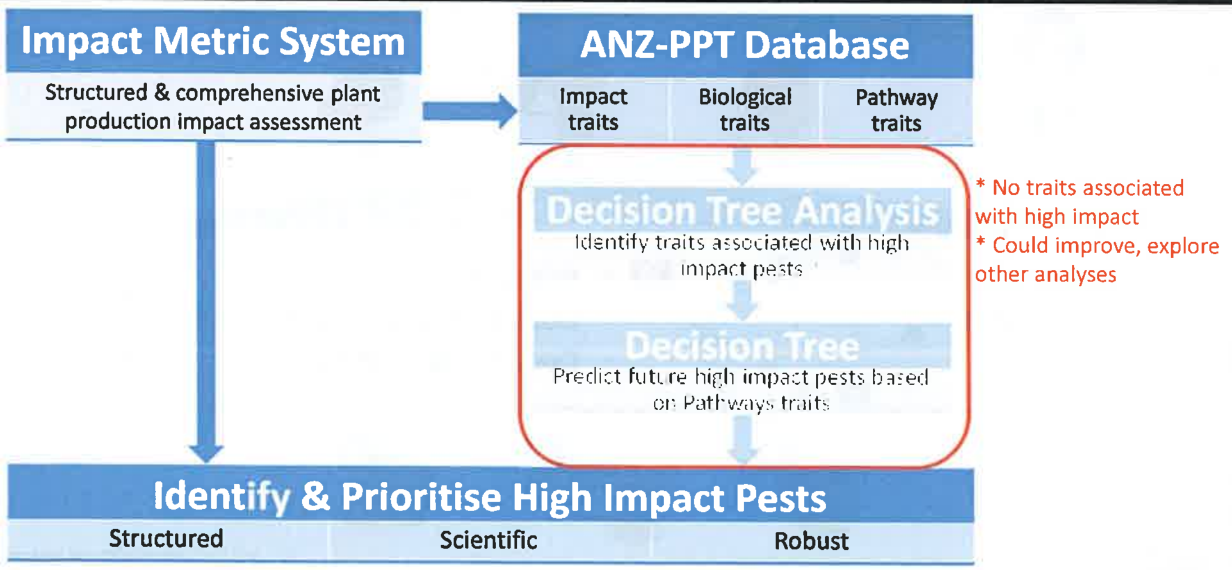
Pathways and Risk Assessment Framework for High Impact Species (PRAFHIS)



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组织

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解决问题

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Biosecurity Plant Division

Biosecurity Plant Division provides a contemporary, responsive, sustainable, intelligence-led and science-based plant biosecurity system that protects Australia's plant health status. The division supports agricultural productivity, competitiveness and market access for plant and plant products imports and exports. The division pursues new market access for Australian exporters, particularly opportunities arising from finalised free trade agreements. Biosecurity Plant division protects industry and the community, and maintains and helps industry benefit from Australia's favourable plant health status. The Division includes five branches: Plant Health Policy, Plant Sciences and Risk Assessment, Plant Export Operations, Plant Import Operations and Plant Systems & Strategies.

On this page:

Plant Health Policy Branch

Bertie Hennecke - Assistant Secretary

Plant Health Policy Branch of Biosecurity—Plant Division provides a national focal point for plant biosecurity issues within Australia, and national leadership in managing Australia's plant health. Our work underpins biosecurity and helps to open new, and maintain existing, domestic and international markets for Australian plant industries. This is achieved by:

- providing focus for national and international plant biosecurity activities
- preparing for and coordinating national responses to plant pests and exotic weeds
- promoting reform of the plant biosecurity system
- improving plant health capacity and capabilities in near-neighbour countries and trading partners and domestically
- improving national surveillance and diagnostic capability and capacity
- assisting the department to meet national and international obligations and influencing plant health policies.

The Plant Health Policy Branch comprises five sections, including the Australian Plague Locust Commission.

Preparedness and Response

Sarah Hilton - Director

The Preparedness and Response team is responsible for coordinating plant pests incursions which threaten Australia's agricultural industries and environment and a range of activities targeted at building departmental and stakeholder capacity to prevent, prepare for, and respond to plant pests. It provides secretariat support to Consultative Committees under the Emergency Plant Pest Response Deed and the National Environmental Biosecurity Response Agreement, and briefing to the National Management Group and National Biosecurity Management Group on Consultative Committee decisions.

National/International Plant Health

John de Majnik – Director

National Policy and Implementation team is responsible for the development of national and operational policies, including relating to fruit fly, that support departmental and national objectives for the plant biosecurity system and preparation of these polices for implementation.

Plant Health Surveillance

Susie Collins - Director

Plant Health Surveillance and Diagnostics team is responsible for collaborating with internal and external stakeholders in managing the offshore and onshore plant health surveillance programs. A critical role of the team is driving improvements to plant health surveillance (including diagnostics), within the framework of the new national Plant Health Surveillance System, developed through the Agricultural Competitiveness White Paper initiative.
We do this through considering the biosecurity continuum rather than focus on solutions for individual plant health surveillance programs, promoting a strategic, risk-based approach to plant health surveillance operations and activities and working closely with the relevant technical and business areas of the department, as well as peak industry groups, Plant Health Australia, state and territory governments, researchers, environmental groups and other stakeholders.

Australian Plague Locust Commission (APLC)

Chris Adriaansen – Director

The APLC is responsible for monitoring and managing locust populations that significantly threaten agriculture in more than one member state. APLC officers are employed as Australian public servants through the Australian Government Department of Agriculture and Water Resources.
In addition to its Canberra headquarters, APLC operates field bases at Longreach, Narromine and Broken Hill.

Strategic Planning and Engagement

Joanne Pearce - Director

Strategic Planning and Engagement team coordinates and facilitates the division's engagement in national and international plant health fora, including the International Plant Protection Convention, Plant Health Quadrilaterals, Plant Health Committee and its subcommittees. It also is responsible for: capacity building programs in the Pacific; strategic planning for building national biosecurity capability and the delivery of projects funded through administered programs; and administered program governance.

Plant Sciences and Risk Assessment Branch

Assistant Secretary – Gabrielle Vivian-Smith

The Plant Sciences and Risk Assessment branch within the Plant Division develops science-based import policies that protect Australia's plant-based industries and the natural environment from exotic plant pests and diseases. The branch also provides scientific and technical submissions that help to maintain, improve and open overseas export markets for Australian plants and plant products.

The branch also provides scientific and technical submissions that help to maintain, improve and open overseas export markets for Australian plants and plant products. This is conducted through the various teams sitting within the branch including;

Grains, Seeds and Weeds

Neil Grant - A/g Director

The Grains, Seeds and Weeds team is responsible for providing technical input into import and export policies for grains, seeds and plant based stock feed. In addition the team is responsible for conducting weed risk assessments (WRA) for all plants proposed for importation into Australia for their potential to become a weed in Australia. They also undertake disease risk assessments of new plant genera accepted through WRA.

Nursery Stock, Timber and Cut Flowers

Alison Roach – Director

The Nursery Stock, Timber and Cut Flowers team is responsible for developing import conditions that are based on rigorous scientific risk analysis and providing scientific and technical submissions that help to maintain, improve and open overseas export markets. The team also prepares responses to complex enquiries for a range of plant commodities including nursery stock (e.g. live plants, cuttings), timber and timber products, fresh cut flowers and foliage and coordinates bio-control agent application and assessment processes.

Pest Group Policies

Dr Wendy Odgers – Director

The Pest Group Policy team is responsible for developing pest group policies for a range of pests including thrips, mealybugs and scales and associated pathogens. Their work aims to improve the effectiveness and consistency of pest risk analysis. The team also coordinates the provision of expert technical advice to support operations and other areas within and external to the department.

Review and Innovation Unit

Dr Glynn Maynard – Director

The Review and Innovation team is responsible for various scientific aspects of Plant Biosecurity with a focus on invasive ants.

Temperate Horticulture

Matthew Smyth – Director

Tropical Horticulture

Alicia de Mamiel - A/g Director

These two teams are responsible for conducting risk analyses for relevant temperate and tropical fruits and vegetables. These teams also negotiate with countries to gain market access for Australian product. In addition, the teams work to improve existing market access, such as recognition of fruit fly pest free areas or improved treatments. They also work to maintain market access such as when countries change their biosecurity requirements or a new pest is detected in Australia.

Both teams provide technical advice to other areas of the Department to support the day to day management of imports and exports of fresh produce or to support decisions on whether new pests are technically feasible to eradicate (through the Consultative Committee on Emergency Plant Pests).

The Temperate and Tropical Horticulture teams also provide scientific input into the development of international standards and represent Australia on the Technical Panel for Phytosanitary Treatments panel of the International Plant Protection Convention.

Plant Export Operations Branch

Assistant Secretary – David Ironside

The Plant Export Operations Branch facilitates trade and market access through the development of practical phytosanitary export inspection and certification policies. The branch does this by developing and implementing policies and guidance materials that ensure Australian horticulture and grain exports meet Australia's export legislation, international obligations and importing country conditions. The branch works with all participants in the export pathway to continuously improve the export framework and ensure expert advice and support is available to the horticulture and grain export industries. In addition, the branch develops and delivers training, assessment and accreditation for authorised officers to conduct inspections.

The branch is divided into five program areas in the Canberra Office:

- Plant Export Regulation Reform Program
- Horticulture Export Program
- Grain and Seed Export Program
- Business Systems Program
- Authorised Officer Program

Plant Export Regulation Reform Program

Julia Pollard – Director

PERRP is responsible for working with internal and external stakeholders to design, develop and implement the new Export Control Act and subordinate Plant Rules. The program is responsible for developing contemporary and innovative business strategies to address increasing complexity of market and operational needs, including leading reform activities to improve the current plant export regulatory framework.

Horticulture Exports Program

Narelle Marro - Driector

HEP's objective is to meet export market access requirements through the provision of consistent and efficient export inspection and certification services for fresh fruit and vegetables, cut flowers and foliage, nursery stock, dried fruit and dried flowers and foliage that meet Australia's Commonwealth export legislation, importing country requirements and international obligations.

Grain and Seed Exports Program

Ray Elson - Director

GSEP's primary role is to add value to export grain and plant products and promote both market access and market advantage. This is achieved by providing independent export inspection and certification services to the grain and related products industry, consistent with the importing country's quarantine needs and Australia's obligations under the International Plant Protection Convention.

The Program is also involved in the export certification of products ranging from bulk grain in ships or containers through to the certification of hay, timber, logs, wood chips, bark, seeds for sowing and small seed lots for research.

Business Systems Program

Peter Neimanis – Director

BSP is responsible for supporting Plant Export Operations through:

- managing, monitoring and reporting on the Branch's finances
- developing systems for auditing Registered Establishments and verifying Authorised Officers
- coordinating legal advice to the other programs and involvement in the process of legislative change
- coordinating the Branch's communication and change management activities
- developing and maintaining IT systems (EXDOC, MICoR Plants, ER, PEMS)
- managing, monitoring and reporting on plant export certification
- update and contribute to the department's website (external and internal)

- coordinating and contributing to the development of Audit and Inspection streams and the National Documentation Hub
- assisting with distressed cargo and certification issues overseas
- developing, maintaining and delivering work instructions and procedures.

Authorised Officer Program

Rosanna Carr - Director

AOP provides the training, competency assessment and accreditation of Plant Export Authorised Officers (AO)s with the department and industry. The program is responsible for:

- providing online information and access to industry AO applicants
- establishing and updating AO policy
- contributing to the maintenance of the online Learning Management System (LMS) including enrolling candidates into e-learning modules
- development, coordination, maintenance and delivery of:
  - instructional materials e.g. e-learning modules, work instructions, Plant Export Operations Manual
  - assessment materials e.g. candidate advices and assessment tools
  - on-the-job training for groups and individuals
  - issuing of Deed of Obligations and Instruments of Appointment for industry AOs

Plant Import Operations Branch

Robyn Cleland – Assistant Secretary

The Plant Import Operations branch contributes towards the maintenance of the favourable plant health status of Australia and, as a result, the maintenance of access to export markets for plants and plant products by facilitating the safe importation of plants and plant material. It does this by:

- coordinating the implementation of national technical operational plant import policy, consistent with international and national rights and obligations, through development and publication of import conditions
- assessing import permit applications and issuing import permits for plants and plant materials
- developing standards and processes for verifying compliance with operational policy, procedures, and standards
- Providing technical advice to staff, clients and stakeholders.

The branch is committed to continuous review and improvement and adopting best practice, including using risk-return principles and project activities. The Plant Import Operations branch comprises the following sections:

Biosecurity Assurance

Anthony Wicks – Director

The Biosecurity Assurance Section identifies, develops and implements business assurance processes for the Branch to ensure import conditions are fit for purpose, biosecurity risks are managed and business outcomes are achieved. The program is responsible for:

- managing, reviewing and developing training and instructional material for plant import activities
- identifying opportunities for risk/return in the plant import pathways, including the Compliance-based Inspection Scheme (CBIS) for plant products
- identifying opportunities for business and process reform
- undertaking program and branch performance assessment and reporting which may trigger reviews as required
- co-ordinating amendments to the Goods Determination
- managing the Changing Biosecurity Risk process
- reviewing and implementing data collection and intelligence sharing to support business improvement processes.

Plants Products and Coordination

Sarah Bruce - Director

The Plant Products and Coordination Program (PPC) also develops import conditions, issues import permits and responds to complex enquiries for a range of plant products including plant-based stock feed, plant-based fertilisers, timber, cut flowers, and non-consumable plant products. PPC also has primary responsibility for managing the finance and human resources for the branch.

Plant Operations Program

Bussakorn Mpelasoka – Director

Plant Operations is responsible for developing import conditions that are based on rigorous risk analysis, issuing import permits and responding to complex enquiries for a range of plant commodities including live plants, bulbs and cuttings, seeds for sowing, fresh fruit and vegetables, processed products for consumption, bio-control agents, research materials of plant origin, and secretariat for the Post Entry Plant Industry Consultative Committee (PEPICC).

Plant Innovation Centre

Mark Whattam – Director

The department has established a Plant Innovation Centre at the national Post Entry Quarantine (PIC@PEQ) facility in Mickleham, Victoria. The purpose of PIC@PEQ is to provide a platform for trialling innovative research and development activities to support the department's core business functions and service delivery challenges. The concept directly links with the department's goal to be more innovative and proactively respond to biosecurity risks from the Active Risk Management strategy and business needs identified in divisional risk registries. The centre will assist in the management of biosecurity risks where new knowledge or technology may need to be tested and/or deployed to address these challenges.

Plant Systems and Strategies Branch

Assistant Secretary - Peter Creaser

The Plant Systems and Strategies Branch provides cross divisional coordination, support and strategic capability to facilitate core plant processes. The branch provides strategic analysis and advice, and technical capacity building, to facilitate import and export market access priorities and to build strong relations with trading partners and industry. The branch program manages the Agricultural Competitiveness White Paper and the transition of the Division to a new operating model.

Content Change Team

Darren Pass - Director

The Content Change Team maintains and improves BICON content to allow external clients to understand and comply with their biosecurity obligations and internal clients to effectively manage biosecurity risk and regulate imports. We do this by:

- working collaboratively with stakeholders to comprehend and implement their BICON content requirements
- optimising use of BICON to publish clear import requirements and onshore management support procedures that effectively manage biosecurity risk

Program Management Office

Jenny Dunn - Director

The role of the Programme Management Office (PMO) is to support the division to achieve the plant division programme's outcomes, including implementation of white paper measures, progressing and reporting on selected projects as identified in tranche plans and supporting the transition of the division to a future operating state that will lead to increased efficiencies and effectiveness.

Risk Analysis Efficiencies and Stakeholder Engagement

Andrew Loch – Director

The Risk Analysis Efficiencies and Stakeholder Engagement team is implementing a project under the Agricultural Competitiveness White Paper to reduce the number of plant import market access requests registered with the department. It is doing this by using innovative ways to prioritise, project manage and finalise import risk analyses.

To make the risk analysis process more efficient, a Principal Scientific Analyst has been engaged (within the Plant Sciences and Risk Assessment branch) to help resolve technical hurdles and improve consistency around import risk analyses. The project has employed a dedicated stakeholder engagement team to liaise with industry, government and specialist areas within the department who are required to contribute to, or who are affected by, the risk analysis work being undertaken.

Ultimately, the project aims to establish better communication, governance and business practices which will streamline the import risk analysis process into the future.

Market Coordination and Strategy

Erin Tomkinson - Director

The Market Coordination and Strategy team operates across the division to provide strategic analysis and advice to facilitate Australia's market access priorities for plants and plant products. The team applies a portfolio perspective in aligning activities with other trade interests and contributes to the department's strategic approach to market access and international engagement. The team is also the primary liaison point for plant sector industry bodies on market access issues and contributes to the industry prioritisation processes for plants and plant products through Horticulture Innovation Australia Limited, the Grains Industry Market Access Forum and other bodies.

Technical Capacity Building

Ian Naumann – Director

The Technical Capacity Building section develops the skills and technical infrastructure of Asia-Pacific countries to enhance capabilities relevant to plant health. These capabilities include surveillance, diagnostics, risk analysis and risk mitigat)on and they assist regional near- neighbours and trading partners to define pest status and detect emerging threats.

The section coordinates and delivers activities that assist market access for Australian exports, manage biosecurity risk offshore to protect Australia from the impact of exotic pests and diseases and provide valuable pre-border biosecurity intelligence on emerging threats.

Maintained by: Plant Export

Last reviewed: Tuesday, 3 September 2019
by Elliott, Jenny

Group pest risk analysis for thrips and orthotospoviruses on fresh fruit, vegetable, cut-flower and foliage imports

The Department of Agriculture and Water Resources has completed its group pest risk analysis (PRA) for thrips and orthotospoviruses on fresh fruit, vegetable, cut-flower and foliage imports.

As our first group PRA, we considered the biosecurity risk posed by plant-feeding thrips insects (from the insect order Thysanoptera) that are, or are likely to be, associated with fresh fruit, vegetables, cut flowers and foliage imported into Australia as commercial consignments. We also assessed the emerging risks posed by all members of the virus genus *Orthotospovirus* (formerly 'tospovirus') that are transmitted by some thrips.

