OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION
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MEMORANDUM

SUBJECT: Mancozeb (014504) Registration Review: Assessment of Use, Usage, Benefits and Impacts of Potential Mitigation for Seed Treatment Uses

FROM: Jeana Hansel, Plant Pathologist
Biological Analysis Branch

Charmaine Hanson, Economist
Economic Analysis Branch

Rachel Fovargue, Biologist
Briana Otte, Biologist
Science Information and Analysis Branch
Biological and Economic Analysis Division (7503M)

THRU: Monisha Kaul, Chief
Biological Analysis Branch

T J Wyatt, Chief
Economic Analysis Branch

Hope Johnson, Chief
Science Information and Analysis Branch
Biological and Economic Analysis Division (7503M)

TO: Benjamin Tweed, Chemical Review Manager
Jordan Page, Senior Regulatory Advisor
Risk Management and Implementation Branch 3
Pesticide Reevaluation Division (7508M)

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SUMMARY

Mancozeb is a broad-spectrum multisite fungicide (FRAC group M03) registered for many agricultural and non-agricultural foliar uses, and as a seed treatment on barley, corn, cotton, flax, oats, peanuts, potatoes, rice, rye, safflower, sorghum, tomato, triticale, and wheat. Mancozeb is currently undergoing registration review; the Agency has identified occupational human health risks and ecological risks from mancozeb seed treatments. Consequently, the Agency is considering the cancellation of most of mancozeb's seed treatment uses.

Mancozeb seed treatment usage was reported on potatoes and cereals (combined estimate of wheat, barley, oats, and rye) over the five most recent years of available data; mancozeb was a market leader fungicide in potatoes but not in cereals. Seed treatment fungicide usage on corn, cotton, peanuts, rice, and sorghum were recently surveyed, but no mancozeb usage was reported, suggesting mancozeb is not widely used as a seed treatment on these crops. The Agency does not have seed treatment data on flax, safflower, tomato, or triticale, but this should not be interpreted as lack of usage. Information from stakeholders indicates that mancozeb is not widely used for seed treatment of cereal grains, cotton, peanut, or tomato.

BEAD finds that mancozeb has high benefits as a potato seed treatment because it has a broad spectrum of control, including diseases not controlled by other available seed treatment fungicides; it is an important component for resistance prevention; and it is cheaper than alternatives. Mancozeb is one of the only seed treatment fungicides for the bacterial disease common scab and the oomycete disease late blight in potato seed pieces. Mancozeb is also effective on a number of fungal diseases of potato seed pieces, including dry rot, black scurf, and silver scurf. Since mancozeb is a multisite fungicide, another key benefit is that it can be used as part of a resistance management program to prevent or delay the development of resistance to single-site fungicides in target pathogens. Dry rot, black scurf, and late blight have developed resistance to single-site fungicides used as potato seed treatments, so mancozeb is important for resistance management for these specific seedborne diseases.

Without mancozeb, potato growers could manage scab through cultural controls and could use single-site fungicides for the fungal diseases, but this would increase the risk of development or spread of fungicide resistance, particularly in dry rot, late blight, and black scurf. Growers needing to replace mancozeb would incur greatly increased costs for potato seed treatment because they would need to use multiple single-site fungicides to cover the same disease spectrum and prevent resistance. However, seed treatments are a relatively small percentage of the per acre operating costs for potato production in many states, so a large increase in seed treatment cost (i.e., double or triple) alone would not lead to large declines in per acre operating net revenue for potato growers. In the near term, economic impacts may be primarily limited to an increase in pest control costs (1 to 3% per acre), but if resistance develops in the alternative fungicides, such that these pests cannot be adequately controlled, then high yield losses (25 to 60%) are possible in the future.

BEAD finds that mancozeb has low benefits as a seed treatment in cereals, oil seeds, and all other seed treatment sites outside of potato, as extension recommendations do not recommend mancozeb seed treatments and/or stakeholders have indicated that mancozeb is not important in these sites. This is supported by available seed treatment usage data, which finds low or no usage in these surveyed crops. In seed treatment use sites for which BEAD does not have usage data, benefits are expected to be low due to the availability of a broad variety of disease-resistant cultivars, a relatively narrow spectrum of seed pests, and multiple fungicides recommended for seed treatments.