This group PRA did not address the risks posed by thrips or orthotospoviruses on nursery stock imports because these will be considered in a separate review. We will consult with stakeholders if any changes are made to existing nursery stock import conditions.

We followed 3 principal steps when conducting this group PRA:

1. Our experts conducted a review of scientific knowledge relevant to the group of pests and prepared a PRA.
2. We released the draft group PRA for a 90-day public consultation period on 14 December 2016 via Biosecurity Advice 2016-35. The draft report identified the biosecurity risks and risk management measures required to achieve Australia's appropriate level of protection (ALOP).
3. We finalised the group PRA, taking into consideration all stakeholder submissions, and released the final group pest risk analysis for thrips and orthotospoviruses on fresh fruit, vegetable, cut-flower and foliage imports on 30 November 2017 via Biosecurity Advice 2017-26.

This group PRA is funded through the Australian Government's Agricultural Competitiveness White Paper to strengthen biosecurity surveillance and analysis.

Final Report Summary

The Australian Government Department of Agriculture and Water Resources is improving the effectiveness and consistency of the PRA process. A key step in this improvement is the development of the group PRA, which considers the biosecurity risk posed by groups of pests across numerous import pathways. It applies the significant body of available scientific knowledge, including pest interception data and previous PRAs, to provide an overarching analysis of the risks posed by the group.

The International Plant Protection Convention (IPPC) defines PRA as 'the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it' (FAO 2016b). International Standard for Phytosanitary Measures (ISPM) 2: Framework for pest risk analysis (FAO 2016a), states that 'Specific organisms may ... be analysed individually, or in groups where individual species share common biological characteristics.' This is the basis for the group PRA, in which organisms are grouped if they share common biological characteristics, and as a result also have similar likelihoods of entry, establishment and spread and comparable consequences—thus posing a similar level of biosecurity risk.

Undertaking and utilising PRAs on groups of pests that share common biological characteristics provides significant opportunities to improve effectiveness and consistency of commodity-based PRAs with which those pests are also associated and to maintain a high level of biosecurity protection against new and emerging risks. The group approach to PRA was initiated by the department to take advantage of these opportunities. Each group

PRA is a 'building block' that can be used to review existing trade pathways, and can also be applied to prospective pathways for which a specific PRA is required.

If a group PRA is used to review existing or new trade pathways there may be no need to undertake further detailed PRAs on these pests—if the trade-dependent factors relating to the likelihood of entry on specific pathways have been verified, the group PRA can be applied.

This is the first group PRA to be finalised—further group PRAs are underway. This group PRA considers the biosecurity risk posed by all members of the insect order Thysanoptera (commonly referred to as thrips) and all members of the virus genus *Orthotospovirus* (formerly tospovirus) that are (or are likely to be) associated with fresh fruit, vegetables, cut-flowers or foliage imported into Australia as commercial consignments. It also assesses the emerging risks posed by orthotospoviruses, which are transmitted by some thrips.

The genus tospovirus has recently undergone taxonomic revision by the International Committee on Taxonomy of Viruses (ICTV 2017) being renamed *Orthotospovirus* and assigned to the new family *Tospoviridae* and new order *Bunyavirales*. This revision will be applied in this report to all 30 species formerly described as tospoviruses, as appropriate.

Thrips and the orthotospoviruses they transmit can cause considerable economic consequences across a wide range of fruit, vegetable, legume and ornamental crops by reducing yield, quality and marketability. Orthotospoviruses are a significant emerging risk to Australia with many recent reports of new species with rapidly expanding host plant ranges, geographic distributions and thrips vectors.

This group PRA identifies and analyses the key quarantine pests of biosecurity importance to Australia in these two groups of organisms. It is built on a foundation of 18 years of PRAs undertaken by the department—all of which were subjected to robust scientific analyses and extensive processes of stakeholder consultation. These pest risk assessments showed marked consistency in the level of biosecurity risk posed by thrips relative to the appropriate level of protection (ALOP) for Australia. They also indicated that certain thrips species are associated with a broad range of plant commodities from many countries.

This report's conclusions have been validated with available scientific evidence including 26 years of interception data collected at Australia's borders, similar interception records available from other countries and an extensive literature review. The report includes significant pests that have been recognised internationally, or by Australian industry, or those identified by states and territories as regional pests for Australia.

This report does not address the risk posed by thrips and orthotospoviruses on nursery-stock imports, which are another significant commercial pathway for the possible introduction of these pests. These will be considered in a separate review. The department will consult with stakeholders if any changes are made to existing nursery-stock import conditions.

The order Thysanoptera comprises more than 6,000 described thrips species within nine families. This group PRA identified the thrips families that are not likely to be associated with fresh fruit, vegetable, cut-flower and foliage imports, or have no potential for economic consequences for Australia and cannot meet the definition of a quarantine pest. As a result, only the phytophagous (plant-feeding) members of the Thripidae and phytophagous members of the Phlaeothripidae were identified as potential quarantine pests for Australia. These phytophagous thrips are the focus of this group PRA.

Selection criteria were used to identify thrips species within the identified phytophagous Thripidae and the phytophagous Phlaeothripidae with potential biosecurity importance for Australia. Within this group, 79 thrips species were confirmed as quarantine pests for Australia. The final group PRA also identified 27 orthotospoviruses that are quarantine pests for Australia.

These thrips and orthotospovirus quarantine pests *were* all estimated to have an 'indicative' unrestricted risk estimate of 'low', which does not achieve the ALOP for Australia. These risk estimates are 'indicative' because the likelihood of entry for quarantine pests can be influenced by a range of factors relating to specific trade pathways.

Fourteen thrips species are known to naturally transmit orthotospoviruses. Eleven of these are already regarded as quarantine pests for Australia. The remaining three are present in Australia and not under official control. This group PRA recommends that the regulatory status of these three thrips species—*Frankliniella schultzei, Scirtothrips dorsalis* and *Thrips tabaci*—be changed from non-regulated to regulated because these thrips can carry and transmit quarantine orthotospoviruses. This change is not expected to significantly affect trade.

Initial evaluation of six viruses other than orthotospoviruses that are transmitted by thrips was also undertaken in this group PRA. The department will undertake further separate analysis for *Maize chlorotic mottle virus* and has sought further information on viruses of potential regional concern to Western Australia (*Sowbane mosaic virus, Tobacco streak virus* and *Strawberry necrotic shock virus*). The thrips vector of *Pelargonium flower break virus* is regulated, which also mitigates the risk from this virus. *Prunus necrotic ringspot virus* is not a quarantine pest.

Phytosanitary measures are identified in this final report for use in specific cases where measures are required. These measures are consistent with long-standing established policy for quarantine thrips and also mitigate the risk posed by the quarantine orthotospoviruses they transmit.

Imported commodities will be regulated if they are infested with quarantine pest thrips or regulated thrips that transmit quarantine orthotospoviruses to reduce the risk of establishment of these organisms in Australia. Regulation will be in accordance with the final group PRA and any other relevant commodity-based PRAs.

The final group PRA identifies measures for quarantine and regulated thrips and alternative risk management options that may be considered on a case-by-case basis when developing new import conditions for specific commodities, or reviewing existing import conditions for commodities that are currently traded.

Where measures are required, they will include:

- freedom from quarantine and regulated thrips and
- verification, such as inspection, to provide assurance that Australia's import conditions have been met and appropriate level of protection achieved.

Imported goods that are frequently found to be infested with thrips may be subject to mandatory treatment.

Written submissions on the draft report were received from five stakeholders. The final report takes into account stakeholder comments on the draft report. The department has made a number of changes to this group PRA following consideration of these comments, and additional review of the literature. These changes include:

- Explaining further the basis for assessing phytophagous thrips as a group, including that they 'share common biological characteristics', a term used in the International Standards for Phytosanitary Measures
- Renaming and revising Chapter 2 to add additional text on thrips biology
- Adding additional evidence to support the removal of *Capsicum chlorosis virus–Phalaenopsis* strain as a quarantine pest for Australia
- Revising the likelihood of spread for orthotospoviruses from Moderate to High

- Rewording text to provide more clarity for reasoning and conclusions.

Responses to key issues raised by stakeholders are presented in Appendix I.

Next steps

We will use this group PRA when reviewing existing import conditions, or when developing new import conditions, for specific commodities when thrips are identified.

New scientific information

Scientific information can be provided to us at any time, including after a risk analysis has been completed. We will consider the information provided and review the analysis.

More information

For more information, you can email us or phone +61 2 6272 5094.

Was this page helpful? Yes No

Group pest risk analysis for mealybugs

Final group pest risk analysis for mealybugs and the viruses they transmit on fresh fruit, vegetable, cut-flower and foliage imports

The Department of Agriculture and Water Resources has completed its group pest risk analysis (PRA) for for mealybugs and the viruses they transmit on fresh fruit, vegetables, cut-flowers and foliage imports.

This is the second Group PRA to be finalised—the first Group PRA was for thrips and orthotospoviruses. This second Group PRA considers the biosecurity risk posed by all members of the Pseudococcidae, Putoidae and Rhizoecidae families, commonly referred to as mealybugs, which in total comprise about 2,300 described species. In addition the Group PRA considers all viruses transmitted by mealybugs that are (or are likely to be) associated with fresh fruit, vegetables, cut flowers or foliage imported into Australia as commercial consignments.We followed 3 principal steps when conducting this group PRA:

1. Our experts conducted a review of scientific knowledge relevant to the group of pests and prepared a PRA.
2. We released the draft group PRA for a 60-day public consultation period on 28 September 2018 via Biosecurity Advice 2018-24. The draft report identified the biosecurity risks and risk management measures required to achieve Australia's appropriate level of protection (ALOP).
3. We finalised the group PRA, taking into consideration all stakeholder submissions, and released the final group pest risk analysis mealybugs and the viruses they transmit on fresh fruit, vegetables, cut-flowers and foliage imports on 31 January 2019 via Biosecurity Advice 2019-01.

This group pest risk analysis is funded through the Australian Government's Agricultural Competitiveness White Paper to strengthen biosecurity surveillance and analysis.

Final Report Summary

The Department of Agriculture and Water Resources is improving the effectiveness and consistency of the Pest Risk Analysis (PRA) process. A key step in this improvement is the development of the Group PRA, which considers the biosecurity risk posed by a group of pests across numerous import pathways. It applies the significant body of available scientific knowledge, including pest interception data and previous PRAs, to provide an overarching analysis of the risks posed by the group.

The International Plant Protection Convention (IPPC) defines PRA as 'the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it' (FAO 2017b). International Standard for Phytosanitary Measures (ISPM) 2: Framework for pest risk analysis (FAO 2016a), states that 'Specific organisms may ... be analysed individually, or in groups where individual species share common biological characteristics.' This is the basis for the Group PRA, in which organisms are grouped if they share common biological characteristics, and as a result also have similar likelihoods of entry, establishment and spread and comparable consequences—thus posing a similar level of biosecurity risk.

Undertaking and utilising PRAs on groups of pests that share common biological characteristics provides significant opportunities to improve effectiveness and consistency of commodity-based PRAs with which those pests are also associated and to maintain a high level of biosecurity protection against new and emerging risks. The group approach to PRA was initiated by the department to take advantage of these opportunities. It is a 'building block' that can be used to review existing trade pathways, and can also be applied to prospective pathways for which a specific PRA is required.

If a Group PRA is used to review existing or new trade pathways there may be no need to undertake further detailed PRAs on these pests—if the trade-dependent factors relating to the likelihood of entry on specific pathways have been verified, the Group PRA can be applied.

This is the second Group PRA to be finalised—the first Group PRA was for thrips and orthotospoviruses. This second Group PRA considers the biosecurity risk posed by all members of the Pseudococcidae, Putoidae and Rhizoecidae families, commonly referred to as mealybugs, which in total comprise about 2,300 described species. In addition the Group PRA considers all viruses transmitted by mealybugs that are (or are likely to be) associated with fresh fruit, vegetables, cut flowers or foliage imported into Australia as commercial consignments.

Mealybugs and the viruses they transmit can have consequences across a range of crops by reducing yield, quality and marketability.

This Group PRA identifies and analyses the key quarantine pests of biosecurity importance to Australia. It is built on a foundation of 19 years of PRAs undertaken by the department, all of which were subjected to robust scientific analyses and extensive stakeholder consultation. These pest risk assessments showed marked consistency in the level of biosecurity risk posed by mealybugs relative to the appropriate level of protection (ALOP) for Australia. They also indicated that certain mealybug species are associated with a broad range of plant commodities from many countries.

This report's conclusions have been validated with available scientific evidence including 30 years of interception data collected at Australia's borders, similar interception records available from other countries, and an extensive literature review. The report includes significant pests that have been recognised internationally, by Australian industry, and those identified by states and territories as regional pests for Australia.

Selection criteria were used to identify mealybug species with potential biosecurity importance for Australia. One hundred and sixty-nine species were confirmed as quarantine pests for Australia. The Group PRA also identified nine viruses transmitted by mealybugs that are quarantine pests for Australia.

Mealybug quarantine pests were estimated to have an 'indicative' unrestricted risk estimate of 'Low' which does not achieve the appropriate level of protection (ALOP) for Australia. This risk estimate is regarded as 'indicative' because the likelihood of entry (importation and distribution) can be influenced by a range of pathway-specific factors (such as the commodity, seasonal considerations, or the incidence of mealybugs in specific export production areas), and must be verified on a case-by-case basis. In some cases the likelihood of entry may need to be adjusted to take account of these factors. In order to achieve an appropriate level of protection for Australia, measures will be required for quarantine mealybugs when the unrestricted risk estimate of 'Low' has been confirmed for a specific plant import pathway.

In contrast, the viruses of biosecurity concern transmitted by mealybugs were estimated to have an 'indicative' unrestricted risk estimate of 'Very Low' for the plant import pathway, which achieves the ALOP for Australia. This is because mealybugs can only transmit viruses for a short period of time (semi-persistent transmission) and these viruses also have a limited host range compared to their mealybug vectors. These biological factors significantly limit the likelihood that mealybugs present on imported fresh fruit, vegetable, cut-flowers and foliage will be able to transmit exotic viruses to a host plant in Australia. Therefore no additional measures are required for these viruses transmitted by mealybugs on the plant import pathway.

Imported commodities will be regulated if they are infested with mealybug quarantine pests to reduce the risk of establishment of these organisms in Australia. Regulation will be in accordance with this PRA and any other relevant commodity-based PRAs.

Phytosanitary measures will also be required if the indicative unrestricted risk estimate is verified for a specific plant import pathway and the ALOP for Australia is not achieved.

The Group PRA identifies measures for mealybug quarantine pests, and alternative risk management options that may be considered on a case-by-case basis when developing new import conditions for specific commodities, or when reviewing existing import conditions for commodities that are currently traded. These measures are consistent with long-standing established import requirements for mealybug quarantine pests.

Measures are applied to ensure that goods in consignments are free from mealybug quarantine pests. Verification measures, such as inspection, are required to provide assurance that Australia's import conditions have been met and the appropriate level of protection achieved. Additional operational procedures may be required on a case-by-case basis for specific plant import pathways, such as a system of traceability, registration of packing house and treatment providers and auditing of procedures, packaging and labelling requirements and specific conditions for storage and movement.

Imported goods that are frequently found to be infested with mealybug quarantine pests may be subject to mandatory treatment, which may be required pre-export rather than as a remedial action on arrival.

Next steps

We will use this group PRA when reviewing existing import conditions, or when developing new import conditions, for specific commodities when thrips are identified.

New scientific information

Scientific information can be provided to us at any time, including after a risk analysis has been completed. We will consider the information provided and review the analysis.

More information

For more information, you can email us or phone +61 2 6272 5094.

Was this page helpful? Yes No

FOOD STANDARDS Australia New Zealand

Food irradiation and safety

Dr Rosalind Dalefield
Senior Toxicologist
Food Standards Australia New Zealand

About us

- Food Standards Australia New Zealand (FSANZ) is an independent statutory agency within the Australian Government Health portfolio.
- An agreement between governments of Australia and New Zealand establishes FSANZ's role in setting joint food standards for both countries.
- Our main function is to develop and administer the Australia New Zealand Food Standards Code (the Code).
- The Code is a legislative instrument, that is given effect by Australian state and territory, or New Zealand, laws.

FSANZ is not responsible for enforcement of the Code.

FOOD STANDARDS

Food Standards Code

- FSANZ develops the standards in the Food Standards Code.
- The Code standards regulate:
  - ingredients
  - processing aids
  - colourings
  - additives
  - vitamins and minerals
  - composition of some foods (e.g. dairy, meat and beverages)
  - foods developed by new technologies (e.g. genetic modification).
- The Code also specifies labelling requirements for packaged and unpackaged food, e.g. specific mandatory warnings.

FOOD STANDARDS

Background

- Research into food irradiation began in 1900s to:
  - decrease numbers of microorganisms
  - destroy insects and parasites in grains, fruits and vegetables, meat and seafood
  - inhibit sprouting in crops like potatoes and onions
  - delay ripening of fresh fruits and vegetables.



Fruit fly control

- Irradiation is a known effective treatment for fruit fly infestation.
- In 2011 the use of irradiation for phytosanitary purposes for domestic trade was approved by all states and territories in Australia.
- Irradiation is an internationally accepted quarantine measure for control of fruit fly and other insect pests.
- Minimum dose of 150 Gy for *Tephritidae* family fruit flies.

How does it work?

- Irradiation source supplies energetic particles or waves.
- As they pass through the target material they collide with other particles.
- Chemical bonds are broken.
- Short-lived radicals are produced.
- These radicals cause further damage.
- Ionising radiation disrupts the normal cellular functions of an insect.
- Radiation prevents reproduction and adult emergence.

Standard 1.5.3

Standard 1.5.3 Irradiation of Food prohibits irradiation of food unless a specific permission is given.

- Exemptions are given on a case-by-case basis.
- Application for a specific exemption to irradiate food must demonstrate a technological need.
- FSANZ conducts a rigorous risk assessment to determine if (i) there are any health concerns from consumption of radiolytic compounds and (ii) if irradiation leads to any major nutrient depletion to consumers in the context of the whole diet.

- ***Note that irradiation is not a substitute for other good manufacturing practices***

Standard 1.5.3

Standard 1.5.3 Irradiation of Food:

- restricts the sources of irradiation to Co-60, X-rays below 5 MeV, electrons below 10 MeV.
- sets requirements for record-keeping and labelling
- provides a table of the foods that may be irradiated with dose limits and conditions of use.

Which foods are already approved?

Fruits and Vegetables (no > 1 kGy)			
apple	apricot	blueberry	bread fruit
capsicum	carambola	cherry	custard apple
honeydew	litchi	longan	mango
mangosteen	nectarine	papaya	peach
persimmon	plum	rambutan	raspberry
rockmelon	scallopini	strawberry	table grape
tomato	zucchini		

- A variety of herbs and spices, and plant material for herbal infusions, are also approved
- FSANZ is also expecting a generic application for a phytosanitary dose up to 1 kGy for any fruit or vegetable.

Labelling

Informed choice for consumers

Irradiated foods, and foods containing an irradiated ingredient, must be labelled, on or in connection with the food.

- Radura symbol optional
- positive labelling
- Electronic pasteurisation.

Is irradiated food safe?

- Irradiated foods have been consumed by humans in over fifty countries for years, with no evidence of adverse health effects.
- FSANZ has previously assessed the potential toxicological hazard and nutritional adequacy of various fruits and vegetables irradiated at doses of up to 1 kiloGray:
  - A413 (ANZFA 2001) herbs, spices and plant materials for herbal infusions
  - A443 & A1038 (FSANZ 2002 and 2011) a range of tropical fruits
  - A1069 (FSANZ 2013) tomatoes and capsicums
  - A1092 (FSANZ 2014) 12 additional fruits and vegetables—apples, apricots, cherries, honeydew melons, nectarines, peaches, plums, rockmelons, strawberries, table grapes, zucchini and squash
  - A1115 (FSANZ 2016) blueberries and raspberries.
- No public health and safety issues were identified in assessment of the Applications.

WHO reports on irradiated food
(1961, 1964, 1969, 1979, 1981)

- 'Toxicology acceptability:
  - All the toxicological studies carried out on a large number of individual foods have produced no evidence of adverse effects as a result of irradiation.
  - Knowledge of the nature and concentration of radiolytic products indicates there is no evidence for toxicological concern.
  - Absence of any adverse effects resulting from the feeding of irradiated diets to laboratory animals, the use of irradiated foods in livestock production and the practice of maintaining immunologically incompetent patients on irradiated diets.
- Microbial and nutritional acceptability
  - The irradiation of food up to an overall dose of 10 kGy introduces no special nutritional or microbiological problems.

Hazard assessment

- A number of compounds may be generated during the irradiation of foods (radiolytic compounds):
  - free radicals
  - various hydrocarbons
  - formaldehyde
  - amines
  - furan
  - 2-alkylcyclobutanones (2-ACBs).
- With the exception of 2-ACBs these compounds are not unique to irradiated food.
- They are naturally present at low levels in food or generated via other processing treatments.

2-ACBS

- 2-ACBs are considered to be uniquely formed during food irradiation.
- The amount of 2-ACB formed during irradiation is dependent on the lipid content of the food.
- Weight of evidence indicates that 2-ACBs are not genotoxic.
- Some evidence in animal studies that 2-ACBs may promote experimental colon carcinogenesis (Raul *et al* 2002).
- International bodies (European Commission's Scientific Committee on Food 2002; WHO 2003; Health Canada 2008; EFSA 2011b) have concluded that 2-ACBs do not pose a health risk to consumers.

Furan

- Furan is a genotoxic carcinogen in experimental animals and can be formed at low temperatures in some thermally processed and irradiated foods.
- Derived predominantly from sugars and ascorbic acid:
  - high furan levels are found in coffee (up to 160 ng/100ml), and
  - baby foods in jars (3 to 49 ng/g).
- Freshly cut fruit and vegetables that had been irradiated at 5 kGy gave the following results:
  - None detected in rockmelon or honey dew melon.
  - Low levels in grapes (up to 3.6 ng/g).
  - Apples and strawberries (below limit of detection).

Irradiated cat food

- In November 2008 Champion Pet foods announced a voluntary recall of Origen brand cat food sold in Australia.
- The withdrawal was in response to reports from the Australian veterinary community of 89 domestic cats showing neurological abnormalities (hindlimb ataxia) after consuming dry cat food imported from Canada.
- The problem was only seen in Australia.
- Twenty-one cats were euthanised due to the severity of the disease.

FOOD

What happened?

- Although the cat food was supplied to 50 countries worldwide, only Australia required irradiation treatment of the dry food.
- Orijen cat food received a minimum level of 50 kGy.
- Cats fed dry cat food irradiated at levels between 36 to 47 kGy develop the same neurological problems.
- Orijen dog food entering Australia was also irradiated but did not cause neurological problems in dogs.
- The effects in cats are considered to be a species-specific response and not relevant to human health risk assessment.

FOOD

What about food for human consumption?

- What is the nutritional impact of phytosanitary doses of irradiation on fruit and vegetables?
  - What nutritional changes are seen after irradiation?
  - What is the natural variability in vitamin levels in fruits and vegetables?
  - What are the dietary implications?

FOOD

What nutrients are sensitive to radiation?

High sensitivity	Medium sensitivity	Low sensitivity
Vitamin C	B-carotene	Vitamin D
Thiamin	Vitamin K (in meat)	Vitamin K (in vegetables)
Vitamin E (α-tocopherol)		Riboflavin
Vitamin A (retinol)		Vitamin B_6
		Vitamin B_{12}
		Niacin
		Folic acid
		Panthothenic acid
		Biotin
		Choline

FSANZ review

- FSANZ (2014) reviewed the nutritional impact of irradiation on a wide range of fruits and vegetables.
- Phytosanitary doses of irradiation had:
  - no effect on carotene levels in fruit and vegetables
  - did not decrease vitamin C in the majority of fruits and vegetables
  - had little effect on other non-vitamin bioactive compounds.
- Recommended that focus be placed on vitamin C with requirements for other nutrients to be determined case-by-case.

Vitamin C (ascorbic acid)

- Sensitivity varies due to exposure to oxygen, storage, temperature and pH.
- Need to consider total ascorbic acid content as irradiation results in some ascorbic acid being converted to dehydroascorbic acid.
- Both forms are found in non irradiated food and both are biologically active.
- Losses due to irradiation maybe overestimated if only ascorbic acid is reported.

Natural variability in vitamin levels

- The natural variability in the vitamin content of fruit and vegetables is large, and influenced by:
  - Plant variety/cultivar
  - Growing conditions including season, location and soil quality
  - Ripeness
  - Post-harvest handling
  - Post-harvest storage

Storage and processing

Storage:

- Ripening continues after harvest.
- Vitamin C susceptible to storage losses:
  - 80% loss in apples long term cold storage
  - 35–75% loss short term room temperature storage

Processing:

- Berries:
  - 30% loss with freezing; 75% loss with canning
- Tomatoes:
  - 50% loss processing to tomato paste

Overall conclusion

- Irradiation possibly reduces some vitamins but data do not allow definitive answer to 'how much', because of high intrinsic variability.
- The conclusion of the dietary intake assessment is that *'there is no impact on population nutrient intakes for any irradiation-sensitive nutrient considered'*.




What do consumers think?

- Consumers tend to react the same way to irradiation as they do to other new technologies e.g. genetically modified foods and nanotechnology.
- 60% of Australians and 68% of New Zealanders were aware of the term 'food irradiation' (Gamble et al 2002)
- Levels of acceptance are lower than levels of awareness.
- Food irradiation is often perceived as high-risk, low-benefit technology.

FOOD

Australian and New Zealand response to food irradiation

Gamble et al (2002) provided respondents with information about two scenarios—one of which included the use of irradiation to remove insect pests from imported fruit.

Consumer preference (%)	Irradiation	Heat treatment	None	Fumigation	Don't know
Australia	45	22	13	8	12
New Zealand	56	12.5	13.5	8	10

FOOD

Conclusion

- Weight of scientific opinion is that irradiated food is safe for consumption when irradiated at doses necessary to achieve the intended technological function and in accordance with the International Atomic Energy Agency's Manual of Good Practice in Food Irradiation (IAEA 2015)
- Consumer education and information may increase acceptance among consumers.

FOOD

Thank you for your attention

www.foodstandards.gov.au or www.foodstandards.govt.nz

/FoodStandards

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FOOD STANDARDS

Australian Government
Department of Agriculture and Water Resources

Australian phytosanitary treatment application standard for irradiation treatment

Version 1.0

Cataloguing data

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This publication is available at http://agriculture.gov.au/export/controlled-goods/plants-plant-products/plantexportsmanual.

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Contents

1 Introduction

The objective of phytosanitary treatment is to prevent the introduction or spread of regulated pests. Effective phytosanitary treatments are critical to managing Australia's plant biosecurity risks and safeguarding trade. The Australian treatment application standards ensure that treatments:

- are carried out in a consistent and effective manner
- reach the required efficacy every time they are applied.

This treatment application standard applies to the use of irradiation as a phytosanitary measure for imported product as well as exported and domestically traded product.

Irradiation is the treatment of product with ionising radiation by either gamma rays, electrons or x-rays. During irradiation, energy is transferred from a source of ionising radiation into the product. The amount of ionising energy absorbed is termed 'absorbed dose' or 'dose' and is measured in Grays (Gy). Its use as a phytosanitary treatment is pest specific. Unlike other treatments, irradiation is effective even if the pest remains alive as it prevents successful development of larvae and causes sterility in adults. Consequently the pest specific dosage is based on sterility rather than the rates required for mortality when using treatments such as fumigation and temperature based treatments.

Irradiation is used as an effective disinfestation treatment for a range of arthropod pests and is particularly effective on internal pests such as fruit flies.

The use of irradiation is subject to regulation by multiple agencies. In addition there are a number of international standards and best practice guides which govern how the treatment is applied. Building and safety requirements are regulated in Australia by the Australian Radiation Protection and Nuclear Safety Authority (ARPANSA), and Food Standards Australia and New Zealand (FSANZ) approves the use of irradiation on food. A list of current FSANZ approved products for irradiation are at www.foodstandards.gov.au. Product not approved for irradiation by FSANZ may be treated for export, to importing country specifications, but must not be sold within Australia for domestic human consumption.

Responsible certifying authorities must ensure, through audit or verification, that treatment facilities can demonstrate that they meet requirements to effectively deliver irradiation treatment. This may include registration, or approval arrangements by third parties.

1.1 Scope

This standard provides guidance on the effective application of irradiation as a phytosanitary measure for regulated pests on plant products for human consumption.

This standard is the baseline for the application of irradiation in trade with and within Australia. Additional requirements may apply to trade with some countries.

The following is out of scope:

- specific import requirements

- dose rates for specific pests
- operational instructions including requirements for facility registration, certification, approval of arrangements, etc.
- building and safety requirements
- work health and safety requirements
- food safety regulations.

The import requirements for trade with Australia can be found on the department's website at www.agriculture.gov.au. The Biosecurity Import Conditions (BICON) database contains the requirements for imports to Australia and the Manual of Importing Country Requirements (MICoR) lists known conditions for exports from Australia. The specific State and Territory Department of Agriculture websites for domestic trade can be found on the relevant state websites.

The application of this standard does not exempt compliance with other current and applicable state and federal regulations.

2 Requirements

2.1 Treatment facility

2.1.1 Treatment facilities must be approved by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) or for off-shore irradiation facilities, the relevant equivalent body recognised by the International Atomic Energy Agency (IAEA).

2.1.2 The treatment facility must:

- be clean and pest free
- provide segregated areas (for example, physical barrier, fence, wall) for handling treated and non-treated products to prevent cross contamination and post treatment reinfestation
- have documented systems for all procedures related to the treatment and handling of product
- have documented systems for traceability (must allow for the identification of product at each step in their path through the facility).

2.2 Personnel

2.2.1 The irradiator operator must be able to competently demonstrate their capability to conduct irradiation treatments. Personnel performing tasks that could impact the effectiveness of the treatment must be competent on the basis of appropriate education, training, skills and experience.

2.3 Irradiator specifications

2.3.1 The irradiator must be capable of providing doses within the specified limits for phytosanitary treatments.

2.3.2 The radiation source must be either:

- gamma irradiation from Cobalt 60 (^{60}Co); or
- accelerated electrons (forming electron beams) with a maximum energy of 10MeV; or
- x-rays with a maximum energy of 5MeV.

2.3.3 The irradiator and it's method of operation must be documented. The following must be described:

- the location of the irradiator within the facility
- means provided for the segregation of non-irradiated and irradiated product
- construction and operation of any associated conveyor system
- conveyor path(s) and the range of conveyor speed
- dimensions, materials and construction of the irradiator container(s)
- manner of operating and maintaining the irradiator and any associated conveyor system.

2.3.4 Software used to control and/or monitor the process must meet the design intentions (for example, as documented by the software provider).

2.4 Radiation source specifications

Gamma irradiators

2.4.1 The type of radiation and radiation source must be documented.

2.4.2 The following specification must be documented:

- type of radionuclide, its activity and source geometry
- means of indicating the position of the gamma source
- means of automatically returning the gamma source to the storage position and automatically ceasing conveyor movement if the process control timer or the conveyor system fails
- means of returning the gamma source to the storage position, and automatically ceasing conveyor movement or identifying affected products if the gamma source is not in its intended position.

Electron beam (eBeam) and x-ray irradiators

2.4.3 The energy of radiation must be documented.

2.4.4 The following specifications must be documented:

- the characteristics of the beam (electron or x-ray energy and, where applicable, average beam current, dose rate, scan width and scan uniformity)
- for x-ray irradiators, the dimensions, materials and construction of the x-ray converter
- the means of indicating that the beam and the conveyor system are operating
- the means of ceasing irradiation if any failure of the conveyor occurs which affects the dose and product requirements
- the means of ceasing conveyor movement or identifying affected product if any fault in the beam occurs.

2.5 Process specifications

2.5.1 For each product treated the process specifications must be documented. These specifications must include:

- description of packaged product, including dimensions, density and orientation of product within the package and acceptable variations
- loading configuration of product within the irradiation container
- irradiator operating conditions and limits (for example, beam characteristics, conveyor speed and source configuration)
- conveyor path(s) to be used
- minimum and maximum doses
- routine dosimeter monitoring position(s)

- relationship between the dose at the monitoring position(s) and the minimum and maximum doses.

2.5.2 If the product is to be given multiple exposures, process specifications must include any special requirements needed between exposures (for example, change of level within the carrier or time restrictions).

2.5.3 If the product has specific handling and storage conditions requirements (for example, temperature and humidity conditions) these must be documented in the process specifications.

2.6 Dosimetry system

2.6.1 Dosimeters (used in accordance with manufacturer's specifications) must be appropriate for the treatment conditions (such as temperature and humidity in the treatment chamber).

2.6.2 Dosimeters must be capable of recording and measuring the entire range of dosages likely to be received by the product.

2.6.3 Dosimeters must be appropriate for the treatment, taking into consideration radiation type, effect of influence quantity, required level of uncertainty and required spacial resolution (see ISO ASTM 51261, ISO ASTM 51707:2005).

2.6.4 Dosimeters must be placed correctly, as per the process specifications, to ensure the specified doses are received by the product.

2.6.5 Dosimeters must be stored according to manufacturer's specifications to negate the effects of variables such as light, temperature, humidity, storage time, and the type and timing of analyses required.

2.6.6 All components of the dosimetry process must be calibrated. The calibrations must be traceable to national or international standards.

2.7 Validation

Installation qualification (IQ)

2.7.1 Installation qualification must be performed when a new irradiation facility is being commissioned. It verifies that the irradiation facility meets its installation requirements. Validation of information generated during IQ is not usually performed by the responsible certifying authority under this standard.

2.7.2 Records must be kept of IQ.

Operational qualification (OQ)

2.7.3 Operational qualification must be performed when a new irradiation facility is commissioned. It verifies the irradiation facility operates to its design specifications. Validation of information generated during OQ is not usually performed by the responsible certifying authority under this standard.

2.7.4 Records must be kept of OQ.

Performance qualification (PQ)

2.7.5 Performance qualification must be performed when a new irradiation facility is commissioned. It verifies the irradiation facility will consistently deliver the required process to a given loading configuration within predetermined tolerances. Information generated during PQ must be reviewed by the responsible certifying authority and the outcome of the review must be recorded.

2.7.6 Dose mapping must occur during PQ.

2.7.7 Records must be kept of PQ.

3 Procedures

3.1 Dosimetry application

3.1.1 Dosimetry must be performed to ensure the specified doses are received by the product and maximum doses are not exceeded.

3.2 Dose mapping

3.2.1 Prior to the initial routine treatment, the product load configuration must be dose mapped to determine the lowest and highest dose absorbance points for each treatment configuration, taking into account absorbance variation arising from the product and its packaging.

3.2.2 Dose mapping studies are required:

- to characterise the dose distribution throughout a process load
- to determine the optimal load pattern, exposure time to source radiation, transit speed, ensuring that the treatment consistently delivers the required dose for each specific product/packaging configuration
- to ensure that the prescribed efficacy for the target pest is achieved.

3.2.3 Dose mapping must be conducted at least three times per load configuration to determine the maximum and minimum doses for that product and load configuration.

3.2.4 The data obtained from dose mapping will determine the required number and placement of dosimeters during routine operations, including positioning of reference dosimeters.

3.2.5 The following product and packaging variation factors must be taken into account when dose mapping to ensure the ionising radiation penetrates to all parts of a three-dimensional load:

- product density and composition
- orientation, stacking and volume
- package shape, composition and/or size.

3.2.6 Configurations used for phytosanitary treatments may require approval by the responsible certifying authority.

3.2.7 As seasonality may impact on whether sufficient product is available for dose mapping, other types of product which display the same characteristics of the target product such as density and packing configuration can be used. Where required, this must be approved by the responsible certifying authority.

3.2.8 Dose mapping records must include:

- description of the irradiation container
- product loading configuration
- conveyor path
- irradiator operating conditions
- dosimeter locations and measurements

- conclusions drawn.