INTRODUCTION

The Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 3(g) mandates that the Environmental Protection Agency (EPA or Agency) periodically review the registrations of all pesticides to ensure that they do not pose unreasonable adverse effects to human health and the environment. This periodic review is necessary in light of scientific advancements, changes in policy, and changes in use patterns that may alter the conditions underpinning previous registration decisions. In determining whether adverse effects are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

Mancozeb is a broad-spectrum multisite protectant fungicide in the Fungicide Resistance Action Committee (FRAC) group M03. It is registered for use on various agricultural and non-agricultural use sites, and as a seed treatment on multiple use sites.

The Agency has identified human health risks to occupational handlers and ecological risks to several taxa (e.g., birds, mammals) associated with the seed treatment uses of mancozeb. To address these risks, the Agency is considering the cancellation of all seed treatment uses of mancozeb except for sorghum, on-farm liquid and dust applications on safflower seeds, and on-farm liquid applications on field corn, cotton, flax, and tomato seeds.

This memorandum analyzes information on the use and usage of mancozeb as a seed treatment, evaluates the benefits of mancozeb seed treatments, and describes the impacts from the potential cancellation of most mancozeb seed treatments. In separate memoranda, BEAD also assessed the usage and benefits of mancozeb on other agricultural and non-agricultural crops. These memoranda are available in the mancozeb docket (EPA-HQ-OPP-2015-0291) at www.regulations.gov.

METHODOLOGY

BEAD defines the benefit of mancozeb seed treatments as the extent to which they are important to the end users, specifically producers of the crops. The benefits of mancozeb seed treatments are based on various agronomic factors, chemical characteristics, and alternative control strategies, all of which influence how a grower manages pests. For agricultural seed treatment uses, the unit of analysis is a crop acre planted with mancozeb-treated seeds. BEAD assesses benefits at this unit of analysis both because crop growers make pest control decisions at the acre- or field-level, and because risks are usually measured at the same spatial levels (treated acres and treated fields).

BEAD first analyzes the available pesticide seed treatment usage data for surveyed use sites to identify if mancozeb seed treatment usage is reported and the relative magnitude of any reported usage among other seed treatment products. BEAD reviews this pesticide usage data, university extension recommendations, and scientific publications, as well as stakeholder comments to identify the important target pests, the damage that might result from said pests, regional importance, and the attributes of mancozeb that make it useful in the pest control system. Together, this information establishes where, when, why, and how growers use mancozeb seed treatments. Additionally, BEAD uses these sources to identify alternative methods of control for mancozeb's target pests. Among the use sites where mancozeb seed treatment usage is available and reported, BEAD identifies why growers choose to use mancozeb over potential alternatives, which is essentially the key benefits from use of this pesticide. Some key reasons for use include: the pests that growers target with mancozeb, the cost of using mancozeb, the length of control that mancozeb provides, the timing of control, and whether mancozeb is being used in addition to other modes of action in order to delay the development of resistance.

The information and analysis allow BEAD to evaluate the magnitude of the benefit for the use sites. Evaluating the magnitude of the benefit is done by assessing the biological and economic impacts that growers might experience should they need to employ alternative pest control strategies, chemical and non-chemical, in the absence of mancozeb seed treatments. Both quantitative and qualitative measures are used to inform the magnitude of the benefit to growers from use of mancozeb seed treatments. The impacts to a grower from using the next best alternative to mancozeb could include monetary costs (e.g., from using more expensive chemicals) as well as loss of utility in resistance management, integrated pest management programs, simplicity of use, and/or flexibility. Additionally, physical and/or managerial effort may increase; and there may also be impacts with respect to crop yield loss and/or quality reductions related to diminished pest control. Where possible, impacts of the absence of mancozeb seed treatments are quantified, monetized, and placed in the context of measures of grower income via a partial budget analysis.