3.2.9 Dose mapping must be repeated whenever changes are made, either in the facility, in its operation or to the loading configuration including to the product, packaging or arrangement of product within the packaging.

Gamma irradiators

3.2.10 The relationship between the source activity, timer setting, conveyor speed and dose must be established and documented for each loading configuration taking into account uncertainties and source decay.

3.2.11 The effect of dose distribution when product of different densities are present in the gamma irradiator shall be determined to define products that can be processed together.

3.2.12 Dose mapping for incomplete (partially filled) process loads is required to determine if the absorbed dose distribution is significantly different from the routine load and to adjust the treatment accordingly.

3.2.13 Dose mapping for the first and last process loads is required to determine if the absorbed dose distribution is significantly different from the routine load and to adjust the treatment accordingly.

Electron beam and x-ray irradiators

3.2.14 The relationship between the beam characteristics, the conveyor speed and the dose must be established for each loading configuration taking into account uncertainties.

Note: Different types of dosimeters can be used for dose mapping and routine dosimetry. For phytosanitary applications reference should be made to ATSM F1355-06.

3.3 Routine dosimetry

3.3.1 Dosimeter(s) must be placed in the process load at the predetermined maximum and minimum dose positions, or at a qualified reference dose location.

3.3.2 If the locations of the dose extremes identified during the dose mapping procedure are not readily accessible during routine processing, alternative positions may be used for routine dose monitoring. The relationships between the doses at these alternative reference positions and the maximum and minimum doses shall be reproducible, established and documented.

3.3.3 The frequency of dosimeter placement in the process load should be sufficient to verify the process is in control. For example, a placement frequency ensuring there is at least one dosimeter in the irradiator at any given moment, with at least one dosimeter on the first and last irradiation containers of each process load. The frequency and its rationale must be documented.

3.4 Routine monitoring and control

3.4.1 Prior to the irradiation process, any specific periodic tests, calibrations, maintenance tasks and necessary requalification should be performed and outcomes recorded.

3.4.2 Procedures for product handling and maintaining product integrity before, during and after irradiation must be documented.

3.4.3 Process parameters (for example, irradiation time, conveyor speed, product loading configuration) must be set, controlled, monitored and documented, taking into account uncertainty in routine dosimetry, to ensure that the product in each process load is processed within specifications.

3.4.4 If process parameters deviate outside prescribed processing limits appropriate actions must be taken. The responsible certifying authority will determine the reporting requirements for deviations outside prescribed processing limits.

3.5 Process interruptions

3.5.1 If a process interruption occurs it must be recorded and appropriate action must be taken. The responsible certifying authority will determine the reporting requirements for process interruptions.

3.6 Process loads

3.6.1 Product must be loaded in the product loading configuration according to the process specification. Products must be presented for processing in the same configuration used for dose mapping.

3.7 Equipment calibration

3.7.1 Documented procedures must be established for implementing and recording calibration and control systems.

3.7.2 All systems should be periodically checked to ensure that they are functioning according to specifications. The calibrations must be traceable to national or international standards.

3.7.3 Instrumentation used to control, indicate or record the irradiation process must be recalibrated at intervals determined by the manufacturer's instructions.

3.7.4 Following any modification or servicing of the instruments they must be recalibrated.

3.8 Equipment maintenance

3.8.1 Documented procedures must be established for all equipment maintenance. All maintenance undertaken must be documented.

3.8.2 Procedures and records must be reviewed at least annually. The results of the review must be documented.

3.8.3 Equipment must not be used to treat product until all specified maintenance tasks have been satisfactorily completed and recorded.

4 Verification of treatment

4.1 Determining efficacy of treatment

4.1.1 The efficacy of the treatment must be verified by dosimetry which confirms the treatment is within the treatment parameters.

4.1.2 Documented systems must be established for reading the dosimeters after irradiation and determining a treatment result. Procedures must take into account the uncertainties of the measurement system.

4.1.3 Immediately following each treatment, the reference dosimeter(s) must be collected by the irradiator operator and analysed to determine what dose has been applied to the product.

4.1.4 Responsible certifying authorities will determine the frequency of auditing of the treatment facility.

Note: Radiation sensitive indicators cannot be used as proof of satisfactory radiation processing or as the sole means of differentiating irradiated products from non-irradiated products.

4.2 Treatment failure

4.2.1 The treatment is deemed to have failed if:

- the minimum dose is not achieved
- the maximum dose is exceeded.

4.2.2 Documented systems must be established for the management of failed treatments including:

- control of product
- procedures for identification of the cause of the failure
- identification of corrective actions
- records of corrections or preventative actions taken.

4.2.3 The responsible certifying authority may require notification when treatments fail.

Note: The phytosanitary dose rates are not always fatal for the target pest, the detection of live insects in irradiated product does not indicate a treatment failure.

5 Phytosanitary security measures

5.0.1 Treatment facilities must have a phytosanitary security system in place and the identity and integrity of each consignment must be maintained.

5.1 Phytosanitary security

5.1.1 Phytosanitary security must be maintained during and after treatment. The responsible certifying body may determine specific phytosanitary security measures. The methods of securing product against pests are:

- using a secure area with product segregation and traceability
- using secure packaging
- a combination of both

5.1.2 Procedures must be in place to identify and segregate treated product and allow for movement without the risk of it mixing with any other product.

5.1.3 The procedures must cover all practices that pose a phytosanitary security risk to the treated goods including receivals, storage and dispatch. The procedures must enable consignments to be linked to a specific treatment and be traced back to a packhouse and grower, if required.

5.1.4 Treated product must be kept in secure conditions to prevent infestation by regulated pests when stored at the treatment facility.

5.1.5 The responsible certifying body will determine when treated product is required to be kept in secure conditions to prevent infestation by regulated pests when transported from the treatment facility.

5.1.6 After treatment, all product must be identified as 'treated' for identification and traceability purposes.

6 Documentation

6.1 Procedures

6.1.1 The following documents must be kept and made available to the responsible certifying authority when requested:

- treatment procedures
- phytosanitary security procedures
- maintenance procedures
- dosimetry procedures

6.1.2 Procedures must reflect current practices and be compliant with this standard.

6.2 Records

6.2.1 The following records must be kept and made available to the responsible certifying authority when requested:

- all records pertaining to irradiation treatment including:
  - treatment certificates
  - dose mapping
  - maintenance records
- internal verification records
- any additional records required by the responsible certifying authority or importing authority.

6.2.2 Treatment certificates must accompany all product treated by the irradiator operator. All details must be:

- legible
- free from erasures and non-certified alterations
- in English.

6.2.3 Treatment certificates must be signed, dated and contain the following details:

- description of the commodities including quantity and distinguishing numbers such as irradiation lot number, specification number or a reference to load configuration
- radiation source, and energy level for electron beam and x-ray
- date of treatment
- name of treatment facility
- minimum and maximum doses (specified and actual)
- consignment owner
- any deviation from the treatment specification.

6.2.4 All records must be retained from a minimum of two years, unless otherwise specified by responsible certifying authority, importing authority or other regulations.

Glossary

Absorbed dose	Quantity of radiating energy absorbed per unit of mass of a specified target. [Note, for the purposes of this Standard, the term dose is used to mean absorbed dose and the unit of absorbed dose is the gray (Gy) where 1 Gy is equivalent to the absorption of 1 joule per kilogram]. [ISO 11137-1:2006]
Calibration	Set of operations that establish, under specified conditions, the relationship between values of a quantity indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards. [ISO 11137-1:2006]
Correction	Action to eliminate a detected non-conformity. A correction can be made in conjunction with a corrective action. [ISO 9000:2005]
Corrective action	Action to eliminate the cause of a non-conformity or other undesirable situation. There can be more than one cause of non-conformity. Corrective action is taken to prevent recurrence whereas preventive action is taken to prevent occurrence. (There is a distinction between correction and corrective action). [ISO 9000:2005]
Dose	The term refers to absorbed dose.
Dose distribution	Spatial variation of absorbed dose throughout the process load, integrated over a complete treatment. The extreme values are the maximum dose (Dmax) and the minimum dose (Dmin).
Dose mapping	Measurement of dose distribution and variability in material irradiated under defined conditions. [ISO 11137-1:2006]
Dosimeter	A device that, when irradiated, exhibits a quantifiable change in some property of the device which can be related to absorbed dose in a given material using appropriate analytical instrumentation and techniques. [ISPM 18 2003]
Dosimetry	Measurement of absorbed dose by the use of dosimeters. [ISO 11137-1:2006]
Dosimetry system	The procedures and interrelated elements used for determining absorbed dose, including dosimeters, instruments and associated reference standards. [ISO 11137-3:2006]

Import requirements	Specific phytosanitary measures prescribed by an importing authority, concerning consignments moving into that territory.
Installation qualification (IQ)	Obtaining and documenting evidence that equipment has been provided and installed in accordance with its specification. [ISO 11137-1:2006]
Irradiation	Treatment with any type of ionising radiation. [ISPM 5]
Irradiation container	Holder in which product is transported through the irradiator. The holder can be a carrier, cart, tray, product carton, pallet, tote or other container. [ISO 11137-1:2006]
Irradiator	The assembly of equipment and its housing where product is exposed to ionizing radiation. The irradiator provides for safe and reliable radiation processing and includes the source of radiation and associated mechanisms together with the conveyor, safety devices and biological shield.
Irradiator operator	Organization or body responsible for irradiating the product. [ISO 11137-1:2006]
Loading configuration	Defined arrangement of product placed in or on the irradiation container.
Maximum adsorbed dose (Dmax)	The localised maximum adsorbed dose within a process load. [ISPM 18 2003]
Minimum absorbed dose (Dmin)	The localised minimum adsorbed dose within a process load. [ISPM 18 2003]
Operational qualification (OQ)	Obtaining and documenting evidence that installed equipment operates within predetermined limits when used in accordance with its operational procedures. [ISO 11137-1:2006]
Performance qualification (PQ)	Obtaining and documenting evidence that the equipment, as installed and operated in accordance with operational procedures, consistently performs in accordance with predetermined criteria and thereby yields product meeting its specification. [ISO 11137-1:2006]
Preventative action	Action intended to eliminate the cause of a potential non-conformity or other undesirable potential situation. There can be more than one cause for a potential non-conformity. Preventive action is taken to prevent occurrence whereas corrective action is taken to prevent reoccurrence. [ISO 9000:2005]
Process	The combination of actions and parameters that result in a product being exposed to the correct dose of irradiation within set minimum and maximum dose. These include pre, during and post treatment actions such as loading

	configuration, conveyor speed, source position or energy level and dosimetry.
Process interruption	Intentional or unintentional stoppage that acts to prevent the irradiation process from proceeding continuously. [ISO 11137-1:2006]
Process load	A volume of product with a specified loading configuration and treated as a single entity. [ISPM 5]
Process parameter	Specified value for a process variable. The specification for a process includes the process parameters and their tolerances. [ISO 11137-1:2006]
Process variable	A parameter within an irradiation process that can be altered in magnitude and by doing so changes or alters the process effectiveness. For example conveyor speed and source position.
Radiation-sensitive indicator	Material which may be affixed to, or printed on, the process load and which undergoes a visual change when exposed to ionizing radiation. These indicators do not provide a quantitative measure of dose and may not work or be unreliable at low doses (for example in the dose range employed for phytosanitary treatments). [Adapted from ISO/ASTM 51539:2005]
Radiation source	Device that emits ionizing radiation.
Radionuclide	Radioactive isotope of an element (such as cobalt-60 or cesium-137).
Product	The plant product to be treated.
Responsible certifying authority	The National Plant Protection Organisation (NPPO) and State/Territory Departments of Agriculture and potentially any other party approved under the authority of the NPPO or State/Territory Departments of Agriculture.
Treatment	Official procedure for the killing, inactivation or removal of pests, or for rendering pests infertile or for devitalization. [FAO, 1990, revised FAO, 1995; ISPM 15, 2002; ISPM 18 2003; ICPM, 2005]
Treatment facility	Any site where irradiation takes place.

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foods

Review

Phytosanitary Irradiation

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Abstract: Phytosanitary treatments disinfest traded commodities of potential quarantine pests. Phytosanitary irradiation (PI) treatments use ionizing radiation to accomplish this, and, since their international commercial debut in 2004, the use of this technology has increased by ~10% annually. Generic PI treatments (one dose is used for a group of pests and/or commodities, although not all have been tested for efficacy) are used in virtually all commercial PI treatments, and new generic PI doses are proposed, such as 300 Gy, for all insects except pupae and adult Lepidoptera (moths). Fresh fruits and vegetables tolerate PI better than any other broadly used treatment. Advances that would help facilitate the use of PI include streamlining the approval process, making the technology more accessible to potential users, lowering doses and broadening their coverage, and solving potential issues related to factors that might affect efficacy.

Keywords: phytosanitary treatment; food irradiation; insects; pests; fruits

1. Introduction

Foods, such as fresh fruits and vegetables, which are transported between countries and regions, may harbor invasive pests that could become established in new areas, harming crops, the environment, livelihoods, and economies. Pest risk assessments and commensurate restrictions on the movements of fresh produce are used to prevent invasive species from spreading. Without effective phytosanitary measures, fresh fruits and vegetables from affected regions can be prohibited from crossing quarantine boundaries within or between countries.

Phytosanitary measures comprise legislation, regulation, or official procedure having the purpose to prevent the introduction or spread of quarantine pests or to limit the economic impact of regulated non-quarantine pests. Treatments are phytosanitary measures designed to kill, inactivate, remove, or render phytosanitary pests infertile and must be certified to a degree of efficacy near 100% in order to permit trade in otherwise quarantined items while preventing the spread of viable pests.

Insects most often raising phytosanitary concerns in terms of trade in fresh produce are, in decreasing order of global importance, fruit flies (family Tephritidae, e.g., Mediterranean fruit fly); butterflies and moths (Order Lepidoptera, e.g., codling moth, oriental fruit moth), and; mealybugs (family Pseudococcidae) [1]. Other important regulated pest groups are scale insects, weevils, whiteflies, thrips, and mites.

Commercial phytosanitary treatments include cold (~0–2 °C), heat (~44–48 °C), fumigation (methyl bromide, phosphine), and, increasingly in recent years, ionizing radiation [2]. Ionizing radiation is used as a phytosanitary treatment in a growing number of countries for an increasing number of fruits and vegetables against a growing number of different pests [1]. The commercial use of phytosanitary irradiation has increased by ~10% every year since 2000 as the use of chemical fumigants is restricted, irradiation treatment protocols and their applicability to different fruits and vegetables are accepted internationally, and more countries and traders adopt the procedure for intra- and inter-national shipments.

2. Nature of Ionizing Radiation

Radiation is the emission of energy as waves (e.g., X-rays) or as moving particles (e.g., electron beams), and it is classified as ionizing if it has sufficient energy to remove electrons from atoms or molecules, for example to create an ion. The definition makes it difficult to precisely describe the energy region at which radiation becomes considered as ionizing since there are many different molecules and atoms and they can be ionized at a broad range of different energies. For example although visible light is generally considered as non-ionizing it ionizes certain chemicals, such as chlorophyll, which is ionized to initiate photosynthesis. Ultraviolet light, which is shorter in wavelength (10 to 400 nm with photon energies of 3 to 124 eV) than visible light can cause ionization and has been studied as a phytosanitary treatment for surface pests [1,2]. Ionizing radiation is generally considered to comprise radiation with energy of several hundreds of kiloelectronvolts or above, and, therefore, includes the higher frequency portion of the electromagnetic spectrum, such as X-rays and gamma rays or high-energy particles, such as electron beams. Gamma rays from the isotope cobalt-60 (1.17 and 1.33 MeV) or caesium-137 (0.66 MeV), electron beams, or X-rays may be used for food irradiation according to the Codex Alimentarius Commission (CAC) [3]. Cobalt-60 is produced from non-radioactive cobalt via neutron irradiation and has a half-life of 5.27 years. When cobalt-60 decays it emits a beta particle and in doing so becomes nickel in one of two highly energetic states, and in actual fact it is this nickel that promptly emits gamma radiation. Caesium-137 has been used for research into food irradiation. It is a nuclear fission product, recovered when processing spent nuclear fuel, has a half-life of 30.07 years, and decays to barium-137 m. Although its longer half-life make it more attractive as an irradiation source than cobalt-60, caesium-137 is not used to irradiate food commercially because cobalt-60 offers higher radiation energy output for a given volume and is also chemically stable in the metallic form. In contrast, caesium is ionic, the stable forms are water soluble salts (e.g., caesium chloride), and the caesium ion is mobile in the environment.

Machine sources of ionizing radiation are electron beams (e-beams) and X-rays. E-beams can be used for food irradiation at energy levels up to 10 MeV. An e-beam directed at a heavy metal (e.g., tantalum or gold) emits X-rays, and energies up to 5.0 and 7.5 MeV, respectively, are allowed for food irradiation by the CAC [3] and the United States Food and Drug Administration [4]. At best, ~14% of the energy from an e-beam is converted to X-rays with the rest lost as heat. The energy of these beams or rays does not induce measurable amounts of radioactivity in food [5,6].

Gamma and X-rays are electromagnetic and have zero rest mass; therefore, they penetrate through large bulky consignments, such as pallets of fruits and vegetables and into any insects that might be present causing tracks with spurs of ionization events along their path. Electron beams are particulate in nature and cause ionization events in dense clusters transferring their energy rapidly. They cannot penetrate as deeply as rays, and are applied to relatively small dimensions of fruits and vegetables (~20–30 cm) often via a two pass irradiation treatment (irradiating first from one side of the package and then the opposite side). Gamma and X-rays, with greater penetration, can be used to treat entire pallet loads of packed product, generally using multiple passes of the radiation source to improve the dose distribution where the containers are irradiated from at least two opposite sides. However, the transfer of energy from gamma ray, X-ray, or electron beam is broadly similar; either the radiation directly removes an electron from a biologically important chemical (e.g., DNA) or electrons are liberated from chemicals in the bulk of the target material and the resulting free electrons, ions, and free radicals react further with their surroundings, ultimately damaging biologically important molecules. Thus, the radiation either directly or indirectly disrupts the structure of organic molecules in the insect, and, above a specific radiation dosage, the disruption is sufficient to prevent insects from developing further or reproducing. Simply because DNA is such a huge target on the molecular level and is key to initiating growth and reproduction, damage to it is generally the reason pests are controlled via irradiation.