For the analysis below, data and crop budgets are sourced from university extension services, United States Department of Agriculture (USDA) (e.g., publicly available crop production, pesticide usage, and cost data, as well as information submitted directly to EPA), public and commercially available grower survey data, public comments submitted to the Agency from various stakeholders, the open literature, and BEAD's professional knowledge. The most heavily used sources of seed treatment data in this memorandum are purchased from Kline (Global Seed Treatment 2018: United States Market Analysis and Opportunities) and Ben Kirk (United States Seed Treatment Product and Brand Historical Database).

CHEMICAL CHARACTERISTICS

Mancozeb is an ethylene bisdithiocarbamate broad spectrum multisite protectant fungicide in the FRAC group M03 (FRAC, 2024). Mancozeb is a complex of two other dithiocarbamate fungicides, maneb and zineb, neither of which are registered outside of their combined molecule mancozeb. Mancozeb, as a multisite fungicide, works by deactivating multiple essential enzymes and amino acids in the cells of target pathogens. Due to these multiple pathways for inhibiting disease development, mancozeb, like other multisite fungicides, has a very low risk of resistance development (FRAC, 2010; FRAC, 2018). Multisite fungicides, including mancozeb, typically have a broad spectrum of activity, and mancozeb's broad spectrum of activity prevents diseases caused by bacteria, fungi, and oomycetes on seed and in the field.

USE AND USAGE

Use

Mancozeb is registered for seed treatment in barley, corn, cotton, flax, oats, peanuts, potatoes, rice, rye, safflower, sorghum, tomato, triticale, and wheat. Mancozeb seed treatments are formulated as dusts and liquids. Seed treatments may be applied on-farm or commercially.

Usage

Seed treatment data available to the Agency can be utilized qualitatively as an indicator of positive usage, though at this time, it is not possible to estimate the geographic extent of the seed treatment usage or provide robust quantitative estimates of usage. Rather, the Agency provides a qualitative description of seed treatment usage based on these datasets; an understanding of how reported usage, or dollar amount of sales, of mancozeb ranks when compared to other fungicide seed treatments may indicate its relative importance for crops for which data are available.

Mancozeb seed treatment usage was reported on potatoes and cereals (combined estimate of wheat, barley, oats, and rye) over the five most recent years of available data (2017 to 2021) (Ben Kirk, 2022; Kline, 2019). In terms of acres planted with treated seed, dollar amount of sales, and volume of AI applied, from 2017 to 2021, mancozeb was a market leading fungicide seed treatment on potatoes (Ben Kirk, 2022; Kline, 2019). In both surveys, mancozeb was not a market leading seed treatment fungicide according to usage reported on cereal grains (wheat, barley, oats, or rye), neither in terms of dollar amount of sales nor pounds of AI applied (Ben Kirk, 2022; Kline, 2019).

Seed treatment fungicide use on corn, cotton, peanuts, rice, or sorghum was surveyed from 2017-2021, however, no mancozeb usage was reported, suggesting mancozeb is not widely used as a seed treatment on these crops (Ben Kirk, 2022). The Agency does not have seed treatment data on flax, safflower, tomato, or triticale. The absence of such seed treatment data should not be interpreted as lack of usage.

DETERMINATION OF ASSESSMENT SCOPE

The primary focus of this assessment is potato seed treatment because there is substantial mancozeb usage reported in terms of acres planted with treated potato seed compared to other fungicide seed treatments on potatoes and because information from stakeholders and university extension publications indicate that mancozeb is an essential component of potato seed treatment mixtures. University extension professionals from the Pacific Northwest and Maine claim via USDA OPMP (2022) that mancozeb has high benefits as a potato seed treatment in these regions, and extension publications throughout the country broadly recommend mancozeb for potato seed treatment, indicating that it is an important use on a national scale.

BEAD also assesses mancozeb's benefits in rice seed treatment because information from the USA Rice Federation relayed via MTF (2021) claims that mancozeb is a highly important seed treatment for rice in Texas.

While mancozeb is registered for other seed treatment uses, stakeholder information provided to the Agency via the United States Department of Agriculture Office of Pest Management Policy (USDA OPMP) indicates that it is not widely used for seed treatment of cereal grains, cotton, peanut, or tomato (USDA OPMP, 2022). BEAD does not have usage data or stakeholder information about mancozeb's benefits as a seed treatment for flax and safflower. NDSU (2023) recommends mancozeb, among multiple other fungicides, for both flax and safflower seed treatment but does not indicate the degree of mancozeb's benefits compared to other seed treatment fungicides, and there is little available recent information on these uses elsewhere. Similar to other cereal and oilseed seed treatment uses, mancozeb may not be important in these sites due to the availability of a broader variety of disease-resistant cultivars and a smaller target pest spectra.

BENEFITS OF MANCOZEB SEED TREATMENTS IN RICE

Information relayed to the Agency from the Mancozeb Task Force (MTF) on behalf of the USA Rice Federation and a rice extension specialist at Texas A&M University claims that mancozeb seed treatment is important for rice in Texas, particularly for kernel smut (*Tilletia barclayana*) (MTF, 2021). MTF (2021) reports that mancozeb is used to prevent a broad spectrum of rice seed pathogens in Texas, including kernel smut and seedling damping-off, rot, and blight diseases. They claim that most seed diseases have alternative fungicides but that mancozeb is the only seed treatment fungicide effective for kernel smut.

The kernel smut pathogen infects developing rice grains and replaces the endosperm of the rice grain partially or fully with black smutty spores. While overall yield losses are insignificant, monetary losses can be high due to quality losses (TAMU, 2018). The disease has become increasingly problematic in Southern rice growing states because environmental conditions are favorable for the disease, and it is difficult to control with fungicides (Khanal et al., 2023; TAMU, 2023). The current recommended management strategy is midseason preventive applications of demethylation inhibitor (DMI) fungicides such as propiconazole or difenoconazole (Khanal et al., 2023; LSU AgCenter, 2022; TAMU, 2018; UADA, 2023).

Seed treatment is not usually recommended for kernel smut, and mancozeb is not recommended for rice seed treatment (Khanal et al., 2023; LSU AgCenter, 2022; UADA, 2023; UCANR, 2018). Efficacy studies have found one of mancozeb's primary component molecules, maneb, to be ineffective as a kernel smut foliar or seed treatment (Khanal et al., 2023). Efficacy studies have found that saltwater treatment, hot water treatment, and copper can be effective in reducing seedborne kernel smut (Khanal et al., 2023). Seed treatments containing the DMI fungicide prothioconazole, which are already recommended for rice seed treatment for a broad spectrum of seed diseases, could also be effective (UADA, 2023). *Tilletia* spp. pathogens pose a low risk for developing fungicide resistance, and there has been no documented fungicide resistance in these pathogens (FRAC, 2019; FRAC, 2020). Therefore, there would be minimal or no resistance management concerns if a single-site fungicide is used instead of mancozeb for control of kernel smut. If unable to use mancozeb as a rice seed treatment, rice growers who need to control kernel smut could use an alternative efficacious treatment, such as hot water, salt water, or a DMI fungicide to reduce kernel smut incidence in seed with little to no impact.

BEAD thanks the MTF and the USA Rice Federation for information on mancozeb's benefits as a seed treatment for rice in Texas; however, BEAD cannot find recommendations for mancozeb as a rice seed treatment or as a treatment for kernel smut. Commonly recommended seed treatments, such as the DMI fungicide prothioconazole, are likely to be more effective than mancozeb for kernel smut and general seed diseases. There is no reported usage of mancozeb on rice seeds from 2017 to 2021 (Ben Kirk, 2022). Therefore, BEAD concludes that there are low benefits to the use of mancozeb as a rice seed treatment and there would be few or no impacts from the proposed cancellation of this use.