3. History and Current Use of Ionizing Radiation as a Quarantine Treatment

Hallman [1] discusses the history of phytosanitary irradiation (PI); this current section provides clarifications and more recent developments. Research in the early 1900s demonstrated the effectiveness of X-rays against the development of egg, larva, and adult cigar beetle to prevent damage to cigars [7]. The first notion of using ionizing radiation as a phytosanitary treatment was published by Koidsumi [8] who suggested it to disinfest fruit of tephritid fruit flies. He also noted that, unlike all other phytosanitary treatments, acute mortality was not necessary to provide quarantine security, but that prevention of adult emergence was a reasonable objective, and this is the measurement of efficacy used today in the internationally accepted generic PI dose for tephritid fruit flies [9].

In 1972, the US state of Hawaii petitioned the US Food and Drug Administration (FDA) to use PI on papayas [10], and 14 years later the FDA [4] approved the use of up to 1 kGy irradiation to disinfest foods of arthropods. That same year (1986), the first commercial use of PI occurred when one load of irradiated mangoes was shipped from Puerto Rico for sale in Florida [2]. The next year a consignment of irradiated Hawaiian papayas was shipped to California, and in 1989 the Animal and Plant Health Inspection Service (APHIS) approved a PI treatment dose of 150 Gy for in-country trade in papayas from Hawaii [11].

In 1992, a cobalt-60 facility was completed in Mulberry, Florida, to irradiate grapefruits as a phytosanitary treatment against Caribbean fruit fly to replace ethylene dibromide, which was being banned, making it the first irradiation facility in the world built expressly for PI [12]. However, the facility was not used for PI until several years later, and it did other types of food irradiation. Presently it does not do PI.

The year 1995 marks the start of continuous and growing use of PI as a commercial treatment. In 1994 personnel from the University of Hawaii and Hawaii Department of Agriculture petitioned the US Animal and Plant Health Inspection Service (APHIS) for a limited use permit to allow untreated papayas to be air-freighted to a cobalt-60 irradiation facility in Morton Grove, Illinois, for PI at a minimum dose of 250 Gy. The dose was raised from 150 Gy because research in the literature called into question whether the lower dose was efficacious [13]. APHIS granted that request in early 1995, and on 5 April 1995 the first shipment was made. Over the next five years increasing amounts and types of Hawaiian fruits were shipped to three facilities in the US states of Illinois and New Jersey for distribution in 15 US states and Washington DC [10].

In 1999, the Florida facility built seven years earlier began to be used for PI when guavas from southern Florida were irradiated to control Caribbean fruit fly and shipped to Texas and California. Several other fruits were also commercially irradiated there. In 2000, the facility began treating white-fleshed sweet potato for shipment to California [14]. This was the first use of PI expressly for a quarantine pest that may occur in the adult stage (sweet potato weevil) on shipped commodities and represents a major step in acceptance of PI because plant protection organizations are especially concerned about having live, albeit reproductively sterile, adults on imported commodities.

In 2000, a commercial X-ray facility exclusively designed for PI began operating in Hawaii and brought about the end to shipments of fruit to the mainland USA for irradiation. Until 2010 it comprised the largest use of PI, irradiating almost 4000 tons of sweet potato and fruit per year. In 2013 another PI facility opened in Hawaii, this one using cobalt-60. The first international shipment of commodity irradiated for phytosanitary purposes was mangoes from Australia to New Zealand in December 2004. In 2014, >2000 tons of mangoes and a few other fruits were irradiated. Since 2010, the largest volume of fresh produce irradiated has been in Mexico, and that volume has more than doubled in the last five years to >13,000 tons today. At present, there are 12 irradiation facilities in seven countries doing PI, and they treated >22,000 tons in 2014. The number of facilities and volumes are expected to continue to increase for the foreseeable future.

3.1. Generic Phytosanitary Irradiation Treatments Used Commercially

A generic phytosanitary treatment is one specific dose that is used for a group of quarantine pests and/or commodities although not all were tested for efficacy [15]. Although used to a very limited extent with some phytosanitary treatments, the concept has found broad commercial application in PI in that virtually all commercial PI is done using generic doses.

The most used generic dose is a minimum of 400 Gy for all insects except pupae and adults of the order Lepidoptera (moths and butterflies). It is approved for all products exported to the USA. New Zealand has a similar generic dose of 400 Gy for all insects except adult and pupae of Lepidoptera [16], but it includes mites of the family Tetranychidae (spider mites). Furthermore it is prohibited for use on disease vectoring species, because, although efficacious to prevent further development or reproduction of the insects, 400 Gy has not been shown to prevent disease transmission before the insect vectors die. However, the 400 Gy dose approved by New Zealand is only for mangoes, lychees, tomatoes, and capsicum peppers. A generic dose of 500 Gy is approved in New Zealand for mites other than Tetranychidae.

A generic dose of 250 Gy for import of lychee and mango into New Zealand is approved against regulated pests including a wide variety of species from the insect orders Coleoptera (beetles), Diptera (flies), Hemiptera (scales, mealybugs, whiteflies, among others), Lepidoptera, and Thysanoptera (thrips). A generic 300 Gy dose for Australian mangoes exported to Malaysia includes many of the same regulated pests for New Zealand, but also includes the mango seed weevil. The reason that the dose is 300 Gy for Malaysia instead of 250 Gy is because the mango seed weevil can become established in Malaysia while mangoes are not grown in New Zealand. Hallman [15] discusses why the dose to disinfest mangoes of seed weevil was set at 300 Gy and not lower. A dose of 150 Gy against all weevils has recently been recommended [17].

Tephritid fruit flies are the most important group of regulated pests requiring a phytosanitary treatment in fresh fruits because of their ubiquity, cryptic nature while infesting fruit, and broad host range [18]. A generic dose of 150 Gy against fruit flies of the family Tephritidae (e.g., Mediterranean fruit fly, oriental fruit fly) is broadly accepted and is commercially used in a few instances where the only regulated pests in certain fruits are these flies [15].

3.2. New Generic Phytosanitary Irradiation Treatments Proposed

A number of new generic doses have recently been proposed (Table 1). A review of literature concluded that 400 Gy would suffice for pupae of Lepidoptera with a measure of efficacy being prevention of hatch of eggs laid by moths emerging from irradiated pupae [19]. This treatment dose was proposed to the International Plant Protection Convention (IPPC) for inclusion in the phytosanitary treatment manual [20], but was rejected for lack of sufficient large-scale tests with tens of thousands of insects. Nevertheless, although the IPPC also rejected a proposed dose of 400 Gy against all insects except pupae and adults of Lepidoptera, that dose is the one used for ~95% of all commodities irradiated for phytosanitary purposes.

Likewise, a dose of 250 Gy proposed for use against all eggs and larvae of Lepidoptera [21] with the measure of efficacy being prevention of normal-looking adults was rejected by the IPPC for lack of sufficient large-scale testing. However, there is sufficient large-scale testing for the most important family in Lepidoptera, the Tortricidae (e.g., codling moth, oriental fruit moth, light brown apple moth), that would satisfy the requirements of the IPPC.

Although a generic PI treatment for all Tephritidae of 150 Gy is broadly accepted, lower doses for individual species allow for use in specific cases. For example, guavas from Florida may be irradiated with 70 Gy against Caribbean fruit fly and shipped to other parts of the USA. Generic doses for groups of pest species within the family Tephritidae may be justifiable; a generic dose of 70 Gy has been proposed for all fruits infested with species of the tephritid genus *Anastrepha*, which includes all but a few of the species attacking commercial fruit in the American tropics and subtropics [22]. That dose could be used on mangoes exported from Mexico to the USA. Currently almost all mangoes exported to the USA from Mexico are treated with water at 46.1 °C, but irradiation provides for a safer and better quality mango [23].

After tephritid fruit flies and Lepidoptera, the next most important group of regulated pests on fresh fruits and vegetables is mealybugs, which are general surface pests on many fruits and vegetables [1]. A generic dose of 250 Gy supported by large scale studies with several species has been proposed [24].

A generic dose of 150 Gy is proposed for weevils of the main weevil family Curculionidae [17]. This dose would allow mangoes from areas that have one of more of the weevils that infest mangoes to be treated with 150 Gy instead of 300 or 400 Gy.

Hallman *et al.* [25] conclude that the generic doses of 400 and 500 Gy, respectively, for Tetranychidae and all other mites accepted by Australia and New Zealand [16], although not supported by large-scale confirmatory testing, are probably high enough to be phytosanitarily safe. After large-scale confirmatory testing it might be possible to develop somewhat lower doses.

Hallman [26] argues that the 400 Gy generic dose for insects other than pupa and adult Lepidoptera can be lowered to 300 Gy with minimal increase in phytosanitary risk. This dose would still leave a respectable margin of security because research indicates that these insects can be controlled with ~250 Gy. Data from this study also indicate that doses of ~250 and 200 Gy, respectively, might suffice for armoured scales (family Diaspididae) and leafminers (family Agromyzidae).

Table 1. Generic phytosanitary irradiation doses approved or proposed.

Pest Group	Dose (Gy)	Approved and Used	References
Tephritidae (fruit flies)	150	yes	[9,27]
Insects except pupal and adult Lepidoptera for export to USA	400	yes	[27]
Insects and Tetranychidae (spider mites) except pupal and adult Lepidoptera or disease vectors for export to New Zealand	400	yes	[16]
Mites other than Tetranychidae	500	yes	[16,25]
Pests of lychee and mango to New Zealand	250	yes	[16]
Pests of mango to Malaysia	300	yes	[16]
Pupae of Lepidoptera	400	no	[19]
Eggs and larvae of Lepidoptera	250	no	[21]
Eggs and larvae of the lepidopterous family Tortricidae	250	no	[21]
Fruit flies of the genus *Anastrepha*	70	no	[22]
Mealybugs	250	no	[24]
Weevils	150	no	[17]
Insects except pupal and adult Lepidoptera	300	no	[26]

4. Effect of Phytosanitary Irradiation on Fruits and Vegetables

For phytosanitary treatments to be commercially feasible they must be efficacious and commodities must not be rendered unmarketable by them. At the doses used for PI (70 to 400 Gy), more fresh fruits and vegetables tolerate radiation than any other broadly applicable commercial treatment [2]. Applying radiation to standard packed pallet loads is economical because commodity can be treated with minimum handling; however, this may result in much of the load receiving a much greater radiation dose than necessary to ensure that all parts of the load receive at least the minimum required dose. For example, fruits on the outside of pallet loads irradiated at a cobalt-60 facility in South Africa can receive almost four times the minimum prescribed dose to ensure that the minimum dose is absorbed by the entire load [28]. This is for two reasons: (1) the irradiation facility aims to deliver a minimum dose higher than the prescribed PI treatment dose to ensure that the actual minimum dose received is at least the PI treatment dose within a large degree of statistical confidence; and (2) the dose uniformity ratio for the process (the ratio of maximum to minimum absorbed dose in the production lot) may be as high as three. Electron beams cannot penetrate deeply and therefore these facilities are designed to process boxes of product and not pallets, and can achieve a dose uniformity ratio as low as ~1.2. No matter what source of radiation is used, commodities in their commercial packaging should be tested for radiotolerance at the maximum doses that could be absorbed by any part of the load configuration.

It may also be necessary to adapt harvesting procedures when using PI. Radiation may slow the rate of fruit ripening, and fruit that is commercially harvested before it is ready to be eaten, such as papayas, mangoes, and many other tropical fruits, may not ripen as quickly as non-irradiated fruit. Delaying the physiological stage of harvest may improve ripening quality, and delayed harvest alone should result in improved quality. However, the fact that papaya, mango, and guava have been irradiated commercially from different countries for many years while in the mature hard green stage testifies to the ability of fruit to tolerate PI and still ripen normally.

The International Database on Insect Disinfestation and Sterilization maintained by the Joint FAO/IAEA Programme on Nuclear Techniques in Food and Agriculture is developing an annotated database on tolerance of fresh commodities to ionizing radiation [29]. This database will help facilitate international use of the technology as it can be used by industry to determine the feasibility of using commercial PI. A publication summarizing the literature with a discussion of research methodology and further research that might be warranted is also planned.

PI has been applied commercially to a wide variety of fresh commodities, and the fact that they have been successfully marketed after receiving doses that may considerably exceed the minimum doses required for efficacy attests to the broad tolerance of fresh commodities at doses of radiation required for phytosanitation. The following commodities are irradiated with minimum doses of 400 Gy that results in much of the commodity absorbing approximately twice that dose without rendering them unmarketable: bell peppers, dragonfruit, grape, grapefruit, guava, lime, longan, lychee, mango, manzano pepper, papaya, persimmon, plum, rambutan, sweet potato, and tomato. A few of the commodities suffered initial problems related to bottlenecks in processing and marketing when the treatments were first being done because of delays in moving the product through the novel marketing channels, but these problems were solved with experience. In time all cases resulted in acceptable product reaching consumers. Often the product was in better condition because irradiation resulted in a better quality product than alternative treatments. Other fruits, such as rambutan, could not be successfully marketed until PI became available.

5. Future Needs

The use of PI to enable trade in quarantined commodities is increasing annually. More countries are participating in this trade, the number of different commodities traded is growing, increasing volumes of produce are being treated, and PI is being used against a growing number of different quarantine pests. However, traded volumes are still rather modest considering the potential of the technology. To optimize potential, several challenges should be addressed.

5.1. Streamline Commercial Approval Process

Currently a number of countries that could benefit from PI do not have the regulations in place to permit it. Others have regulations that are overly complex; for example specifying certain fruits and vegetables that can be treated by PI but requiring additional commodities to undergo comprehensive tests to demonstrate that the process does not significantly alter nutritive quality, even if they are very similar to the ones already approved. Other countries regulate in terms of broad food categories, such as fresh fruits and vegetables, or on the basis of a maximum dose limit applicable to all fresh commodities. There is no technical reason why permissions cannot be given to fresh commodities as broad food categories. Countries are encouraged to use international standards, adapt regulations and approaches that have been successfully developed by other countries and organizations, and consider streamlining the approval of PI.

With increasing use of PI it is more efficient to adopt a multi-lateral approach to trade between several countries or regions affected by specific phytosanitary pests, as exemplified by the International Plant Protection Convention phytosanitary treatment manual [20], instead of relying on individual bilateral agreements with each trading partner.

5.2. Reduce Negative Impact of Labeling

Products irradiated for phytosanitary purposes must be labeled as irradiated, which is considered as unnecessarily negative by some because it may be interpreted as a warning. In contrast, products disinfested by fumigation are not labeled although fumigant residues may be found, and mangoes treated by hot water immersion need not be labeled although it is the only treatment documented to have killed consumers of treated product [23]. Knowing what has been done to their food is a right of the consumer but it should be done in a uniform way; if fruit processed by other phytosanitary treatments need not be labeled, fruit irradiated for phytosanitary purposes should not require labeling either.

5.3. More Accessible Commercial Application

The start-up costs of a PI facility are often more expensive than for other phytosanitary treatments because of the initial cost of construction. The business is seasonal, and the need to transport product to those facilities and associated logistics can also affect operating costs. Tools to decide on the optimum location and business model for operation would assist commercial siting and use of facilities. Reducing costs of PI may involve development of modular approaches to building facilities so that a simple facility can be expanded by the addition of more capacity as throughput increases or developing tailor made PI facilities with in-line irradiators incorporated into individual packing operations. However, as facilities become smaller and more localized, regulatory challenges in plant protection and safety may need to be considered at each of these localities, thus, resulting in increased relative costs of operation.

5.4. Wider Acceptance of Phytosanitary Irradiation

Much has been discussed about consumer and retailer wariness towards food irradiation. The primary issue seems to be fear of consumer rejection among retailers; in practice the indications are that when a retailer makes irradiated food available it is accepted by the majority of consumers and sells well [30]. The refusal of the "organic" industry to accept PI is discussed by Hallman [1] and considered to be in part due simply to a conservative mind-set of adherents to this philosophy that could change in time as PI becomes more familiar. Low-dose irradiation is routinely used to screen for bones in meat and foreign objects in food. The irradiation of commodities (including food) is also used as a security measure and to screen for contraband. These applications of ionizing radiation do not affect the certified organic status of a food, whereas using PI results in that product not being considered "organic".

5.5. Phytosanitary Irradiation Efficacy Doses

Indications are that most currently accepted commercial applications of PI specify doses that are higher than necessary (Figure 1). Ongoing research throughout the world supports new PI doses and the lowering of existing doses. A special issue of Florida Entomologist reports on much recently finished research from an IAEA Coordinated Research Project that supports various individual and generic PI doses that should be considered by plant protection organizations. Some research has been done and continues to be done using methodology (e.g., artificial infestation) that is not accepted by plant protection organizations. Other research is wasted pursuing objectives that need no further research, such as most radiotolerant stage and studies with insects that have already been adequately studied. Researchers should adopt accepted methods and base research on real needs. A new international phytosanitary measures research group is a good way to coordinate effort [31].

5.6. Solve Issues of Factors Affecting Efficacy

Of the various factors that have been hypothesized as affecting the efficacy of PI [32], oxygen content is the one that has already impacted regulation of the treatment. Irradiation under hypoxic conditions may reduce efficacy. Therefore, plant protection organizations have prohibited the use of PI on commodities stored in hypoxic atmospheres if the research supporting its use under hypoxic conditions has not been done [27,33]. Although some research has shown that this is not a problem for tephritid fruit flies [34,35] definitive research is needed to put to rest this issue for this important group of quarantine pests. Additionally, some research was done using larvae reared on diet and inserted into holes bored to the centre of fruits [35], which presents a series of untested assumptions concerning results of these studies. Regardless of the final conclusion for fruit flies, irradiation in hypoxic atmospheres seems more of a concern for most other quarantine pests, which seem to respond to hypoxia to a greater extent than fruit flies [36].

Another issue that is of concern is whether temperature during irradiation affects efficacy. It does not seem to be the case [32], but further research may be warranted before putting the issue to rest.

The two main physical characteristics that differentiate gamma from electron beam irradiation are depth of penetration and dose rate; electron beams have low penetration but deliver very high dose rates whereas gamma rays are penetrating and have relatively low dose rates. Dose rate is hypothesized to directly affect PI efficacy; *i.e.*, a faster dose rate may lead to increased efficacy because it overwhelms radiation damage repair mechanisms. High dose rates also result in oxygen depletion and the presence of oxygen significantly increases the efficiency and nature of radiation damage. Therefore, dose rate effects are especially of interest because electron beams are increasingly being used in PI and most research was previously done with slower gamma sources. Fresh commodities and insect pests could conceivably have different tolerances to fast dose-rate sources but there are few studies in this area and there is no evidence of the effect being significant at the dose rates used commercially.

Figure 1. Mexican guava is the largest single use of phytosanitary irradiation. It is successfully irradiated at a minimum dose of 400 Gy to control a wide variety of insects that may infest it including fruit flies, mealybugs, caterpillars, scale insects, weevils, and whiteflies before export to the USA. With appropriate research that dose might be reduced to 250 Gy.

6. Conclusions

The commercial use of phytosanitary irradiation (PI) increases by ~10% annually as the use of chemical fumigants is restricted, irradiation treatment protocols and their applicability to different fruits and vegetables are accepted internationally, and more countries and traders adopt the procedure for intra- and inter-national shipments.

Generic treatments, one dose is used for a group of pests and/or commodities although not all have been tested for efficacy, has found broad commercial application in PI in that virtually all commercial PI is done using them.

Fresh fruits and vegetables tolerate PI better than any other broadly used phytosanitary treatment.

Advances that would help facilitate the favourable use of PI include streamlining the approval process, making the technology more accessible to potential users, lowering and broadening doses, and solving potential issues related to factors that might affect efficacy.

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Review

World Market Development and Consumer Acceptance of Irradiation Technology

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Abstract: Food irradiation is an efficient technology that can be used to ensure food safety by eliminating insects and pathogens to prolong the shelf life. The process could be applied to fresh or frozen products without affecting the nutritional value. Presently more than 60 countries have adopted the technology. However, the technology adaptation differs from one country to another and, in some cases, consumers' misunderstanding and lack of acceptance may hinder the technology adaptation process. This review summarizes the development of irradiation treatment worldwide and consumer attitudes towards the introduction of this technology. Also, the wholesomeness, beneficial effects, and regulation of irradiation are assessed.

Keywords: irradiated foods; food quality; nutritional value; bacterial radiosensitivity; consumer acceptance; consumer response; consumer communication; global perception

1. Consumers' Acceptance of Novel Agri-Food Technologies

In recent decades novel technologies have emerged worldwide in food production, processing, and preservation. These technical innovations are in development as a result of modern demands for foods that are fresher, have higher nutritional value, and are more natural with minimum food additives and no toxins or allergens [1,2]. As a result of these emerging technologies, higher-quality foods are produced with safer attributes since they have an extended shelf life and are sold at a reasonable cost. According to Rollin et al. [3], the use of novel foods or novel food ingredients in Europe and their marketing within the European Community was first defined by Regulation (EC) No. 258/97. In this legislation, novel foods or food ingredients are defined as those containing or produced from genetically modified organisms (GMOs), with a new modified primary molecular structure, consisting of or isolated from microorganisms, fungi or algae, plants, or animals not obtained by traditional propagation or breeding practices, and having a history of safe use. They also encompass processes that give rise to significant changes in composition or structure of a food or its ingredients. Research in this field is expanding, with food safety being a major driver for the development of new food technologies in order to reduce, control, and eliminate foodborne pathogens.

These novel technologies have the ability to enhance the nutritional values of food, lower the carbon footprint in food production, and reduce water consumption in food production lines. According to Agriculture and Agri-Food Canada [4], new processing and production technologies are being applied in the form of extraction methods and ingredient processing such as the development of water-soluble lipids for addition to foods and beverages, the application of pulsed ultraviolet light to improve the nutritional content of mushrooms, the conducting of genetic manipulation, stem cell applications, and cloning in breeding techniques, and the enhancement of delivery systems for bioactive ingredients through the use of nanoemulsions or microencapsulated probiotic cultures or organogels to preserve and extend food shelf life. Some of the novel food technologies highlighted by Frewer et al. [5] include genetic modification, animal cloning, nutrigenomics, nanotechnology, high-pressure processing (HPP), and pulsed electric field processing (PEF). These technical innovations are revolutionizing the food industry and impart a more competitive edge to agri-business.

The human diet has drastically changed over the years since the Industrial Revolution due to changes in agricultural production and animal breeding methods [6]. With the diversification of agricultural food practices and improvement in transport, farm products have since then moved easily between cities and across continental borders. Moreover, some means of conservation technologies such as refrigeration were welcomed with enthusiasm by consumers. However, an increasing body of literature suggests that consumers tend to oppose newly developed food technologies such as genetic modification of crops, which has stirred much controversy among consumers [6,7]. According to Slovic et al. [8], general consumers often evaluate the risks of novel technologies differently from experts. Erdem et al. [9] are also of the same view, and opined that the general public often diverges from experts in the evaluation of food processed by new technologies. Consumers are mostly of the view that risks stem from farming practices and processing, while farmers, on the other hand, believe that the greatest food safety risks occur as a result of consumer and processor actions. The lack of knowledge on the part of consumers and poor communication from the farmers and food processing technologists or engineers increases the misunderstanding between these two groups. To exemplify this aspect, a joint meeting in 1997 involving the World Health Organization (WHO), the Food and Agricultural Organization (FAO), and the International Atomic Energy Agency (IAEA) clearly determined that food irradiated with an appropriate dose to achieve the intended objective was both safe to consume and nutritionally adequate [10]. In fact, irradiation technology has proved to be efficient in reducing bacterial contamination to produce sterile food, which is particularly important for patients with impaired immunity such as those suffering from AIDS and cancer [3]. However, research has shown that the public tends to be averse to irradiated food despite the fact that it has been recognized as safe by authorities [11]. A number of factors may explain this reluctance, one of which is the lack of proper knowledge about the technology employed to process the food. According to Frewer et al. [5], public awareness is not high about food irradiation, and many people do not even know what irradiation is. A recent study by Nayga et al. [12] showed that awareness about the nature and benefits of food irradiation led to positive changes in consumers' perception and influenced their decisions to buy irradiated food.

Novel agri-food technologies has led to the development of food preferences and food neophilia (individuals being willing to try new foods) versus neophobia (individuals being reluctant to try novel foods) [13]. Based on these concepts, Pliner and Hobden [14] even introduced a scale to measure food neophobia. Cox and Evans [15] modified this approach to establish a measure of food technology neophobia. This scale gauges the fear and reluctance of consumers to eat foods produced by innovative technologies. In a study conducted by Capiola and Raudenbush [16], it was found that food neophilics and food neophobics tend to exhibit different sensory evaluations, psychophysical ratings, stimulus sampling, physiological responses, and genetic predispositions.

2. Factors Driving Consumer Response to Emerging Technologies

For years investigators have conducted research in view of assessing consumer responses to novel food technologies, and examined a variety of factors that may influence the perception of consumers towards these emerging technologies. In this context, the risks associated with these responses have been evaluated based on different scenarios such as voluntary and involuntary, immediate or delayed, observable or unseen, fatal or non-fatal, the degree to which the risk is known or not, and the degree of control that the consumers have over the risk [11,17]. A range of foods processed by different technologies such as irradiated food, genetically modified food, food treated by pulsed electric fields and ultraviolet laser, and microbially contaminated foods have been under scrutiny to assess their perceived risks and consumers' concerns [18–20]. Based on a study conducted by Cardello et al. [21], 20 different traditional and novel food processing technologies were evaluated for their acceptance by consumers. Genetic food manipulation was at the top of the list and elicited the highest level of concern from consumers, followed by the addition of bacteriocins, irradiation, and pulsed X-rays. Consumers displayed less concern about technologies such as UV light, pulsed electric fields, and oscillating magnetic fields. The perception of food technologies by consumers in turn plays a crucial role in their choices, purchasing behavior, and acceptance of these foods. From an economic point of view, it is essential to optimize the sensory quality of food products so as to foster their consumption by the public. According to Bruhn [22], good flavor or unique flavor combinations of food products largely determine their success with consumers. Such intrinsic features also include the nutritional value of the food products such as fiber, beneficial fatty acids, lycopene, vitamin C, and probiotic, among others [23]. An increasing number of consumers are opting for more "natural" food products with no food additives or those that have been produced in environmentally friendly or sustainable ways. In addition, food convenience also plays an important role, such that over 80% of consumers, in a study, indicated that their purchase was heavily dependent on convenience [24].

However, relying only on the sensorial quality of foods does not guarantee their success in the marketplace since there are other factors that contribute to their acceptance by consumers. According to Cardello [21], contextual, cognitive, social, cultural, and attitudinal attributes also drive consumers' food choices. With regards to novel food technologies, consumers show concern about the nature of the resulting processed food or the nature of the processing technology itself, and these play a crucial role in determining whether consumers will buy the food or not. Studies have shown that a lack of knowledge among consumers regarding novel food processing technologies is a major impediment to their acceptance [25]. Hence, consumer communication is essential for consumers to accept innovative food technologies. To some extent, the dread/control framework may explain the aversion of consumers to new food technologies. Many consumers have little knowledge about modern production agriculture; according to Campbell and Fitzgerald [26], the new technologies applied in food processing are foreign to contemporary consumers, and the low literacy of consumers often limits their acceptance.

According to Li-Cohen and Bruhn [27], information about the processing of food should be presented to consumers through different routes depending on age and gender. Based on this study, it was found that men and younger consumers tend to prefer web-based sources than women or middle to older people, who rely more on television, newspapers, magazines, and supermarket brochures. In addition, consumers appear to be cautious about accepting novel technologies applied to food based on the perceived risks and lack of benefits. A study conducted by Cox et al. [28] showed that males, on average, display less concern about these emerging technologies but give more importance to the cost and size of the food products. On the other hand, females show more negative beliefs about innovative food technologies.

3. Overcoming Aversion of Novel Foods: Communication

In an effort to mitigate the negative perception of the impact of foods derived from novel technologies and inculcate trust among consumers, food industry researchers are focusing their attention on public education and dissemination of information regarding these food products [29–31]. Educational programs should be set up to impart the right information to the public regarding food produced from novel technologies. Very often, the future benefits of the technology are praised rather than the immediate, direct consumer benefits. According to Bruhn [22], emphasis should be laid on immediate consumer benefits, and the information should be imparted to them using layman-suitable terminology. In addition, to maintain the trust of the public, it is imperative to be transparent and share both what is known and what is not known with regard to the risks and benefits. The food industry should also anticipate and respond in a timely manner to concerns about potential risks expressed by the public. According to Costa-Font et al. [32], proper labeling can effectively provide information about the technology employed and its benefits to raise awareness and enhance transparency. Curtis et al. [33] and Frewer et al. [34] prefer food products to display clear and detailed labels. Consumers tend to accept the associated risks if they are aware of them and have control of them. Studies have shown that if these approaches are implemented, the aversion of consumers towards novel products decreases and their acceptance increases in general [35,36]. Educational and other information-based approaches to changing consumer attitudes appear to work in most cases. However, studies performed by Grunert et al. [19] and Wilson et al. [37] on consumer responses to genetic modification of food have shown that addressing the information deficit does not completely reassure consumers. Nonetheless, it has not been shown that the same situation applies to other emerging food processing technologies such as food irradiation. In the latter case, Nayga et al. [12] showed that educating consumers about the nature and benefits of food irradiation may effectively induce a positive response and improve its acceptance.

4. Food Irradiation as a Safe Technology

Food irradiation is a processing technique that involves exposing food to ionizing radiation such as electron beams, X-rays, or gamma radiation to induce the demise of bacteria that can cause food poisoning, control insect infestation, delay fruit ripening, or prevent vegetables from sprouting [38,39]. Studies have shown that this technology can prevent the proliferation of microorganisms that cause food spoilage, such as bacteria and molds, by changing their molecular structure [40]. Also commonly known as "cold pasteurization," it offers a wide range of benefits to the food industry and the consumer by ensuring the hygienic quality of solid or semi-solid foods through inactivation of foodborne pathogens [41]. Interest in irradiation food technologies is increasing because of persistently high food losses from infestation, contamination, and spoilage by bacteria and fungi, rising concern about foodborne diseases, and a growing international trade in food products that must meet strict import standards of quality and quarantine. In all these areas, food irradiation has demonstrated valuable and practical benefits when integrated within an established system for the safe handling and distribution of food products [42]. In addition, with increasingly restrictive regulations or complete prohibition on the use of a number of chemical fumigants for insect and microbial control in the food industry, irradiation is becoming a preferred alternative to protecting food against insect damage and as a quarantine treatment for fresh produce [43,44]. As such, irradiation can help to ensure a safer and more plentiful food supply by extending food shelf life through the control of pests and pathogens. Importantly, according to the World Health Organization (WHO) and Food and Agriculture Organization (FAO) [10,39], it is a safe technology for the processing of food commodities when the appropriate radiation dose is respected.

5. Wholesomeness of Irradiated Food

Many studies have been conducted over the last 100 years on the 'wholesomeness of irradiated foods', a terminology developed during those efforts [45]. As mentioned before, irradiation is a non-thermal process utilized to achieve the preservation of food. Irradiation (even for radurization at 0.4–10 kGy and radicidation at 40–45 kGy) does not impart heat to the food and the nutritional quality of the food is generally unaffected [46]. The irradiation process can reduce microbial contamination in food, resulting in improved microbial safety as well as extended shelf life of the food. There is an established framework of international standards for food irradiation covering human health, plant protection, labeling, dose delivery, quality assurance, and facility management. Approximately 60 countries permit irradiation of one or more foods or food classes [47].

The Codex Alimentarius Commission (Codex) is the body responsible for standards related to human health. Food irradiation must be conducted according to good management practice and comply with the Codex Alimentarius General Principles of Food Hygiene [48]. The foundation for food irradiation was set with the adoption of the Codex World-wide General Standard for Irradiated Foods in 1983 [49] and a significant revision in 2003 [50]. The General Standard states that the minimum absorbed dose should be sufficient to achieve the technological purpose and the maximum absorbed dose should be less than that which would compromise consumer safety of wholesomeness or would adversely affect the structural and functional properties or nutritional and sensory attributes [50]. In 1983, the Codex Alimentarius Commission accepted that foods irradiated up to 10 kGy were safe and therefore toxicological testing was no longer necessary. In 1997, the United Nations confirmed that foods could be treated at any dose without any detrimental effect on the food's wholesomeness. The study group concluded that high-dose irradiation, conducted in accordance with good manufacturing and irradiation practices, could be applied to several types of foods to improve their hygienic quality, make them shelf stable, and produce special products [51] (Table 1).

Table 1. Foods permitted to be irradiated under FDA regulations (21 CFR 179.26). Data were updated by Komolprasert [46].

Food	Purpose	Dose
Fresh, non-heated processed pork	Control of *Trichinella spiralis*	0.3 kGy min. to 1 kGy max.
Fresh foods	Growth and maturation inhibition	1 kGy max.
Foods	Arthropod disinfection	1 kGy max.
Dry or dehydrated enzyme preparations	Microbial disinfection	10 kGy max.
Dry or dehydrated spices/seasonings	Microbial disinfection	30 kGy max.
Fresh or frozen, uncooked poultry products	Pathogen control	3 kGy max.
Frozen packaged meats (solely NASA)	Sterilization	44 kGy min.
Refrigerated, uncooked meat products	Pathogen control	4.5 kGy max.
Frozen uncooked meat products	Pathogen control	7 kGy max.
Fresh shell eggs	Control of *Salmonella*	3.0 kGy max.
Seeds for sprouting	Control of microbial pathogens	8.0 kGy max.
Fresh or frozen molluscan shellfish [1]	Control of *Vibrio* species and other foodborne pathogens	5.5 kGy max.

[1] Data provided by FDA [51].

The FDA considers four broad areas to establish the safety of irradiated foods: radiological safety, toxicological safety, microbiological safety, and nutritional adequacy. No evidence of toxicity and radioactivity attributable to irradiation of food was found. Furthermore, under realistic conditions, radiation has been approved to achieve the intended microbiological effect by eliminating the *Clostridium botulinum* and its toxin as the most resistant bacterium and will not increase the microbiological risk [52–54].

5.1. Nutritional Aspects

Food irradiation is a technology that addresses both food quality and safety because of its ability to: inactivate the parasites, spoilage, and food-borne pathogenic microorganisms; and, under certain conditions, deactivate viruses, delay the ripening of fruits, inhibit germination (e.g., onion, garlic), and control the post-harvest losses caused by insect infestation without significantly affecting the sensory or other organoleptic attributes of food, thus contributing to improvements in food hygiene and enhancing public health [40,55,56]. Furthermore, irradiation treatment can stimulate the biosynthesis of bioactive compounds [38]. In some conditions, irradiation can also activate the synthesis of phenolic compounds and enhance the vitamin content in fruits and vegetables [38]. Recent studies showed that radiation treatment generally increased the levels of certain beneficial phytochemicals and enhanced the biological properties of some plants with nutritional value [57]. Indeed, the addition of any energy to food can break down its nutrients. Foods are irradiated to provide the same benefits (such as destroying pathogenic bacteria) as when they are processed by other technologies such as heat, refrigeration, freezing, or chemical treatment. Indeed, non-thermal food treatments have no potentially harmful residues and, also in these techniques, nutrient losses are relatively small and often substantially less than the nutrient losses associated with other methods of preservation, such as canning, drying, and heat pasteurization and sterilization [56,58]. Furthermore, it should be noted that the main advantage of food irradiation is that it can be used to treat packaged foods, which will remain safe and protected from microbial contamination after treatment [59]. From a nutritional point of view, trace elements and minerals are not affected by irradiation. Macronutrients such as protein, carbohydrates, and fats are not significantly affected by doses up to 50 kGy [52,55]. Saturated and mono-saturated fatty acids represent the essential content of neutral lipids in meat. Different studies on meat irradiation and its effect on lipids have shown that at low radiation doses, lipids in the presence of their natural protectors are not particularly sensitive to radiation-induced peroxidation. They also found no significant difference in total saturated and unsaturated fatty acids between irradiated (1, 3, or 6 kGy) and un-irradiated frozen chicken muscle [60,61]. Proteins are built of amino acids, which are the essential nutrients for the body. The effect of radiation on protein is related to their state, structure, and composition, whether native or denatured, whether dry or in solution, whether liquid or frozen, and to the presence or absence of other substances. However, long-term feeding studies also concluded that irradiation of raw and prepared meat, including precooked shrimp and chicken, to prolong shelf life, does not lead to a reduction in their protein nutritional value and no distinct decrease of the biological value of proteins was observed [62–64]. The amount of vitamin loss due to food irradiation is affected by several factors, including doses, temperature, presence of oxygen, and food type. Generally, radiation at low temperatures in the absence of oxygen reduces any vitamin loss in foods, and the storage of irradiated foods in sealed packages at low temperatures also helps prevent future vitamin loss. However, not all vitamins have the same sensitivity to irradiation [65] (Table 2).

Table 2. Relative sensitivity of vitamins to irradiation.

High Sensitivity	Low Sensitivity
Vitamin C *	Carotene
Vitamin B1 (thiamin) *	Vitamin D
Vitamin E	Vitamin K
Vitamin A	Vitamin B6 (pyridoxine) *
	Vitamin B2 (riboflavin) *
	Vitamin B12 (cobolamin) *
	Vitamin B3 (niacin) *
	Vitamin B9 (folate) *
	Pantothenic acid *

* Water-soluble vitamins, Fat-soluble vitamin. Updated from Woodside 2015 [55].

Most of the studies confirmed that irradiated foods are generally nutritionally equivalent or even better than non-irradiated foods that are subjected to normal processing [57,64,66,67]. Finally, according to a collective agreement between the Food and Agriculture Organization (FAO) of the United Nations, the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO), on the basis of knowledge derived from over 50 years of research, irradiated foods were considered safe and wholesome at the specified radiation dose [68]. A joint FAO/IAEA/WHO Study Group on High-Dose Irradiation (JSGHDI) stated that any food treated at any high dose is acceptable and healthy as long as it is palatable. This statement acknowledges that any food destroyed by inappropriate irradiation treatment may have lost its essential properties but is not necessarily hazardous for consumption [45,69].

5.2. Sensory Aspects

The consumer attitude towards food is very complex as it is influenced by sensory and non-sensory attributes, as well as by the interactions between them. Recently, many studies on sensory acceptance of radiated foods and the influence of food irradiation on consumer behavior have been performed [70]. The findings confirmed that food irradiation is a technology that addresses both food quality and safety because of its ability to control spoilage and food-borne pathogenic microorganisms without significantly affecting the sensory attributes or other organoleptic attributes of the food [56,71]. Many studies found no significant difference in sensory quality and protein content of stir fry chicken dices and ground meat after irradiation during the storage time [71,72].

The irradiation of vegetables, nuts, green tea, grains, and fresh and dried fruits (such as spinach leaves, carrots, lettuce, broccoli, red kidney beans, raisins, pistachios, dried figs, apricots, apples, and pears, and fresh strawberries, pineapples, clementines, and mangoes) was also shown to lead to good sensory and organoleptic quality acceptance [40,66,67,70,73,74]. Furthermore, in some cases, radiation processing also leads to an increase in the nutritional values of irradiated fruits and vegetables, such as vitamin C content and phenolic compounds [38,75,76].

5.3. New Perspectives

Irradiation combined with other processes can contribute to food safety, improve the nutritional value of products, and control losses during transportation and commercialization [77–79]. Many studies have demonstrated that depending on various added compounds such as essential oils (EOs) extracted from plants and the combined treatment used (e.g., modified atmosphere packaging (MAP), mild heat treatment), the relative bacterial radiosensitivity (RBR) increased 2 to 4-fold [79,80]. The findings showed that the combined treatment leads to a decrease in the needed dose of radiation, obviates the need for high-heat treatment, and finally protects the nutritional values and sensory quality of natural products, thereby obtaining higher quality products. Recent studies have approved radiation in combination with mild heating treatment or the addition of some EOs such as carvacrol or cinnamon to increase bacterial radiosensitivity (RBR) [79,80].

Many studies have shown that irradiation technology in combination with other treatments such as mild heat treatment can be used as an innovative and effective method to reduce or eliminate the growth of bacteria and parasites and subsequently extend the shelf life of food products with acceptable nutritional values [81].

6. Food Irradiation around the World

According to the Institute of Food Science & Technology (IFST) [82], more than 50 countries have given approval for over than 60 products to be irradiated in the world. In Asia the use of irradiation for food decontamination and phytosanitary purposes was estimated to 285,223 tons per year in 2010. In the European Union, the quantity of irradiated foods was estimated to 9264 tons, especially for spice decontamination. In the USA the total was estimated at 103 tons [83]. The USA, China, The Netherlands, Belgium, Brazil, Thailand, and Australia are the major countries that have adopted the technology commercially [82]. The use of irradiation for phytosanitary purposes is important around the world. More than 18,446 tons of food are irradiated worldwide for phytosanitary purposes, representing 5734 tons in Hawaii, 493 tons in Australia, 100 tons in India, 951 tons in Thailand, 850 tons in Vietnam, and 10,318 tons in Mexico, mostly for export to the USA [83]. Australia was the first user of irradiation for phytosanitary purposes in 2004, especially to export to New Zealand. India started to export to the USA in 2007, followed by Thailand and Vietnam. Mexico started to ship irradiated foods to the USA in 2008 and the export increased from 257 tons in 2008 to 3521 tons in 2009, making it now the most important exporter to the USA.

6.1. Food Irradiation in America

According to Kume et al. [83], the USA has an important commercial irradiation program and information is distributed via an update newsletter. Around 120,000 tons of food are irradiated annually in the USA for human and animal consumption [84]. The most important irradiated products in the USA are spices (80,000 tons), pet treats (20,000 tons), fresh products (14,000 tons), and ground beef (8000 tons). Approval for food irradiation started in the USA in 1963 for wheat and wheat flour at a dose of 0.5 kGy, and in 1985 for parasite elimination at 1 kGy. Then, from 1985 to 1992, the irradiation of dry enzymes, fresh products, spices, and poultry at doses of 10, 1, 30, and 3 kGy, respectively, was accepted. From 2000 to 2008 red meat, eggs, seeds for sprouting, pet food, sweet potatoes, shellfish, lettuce, and spinach were added in the list of approved irradiated foods at doses of 8, 50, 1, 5.5, 4, and 1 kGy, respectively. In 2012, the Food and Drug Association of the USA extended its approval to cover irradiated unrefrigerated meat. However, according to IFST [82], an outbreak of *E. coli* O157:H7 in 1993 that resulted in four deaths and hundreds of hospitalizations, attributed to undercooked hamburgers, was a major stimulus to adopt the irradiation of foods. Following a 2006 outbreak of spinach contaminated with *E. coli*, approval of the irradiation of spinach and lettuce was given in the USA in 2008. In 2009, approval of irradiation of oysters to eliminate *Vibrio vulnificus* was given. Presently, more than 6000 tons of products including papaya, sweet potatoes, basil, ginger, melons, taro leaves, curry leaves, longan, litchi, mangosteen, and rambutan are irradiated annually in Hawaii [85]. The irradiated products are exported to the U.S. mainland, Germany, and Switzerland.

In Canada around 2000 tons of spices are irradiated annually. Only potatoes, onions, wheat, flour, flour, whole and ground spices, and dehydrated seasoning preparation are approved for irradiation. The regulations were adopted in 1960 and 1965 to treat potatoes and onions, respectively, at a dose of 0.15 kGy; in 1969 to treat wheat and flour at a dose of 0.75 kGy; and in 1984 to treat spices and seasoning at a dose of 10 kGy. A regulatory proposal was submitted in 2002 for ground beef, poultry, shrimp, prawns, and mangoes but is still under consideration.

In Mexico, around 7500 tons of irradiated guavas, mangoes, and peppers are irradiated for export to the USA [82]. According to Kume and Todoriki [83], exports increased to more than 10,318 tons, especially guava (9121 tons), sweet lime (600 tons), mangoes (239 tons), grapefruit (101 tons), and manzano peppers (257 tons).

In Brazil, quantity of irradiated foods was estimated at 20,000 tons for spices, 3000 tons for fruits, and 23,000 tons in total in 2009 [86].

The total quantity of irradiated foods in the USA, Canada, and Brazil in 2009 was around 101,400 tons of spices, 7000 tons of fruits, and 8000 tons of meat, for a total of 116,400 tons of food [86]. According to this research, as spices are mainly used in industrial processed foods, special labeling is not required for them; however, irradiated fruits and meat should be labeled.

6.2. Food Irradiation in Asia

More than 285,223 tons of foods were irradiated in Asia in 2010 [83]. According to this research, China is the largest Asian producer of irradiated foods, with more than 100 irradiators to irradiate more than 200,000 tons of garlic, spices, dried vegetables, cooked meats, fruits, and grain [83]. Vietnam also irradiated more than 66,000 tons of foods, including frozen seafood and fruit in 2010. Japan irradiated around 6246 tons of potatoes. In Indonesia similar amounts of food were irradiated in 2010, especially cocoa, frozen seafood, spices, and others. Then, India and Thailand irradiated around 2000 tons of spices, dried vegetables, fruits (Mango, Mangosteen, Logan), fermented sausage (Nham), herbs, sweet tamarind, and others in 2010. Pakistan, Malaysia, and the Philippines irradiated around 1000 tons of food, including spices, fruits, nutritional drinks, herbs, and dried vegetables [83]. The authorization can, however, include more items. For example, in Pakistan the regulations include potatoes, onions, fresh fruits, grains, chicken and meat, fish and seafood, spices, herbs, and dry food for animals [87]. In Korea, 5394 tons of spices and dry vegetables were irradiated in 2009 [86]. However, the authorized products in Korea include potatoes, onions, garlic, chestnuts, fresh and dried mushrooms, dried meats, powdered fish, shellfish, soybean paste powder, hot pepper powder, soybean sauce powder, starch, dried spices and vegetables, yeast and enzymes, powdered aloe, ginseng, and sterile meals for hospital patients. The irradiation of these products was accepted from 1987 to 1995 [87]. Bangladesh obtained authorization for food irradiation in 1995. In 1998, around 1300 tons of different foods including frozen foods were irradiated [87].

6.3. Food Irradiation in Australia

From 2004 to 2010, 256–1205 tons of mangoes, litchi, and papaya were imported to New Zealand. In 2010, the irradiation of mango and litchi was 460 tons and 33 tons, respectively [83]. In 2012, the Food Standard Authority in Australia and New Zealand also approved the use of irradiation for capsicum and tomatoes [88].

6.4. Food Irradiation in Africa and Other Regions

Eighteen thousand tons of spices and honey were irradiated in 2009 in South Africa. Egypt also uses the technology for the irradiation of spices and dehydrated vegetables (550 tons/year). In the Ukraine, more than 70,000 tons of grain and fruits are treated by irradiation annually [86].

6.5. Food Irradiation in the European Union

Around 9264 tons of food were irradiated in the European Union in 2010 [89]. Ten countries are doing commercial application of food irradiation. The most important countries are Belgium, France, and The Netherlands. In Belgium, irradiation treatment is especially performed for frog legs, poultry, herbs and spices, dehydrated blood, fish and shellfish, and meat (7279 tons/year). In The Netherlands, irradiation is practiced for dehydrated vegetables, frog parts, spices, herbs, egg white, poultry, and shrimp (3299 tons/year). In France, frozen frog legs, poultry, Arabic gum, herbs, spices, and dried vegetables are treated by irradiation (3111 tons/year). Spain, Poland, Hungary, Germany, the Czech Republic, Romania, and Estonia especially treat herbs, spices, and vegetable seasoning (about 369, 687, 151, 127, 27, 10, and 17 tons/year, respectively) [83,86].

7. Global Perceptions of Food Irradiation

Food irradiation has been approved since 1989 by the USDA and FDA. Irradiation treatment is widely applied for blood and spices. However, this technology is still controversial due to its bad reputation such as modification of food properties, formation of dangerous substances, and fall out dangerous process or accidents and its association with the nuclear establishment. Actually, new research has demonstrated that almost all of these prejudices are misleading statements and overestimated. However, recent studies have shown that consumers still remain reluctant to purchase irradiated products. This is intimately related to the lack of information about irradiation process and the natural human resistance to change. In fact, the perception of irradiated food by consumers depends on the degree of awareness of people about irradiation technology. However, due to the growing number of recalls after food poisoning incidents, it is important to revise the marketing policy of irradiated food to make consumers more conscious of the benefits of this technology for human wellbeing. Based on a broad search, Heddle et al. [90] proposed six recommendations to increase the acceptance of irradiated food by consumers

1. Set up a public education campaign to address needs.
2. Develop a knowledge translation strategy for health care professionals.
3. Develop risk communication strategies to address risk perceptions.
4. Identify a strategy and focus of ongoing research and surveillance related to pathogen reduction.
5. Explore society's willingness to pay attention to pathogen-reduction technology, by considering the economic impacts associated with this technology, including direct and indirect costs and the potential for offsetting additional costs by eliminating redundancy.
6. Consider the issue of choice.

Most studies on consumers' perception about irradiated food have shown that education seems to be the key to consumer acceptance. Numerous consumer studies clearly showed that when given a choice and even a small amount of accurate information, consumers are not only willing to buy irradiated foods but also often prefer them over food treated by conventional means. A variety of market research studies conducted over the past four decades demonstrated that the majority of consumers will choose irradiated products over non-irradiated ones after they learn the facts and understand the benefits [91].

7.1. America

7.1.1. South America

Thirty years ago, a study demonstrated that Argentinian people were impressed by irradiated onions and garlic. Six tons of onions and one ton of garlic were sold between 1985 and 1986 and global consumer appreciation gave interesting results. Recently, the work of Finten et al. [74] confirmed that, in Argentina, people have little awareness about this technology. Approximately 39% of respondents believed misleading myths about food irradiation and had doubts about it. However, after being supplied with informative materials, 42% of respondents were willing to purchase or eat irradiated ready to eat (RTE) spinach leaves, while 35% were doubtful. This emphasizes the importance of having well-informed and more aware consumers.

7.1.2. North America

In the USA in the 1980s, irradiated apples sold well even at a higher price than unirradiated apples ($0.1/lb) [92]. This demonstrated that consumers are looking for a product of good quality and irradiation treatment is not a real barrier.

The approval of fresh meat and meat products irradiation in February 2000 allowed the control of meat pathogens. The challenge was that only half of adult resident were willing to buy irradiated ground beef or chicken and only a quarter were willing to pay extra for these products [93]. These statistics were discouraging for companies.

On the other hand, consumers have recently become more concerned about irradiation risks. According to Crowley et al. [94], acceptance of meat irradiation was clearly driven by concerns about the risks of irradiation, but not the risks of bacterial contamination, confirming differences in the perception of natural and technological risks. Thus, a general lack of concern about foodborne illness and the fear of perceived, possibly negative "radiation" side-effects impede willingness to endorse this food processing technology. The respondents are afraid of different aspects of the technological risks associated with irradiation such as over-irradiated meat, health risks associated with eating irradiated meat, radiation exposure due to accidents, and the belief that the negative health consequences of meat irradiation would be worse than its potential benefits.

Efforts are needed to educate people to improve their perception about irradiated foods. Thomson et al. [95] demonstrated that educators' beliefs about the safety of food irradiation were influenced by their perceived understanding of it. In the USA, after a relatively short explanation about irradiation and alternative processes, consumers generally become more accepting of irradiation especially when compared to treatments that involve exposure of food to chemical additives and residues. The marketing of irradiated hamburger, Hawaiian papaya, and sweet potato was a great success for at least 10 years. New irradiated exotic fruits from Mexico and several Asian countries are now available in markets [69]. In Michigan and Florida, public education efforts have achieved some success in changing peoples' attitudes about purchasing irradiated foods. One store's efforts have enabled it to sell a variety of irradiated produce including grapefruits, oranges, onions, tomatoes, mushrooms, and blackberries [38]. The report of Hunter [96] showed that consumers' most important motivations when buying irradiated food are killing foodborne pathogens (77%), controlling insect infestation (64%), and reducing the use of insecticides (60%). A study performed by the National Cattlemen's Beef Association in 2002 reported that 85% of participants would accept irradiated beef if some improvements were made: 1—replacement of the word "irradiation"; 2—explaining the irradiation process; 3—giving consumers a choice between irradiated and non-irradiated beef; and 4—improvement of the quality of the final product [97].

Also, Canadian consumers are not really informed, as 57% of Canadians had not previously heard about irradiation. However, Canadian consumers of different genders and ages also appear to behave differently about accepting novel technologies, as men and people aged over 55 years old (48%) were more awarded. After a brief presentation about irradiation techniques, 74% of people aged over 55 years were ready to support food irradiation. In total, 66% of respondents supported food irradiation, against 34% who opposed this option [98].

7.2. Europe

Despite the effectiveness of irradiation for food decontamination, the limited diffusion between EU member countries of ionizing radiations for the treatment of agri-food reduces its popularity.

Italian people, for example, have a historical fear of nuclear technology, and too often consumers are misinformed about food irradiation technology. However, contrary to what one might imagine, in 1976 irradiated potatoes were appreciated by the Italian people because of their better quality and storability.

Irradiated foods have sold well in Poland (irradiated potatoes and onions in 1987–1988), with 90% overall acceptance for potatoes and 95% for onions; in France, irradiated strawberries sold well in 1987 even an additional 30% added to the conventional price, which indicates a good acceptance (only 2% of people rejected strawberry irradiation) [92]. Irradiated frog's legs were also successfully retailed in France and Belgium.

In the United Kingdom, no significant difference was observed between chilled ready meals irradiated at 2 kGy and non-irradiated meals (carrots, broccoli, beef and gravy, roast potatoes, and Yorkshire pudding) [99]. Irradiation was found to be the least acceptable intervention by Scottish people [100].

Turkish people also have a lack of information about the irradiation process (only 29% of consumers are aware of food irradiation) [101]. In an evaluation, between 69% and 80% of respondents were very concerned and uncertain about the safety of irradiated foods and were cautious about what they purchase [101,102]. Only 11% expressed that irradiated foods are safe.

According to Parlato et al. [103], the anti-irradiation message can be effectively counteracted and consumer confidence in the safety of irradiation process can be restored by detailed science-based information on irradiation. This starts with a huge effort from the health authorities and other institutions to allow correct understanding of the potential advantages of irradiation for the necessary investment to occur.

7.3. Africa

Few studies have been carried out on the African continent. Between 1978 and 1988, 90% of South African consumers of irradiated potatoes, mangoes, papaya, and strawberries judged that they were satisfied with the quality of the irradiated items [92].

7.4. Asia

In Thailand, irradiated onions were well accepted by consumers in 1987 and respondents were ready to purchase them even at a slightly higher price than unirradiated onions [92]. Fermented sausage was also well accepted and over 94% of consumers indicated a willingness to buy irradiated sausage again.

In Bangladesh, irradiated fish was well accepted by consumers, especially for its better quality and appearance [92]. Also, when onions were sold, consumers were in favor of the irradiated onions. In China, spicy chicken feet were also well accepted by consumers. In the Philippines, for similar prices, irradiated onions and garlic were preferred to unirradiated ones.

In Korea, studies on irradiation acceptability to women demonstrated that it is more convincing to hear a lecture by an expert followed by watching a video- and reading a book with a group. In addition, acceptance of irradiated food has been shown to lead to support for the nuclear industry [104].

Japan invested in public education about radiation for schoolchildren and their parents. More than 60% of kids were satisfied with the information given. Consumers' perceptions about irradiation thereby seemed to shift to become more positive [105,106].

7.5. Oceania

In New Zealand, irradiated mango and litchi have been imported and sold since 2005. Presently a significant volume of irradiated mangoes, lychees, tomatoes, and capsicums are now purchased by consumers in New Zealand. It is clear that irradiation fulfills not only a technological need but also a consumer need by making quality produce available at competitive prices. Consequently, a significant proportion of the New Zealand public will consistently buy irradiated fresh products when they are made available [107].

8. Communication: An Important Factor in Consumer Acceptance of Irradiated Food

In the last decade, with the awareness of health problems caused by food spoilage, the food industry has utilized new technologies to improve the safety and shelf life of food. Some of the new technologies being applied are biotechnology, ionizing radiation, pulsed electronic fields, ultraviolet laser treatment, etc. However, those emerging technologies pose challenges to the industry in terms of consumer choice and acceptability. One of the major barriers of commercialization is the influence on sensorial characteristics that influence the purchase of the product, but there are also some extrinsic factors that might influence consumers, including contextual, social, cultural, and attitudinal variables [21].

To evaluate the reaction of people, studies have evaluated the perceived risk to consumers of new food technologies [108,109]. Data showed that consumers have significant levels of concern about the hazards of new technology, which from a technical/rational point of view was evaluated as a low risk. In general, consumers perceived gamma irradiation as a risky technology because of (1) the carcinogenic nature of irradiated food; (2) the risks of using irradiation technology; (3) the risk of irradiation escaping; and (4) the risks associated with the transportation of radioactive material [110]. This negative perception of new technology was studied by Cardello [21], who related the perceived risks to the consumer's lack of awareness about any processes applied to the purchased food—either because these are out of the consumer's control or because they are unobservable. Therefore, consumers do not know if what they are consuming is irradiated or not or if it might have negative effects on their health.

Several authors [101,111,112] studied people's opinions and readiness to accept irradiated products. Junqueira-Gonçalves et al. [113] indicated that the people surveyed had a lack of information and understanding of food irradiation. Briefly, 45.9% of the responders answered that irradiated food means radioactive food, and 57.1% of people were uncertain if gamma irradiation can cause damage to human health and/or the environment. Nevertheless, marketing has shown that consumers are willing to purchase irradiated products if they are informed about the effects and the process [91].

Several studies have demonstrated that food irradiation can mitigate the development of food-borne diseases, which continue to grow with approximately 76 million illnesses, 325,000 hospitalizations, and 5000 deaths in the United States annually [114], and 1.6 million illnesses, 4000 hospitalizations, and 105 deaths in Canada [115]. Even though scientists recognize food irradiation as a safe and effective process, there can still be either a negative bias or a lack of information, which can be a limiting factor when addressing consumer resistance towards food irradiation.

Scientists have realized that consumer perception of novel technologies relies heavily on the communication approach employed. It was proven by Furuta et al. [106] that more than half of interviewed people present at a "Radiation fair" held in Japan recognized the word "radiation," which was taught to them in elementary school and by the mass media. In addition, results showed that image can be improved if correct information about radiation is relayed to the public. Hence, factors such as teaching, labeling, and food retail could play an important role in diffusing new technology and the creation of a positive link with consumers.

8.1. Teaching

Although gamma irradiation has shown many beneficial effects such as insect disinfection, extension of food shelf life, and reduction of bacteria [69], irradiation has not been widely adopted as a commercial process. It was suggested by Zimmerman et al. [116] that in terms of new food technology either cognitive or affective perceptions can have an influence on consumer attitudes. Similar findings were mentioned by Edwards [117], who demonstrated that people's perceptions are usually based on the global attitude towards new technology when knowledge of the specific topic is low [118,119].

However, not only the global adoption of the novelty but also educational programs can have significant impact on consumer attitudes. Recent studies point out that once consumers are educated, they will buy irradiated food and adopt a positive attitude towards food irradiation [120,121]. With the aim of accomplishing this goal, scientists must take into account the non-technical perceptions of people about the believed "risk" of the gamma irradiation technique [122]. In comparison to other food procedures, gamma irradiation was ranked alongside food preservatives and sodium nitrate as a less-feared factor.

Although nowadays consumers are looking for food safety and "freshness," there is evidence that consumers regard food safety as a basic requirement. Thus, consumers do not value the extension of product shelf life that results from gamma irradiation. In 1988, the United Kingdom was confronted with *Salmonella* infection in egg production, while consumers were not aware that this crisis could occur in eggs. This is the reason why highlighting improvements caused by irradiation in food safety can serve as a proof of the advantages of this technology.

Some authors such as Rogers [123] have proposed that the topic of gamma irradiation should be included in educational programs so as to introduce consumers to it. Rogers [123] mentioned the importance of including characteristics such as advantages, compatibility, complexity, trialability, and observability in the diffusion and adaptation of new technology. Complexity is defined as the degree to which an innovation is perceived as difficult to understand and use. Observability is defined as the degree to which the applied technology is visible to others; this will allow consumers to observe the process and the results of the irradiated food. Trialability is expressed by Rogers [123] as the degree to which the innovated product can be experienced on a limited basis. For instance, when a consumer has his first contact with irradiated food, his organoleptic senses will allow him to compare and determine his opinion with respect to irradiated and non-irradiated foods.

8.2. Labeling; RADURA Symbol

In order to identify an irradiated product and alert consumers to its quality, the Pilot Plant for Food Irradiation at Wageningen, The Netherlands, created the symbol RADURA (Figure 1). This word is related to "radurization," a word derived from radiation and the Latin word "*durus*" for "lasting." The term is used for the process of exposing food to ionizing radiation to enhance and extend the shelf life. Thus, the product is irradiated at doses in the range from 0.4 to 1 kGy to decreased number of spoilage bacteria [124]. Due to the fact that external microorganisms can also encounter the irradiated product, food packaging is part of the process. The "RADURA" symbol was established to represent the irradiation treatment. The symbol presents a plant (dot and two leaves), in a closed package (circle), irradiated with ionizing rays passing through the package to the food (dashed lines). Despite the fact that the use of the RADURA symbol is optional, according to the Codex Alimentarius standard [125], if the food or an ingredient product is treated with ionizing radiation a written statement shall be placed in proximity to the food to indicate that the treatment was done. This last requirement might change from country to country. For instance, in the United States, labeling is only required if the whole food has been irradiated and labeling is not required at restaurants/catering establishments [126]. Canada requires labels and written statements such as "irradiated," "treated with radiation," or "treated by irradiation" when the whole product was irradiated or more than 10% of the ingredients that compose the final product [127]. On the other hand, New Zealand demands labeling for even minor ingredients and in restaurant/catering establishments [32].

Figure 1. The RADURA symbol.

Labeling is an important step that assures consumers whether they are deciding to buy or not buy irradiated products. Indeed, once consumers know about the identification of products, it is easy for them to accept the risks of purchasing food derived from a new technology [128].

According to Junqueira-Gonçalves et al. [113] the RADURA symbol is not frequently present on food labels in Chile. However, studies mentioned that 55.8% of people would buy irradiated food because the symbol transmits the sensation of confidence and safety. Similar discussions were held by Rollin et al. [3], who said that labeling products treated with new technology will raise awareness and improve transparency. However, there are still ambiguous reactions demonstrated in the study performed by He et al. [128], who reported that over 30% of people in the USA would consider the term "irradiated" beef product as a warning and only 21% would consider it safe and buy it.

9. Food Retailers

Since food irradiation is not a familiar technology for everybody and does not show any detectable changes in food, consumers' confidence relies on food processors who might inform them whether the product was irradiated or not [110]. Thus, the role of food retailers is as important as that of educators, giving a sense of assurance of food quality to people who still are scared and avoid the technology [129].

However, even if trust between food retailers and consumers is gained, it can be easily lost with a single mistake [129]. Trust-destroying mistakes such as withholding of information or scientific tests indicating that a product is less safe than originally conceived might affect consumer perceptions about gamma irradiation.

Thus, in order to be transparent and maintain consumers' confidence, food retailers should firstly give consumers the freedom to choose between irradiated and non-irradiated products. For this, positive disclosure is required. Secondly, because irradiation is a process that does not exhibit any modification on food, retailers must indicate that the irradiation process has been done in an appropriate manner.

Moreover, food retailers are the first facilitators in developing irradiation acceptability by merchandising irradiated goods to the consumer. As the first contact of consumers with such product is in the market, food retailers should give consumers the opportunity to observe and judge for themselves about the new technology. Thus, consumer confidence in the food supply chain will be enhanced.

10. Future Directions for Gamma Irradiation

To encourage consumers to accept gamma irradiation, some authors have considered future strategies for increasing retail of irradiated food [69,110,130]:

- Highlight the advantages of the technology rather than pointing out the technology. Consumers value "freshness" more than increased shelf life, which can be seen as "unnatural."
- Take into account the positive and negative aspects that will coexist in any food debate.
- Use labels to show advantage information, thus offsetting the warnings that labels are perceived to bring with them. A labeled product will be assured. , thus decreasing consumer opposition to irradiated food. This fact was observed in Australia and New Zealand.

- Create a partnership with food retailers so they can promote the marketing of irradiated food, especially to those who are small or medium-sized.
- It can be worthwhile to have stakeholders that believe in the value of food irradiation, thus food retailers will be seen as less biased and consumer trust will increase.

11. Conclusions

Foods processed by novel and emerging technologies, e.g., biotechnology, ionizing radiation, pulsed electric field, ultra violet laser treatment, etc. pose a serious challenge to factors such as consumer choice, purchasing behavior, and acceptance of irradiated foods. Future research on novel food processing and preservation technologies should focus more directly on questions and issues related to consumers' expectations. Developing a better understanding of the variables that directly influence the acceptance of these products and more effective marketing and informational strategies could improve the acceptance of these novel technologies in tomorrow's marketplace.

Evidence has shown that gamma irradiation, especially related to food, represents a hazardous technology to consumers. This is the reason why commercialization has encountered several barriers to being adopted and accepted by consumers. It has been demonstrated that communication, labels, and education about new technology will enhance consumers' perception of irradiated food. Thus, showing the possible problems carried by food-borne diseases can create consciousness of the importance of food safety. On the other hand, due to the fact that gamma irradiation is a process that does not affect physical aspects of the product, the role of the food industry and food retailers should be to inform the public either by labeling products or by telling consumers about the benefits of the irradiation.

New strategies based on positive messages of gamma irradiation marketplace will thus encourage consumers to be more receptive to safety-enhanced and high-quality irradiated foods.

Based on knowledge derived from over half a century of research, irradiated foods are safe and wholesome at a specified radiation dose. The irradiated foods are generally nutritionally equivalent to non-irradiated foods subjected to normal processing, even better in some cases; radiation processing can lead to an increment in the nutritional value of irradiated fruits and vegetables such as vitamin C content and phenolic compounds.

Furthermore, many studies have shown that irradiation technology in combination with other treatments can be used as an innovative and effective method to add value to food products. As previously detailed, people are still confused and fail to differentiate irradiated foods from radioactive foods. When well informed, a reduced number of consumers will reject irradiated food. What a consumer is looking for is a product with good quality and a competitive price. When consumers are aware of the short- and long-term dangers of chemical additives, they accept more irradiation treatments being applied to food products. However, companies should update their quality system and implement new procedures to support risk management and the supply and distribution chains.

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NATIONAL COLLECTIONS AND MARINE INFRASTRUCTURE
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Ten things you need to know about collections

1. Our biodiversity is unique

Australia is home to half a million - around eight per cent - of the world's species. Seventy per cent of our species are endemic (not found elsewhere on Earth).

2. Biodiversity is a free, planet-scale life support system

Biodiversity takes care of essential processes like sequestering carbon, cycling nutrients, purifying water, regulating ocean and atmospheric temperature, turning waste into energy, suppressing pests and diseases, and pollinating crops. Many Australian species also support our industries, including agriculture, fisheries and tourism.

3. Collections are critical research infrastructure for the nation

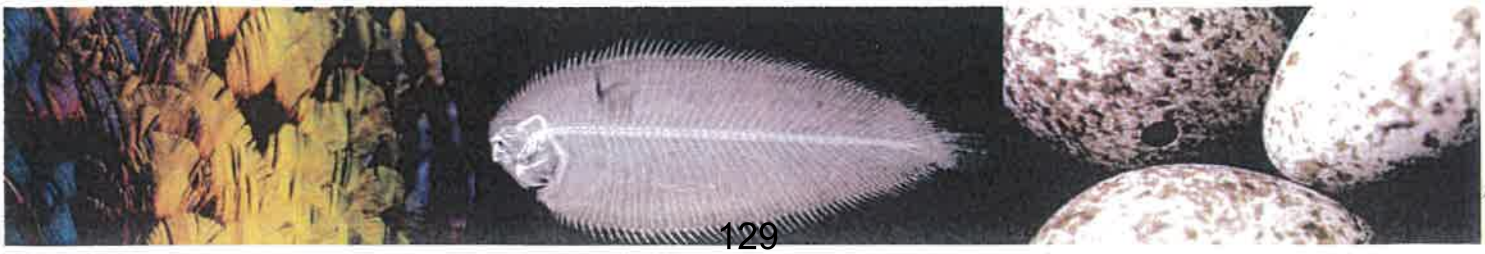
Biological collections have a long history in Australia, dating back to the late 1700s. Today they underpin research, policy and everyday practice in: biosecurity, biodiversity, restoration, emerging infectious diseases, biofuels and novel products, evolutionary biology, genetic resource management, breeding, bio-inspiration and bioprospecting.

4. The National Research Collections Australia are home to 15 million specimens

From fishes to birds to native plants, weeds, pest insects and much more, our collections are a continental-scale, 200+ year time series that reveals Australia's biodiversity. Our collections are made up of natural history specimens, including whole organisms, skins, tissues samples, skeletons and DNA samples; and their metadata, including what species they are, when and where they were collected, site descriptions, species associations, etc.

5. We are digitising the National Research Collections Australia

Our digital collection is made up of photographs, 3D scans and x-ray images of our specimens and their metadata. We also have a library of bird and wildlife sounds and collections of DNA sequences. As we digitise our collections, we are making them available on the Atlas of Living Australia. There are millions of free public downloads of our biodiversity data each year from the Atlas for use in education, research and policy.



6. Our collections result in impact

Our insect collection protects Australia's biosecurity by enabling insects to be identified at our borders and revealing how insecticide resistance develops. Our fish collection provides data on what fishes exist where and was crucial for developing key biological datasets for Australia's Marine Bioregional Plans. Our wildlife collection is revealing how birds are responding to climate change and is a vital record of historic species distributions for restoration projects. The Australian National Herbarium, which is a joint venture between CSIRO and Department of the Environment and Energy, supports threatened species recovery and weed seed identification at our borders.

7. Our collections include two living, commercial collections

We supply microalgae strains from the Australian National Algae Culture Collection around the world to help understand harmful algal blooms, create novel products from algal oils and provide feed for aquaculture. The seed banks and seed orchards of the Australian Tree Seed Centre support conservation of our iconic native trees and supply seeds around the world for essential crops like eucalypts and acacias.

8. We are part of a bigger whole

Across Australia there are 60 million natural history specimens held at museums, universities, botanic gardens, herbaria, seed banks and CSIRO. We host hundreds of visiting scientists each year and loan 50,000+ specimens for research.

9. Genomics is transforming the way we use, understand and benefit from collections

Thanks to huge advances in genomics, even decades old specimens in collections are a ready source of DNA, which is opening up collections as a resource for research. Genomics also enables us to explore new kinds of collections, like soil microbes. We've built a comprehensive reference database, or map, of the Australian soil microbiome: Biomes of Australian Soil Environments (BASE). It's creating positive impact for Australia in mineral exploration, restoration biology, agriculture, land management and commercial development of soil-related products.

10. Our Environomics Future Science Platform builds on collections

Through our Environomics (environmental + genomics) Future Science Platform we are transforming environmental science. Based on genomics and drawing on the 15 million specimens that make up the National Research Collections Australia, our Environomics projects include:

- mapping pollinator networks
- mobilising collections through digitisation
- understanding microbial function in our soils and waterways
- assessing stress in plants, animals and ecosystems.

The National Research Collections Australia form part of the science-ready national research infrastructure managed by CSIRO for use by Australian and international researchers.

Find out more about our work at **www.csiro.au/nrca**

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