BENEFITS OF MANCOZEB SEED TREATMENTS IN POTATO

Seed treatments are particularly important during potato seed piece processing (USDA OPMP. 2022; UMaine, 2021). Potatoes are not propagated by true seeds but by seed pieces, which are blocky tuber chunks. Whole tubers are fed through a mechanical cutter, which cuts the tubers into two to four pieces (UMaine, 2021). The machines handle many tubers at once, so there is a very high risk of disease transmission during seed cutting and handling processes (UF, 2016). The wounded surface of the seed piece is very vulnerable to disease if not protected by an effective seed fungicide like mancozeb (UC IPM, 2019; UF, 2016).

Stakeholders report that potato seed pieces are treated on-farm and at commercial facilities (USDA OPMP, 2022). Stakeholders indicate that mancozeb is applied to seed tubers either alone or, more commonly, in a mixture with single-site systemic fungicides to control a broad spectrum of seed diseases and prevent or delay resistance to highly effective single-site fungicides (USDA OPMP, 2022). After seed tubers are cut, they must be stored for at least one week to cure the wounded tuber skin, which protects the seed tuber from soil pathogens at planting (UMaine, 2021). Extension guidelines recommend that growers use disease-free seed, inspect seed for disease, keep seed cutting and planting equipment clean, and use effective fungicides, such as mancozeb, to reduce the spread of diseases during potato seed piece processing (NDSU, 2023; UC IPM, 2019; UF, 2016; UMaine, 2021).

Below, BEAD assesses the benefits of mancozeb as a potato seed treatment and potential alternatives in the absence of mancozeb.

Mancozeb Target Diseases

Mancozeb, as a broad-spectrum fungicide, is effective on a number of fungal and non-fungal diseases of potato seed pieces. Mancozeb is one of the only seed treatments for common scab, caused by *Streptomyces* spp. bacteria, and late blight, caused by the oomycete *Phytophthora infestans* (NDSU, 2023; UMaine, 2019). Because the causal organisms of these diseases are not fungi, most single-site fungicide treatments are generally not effective. The University of Maine (2019) compares different seed treatments for efficacy and rates all products as “poor” for seedborne scab and late blight, except for products containing mancozeb which are rated “excellent” for scab and “good” for late blight.

Mancozeb is also effective for fungal diseases that affect potato seed pieces, such as dry rot (*Fusarium* spp.), black scurf (*Rhizoctonia solani*), and silver scurf (*Helminthosporium solani*) (MSU, 2009; NDSU, 2023; UMaine, 2019; USDA OPMP, 2022). All potato seedborne diseases can co-occur, highlighting the need for broad-spectrum fungicide treatments such as mancozeb.

<u>Non-Fungal Diseases</u>

Common scab

Common scab in potatoes is caused by *Streptomyces scabies* or *Streptomyces acidiscabies*, depending on the soil pH. *Streptomyces* spp. is a widely-distributed genus of soil-dwelling bacteria, and scab inoculum can be spread through infected soil, water, and seed tubers (NDSU, 2017; UC IPM, 2019). Scab does not usually affect total yield but can cause significant economic losses from reduced tuber marketability from scab lesions on tubers (Cornell, 2021a). Young tubers are most susceptible to scab; mature tubers with well-developed skins are not susceptible (NDSU, 2017; UC IPM, 2019).

Most extension resources recommend managing scab solely through cultural controls, such as crop rotation, soil moisture and nutrition management, planting certified scab-free seed, cover cropping, and planting resistant potato varieties (Cornell, 2014; Oregon State et al., 2023; UC IPM, 2019; UConn et al., 2023). UMaine (2020) and UMass (2022) recommend that growers plant certified seed with no scab lesions but suggest mancozeb for seed with some scab contamination. NDSU (2017) recommends cultural controls and seed treatment with fludioxonil or *Bacillus* biopesticide products. In general, seed treatments are not applied specifically for scab. Scab is not a primary target pest of mancozeb seed treatments on potato, but when mancozeb is used for other diseases, it can provide some level of added scab control and can reduce the spread of scab during seed cutting operations if scab is present on seed tubers.

Late blight
Late blight, caused by the oomycete *Phytophthora infestans*, is one of the most pervasive potato diseases, affecting potatoes at all stages of growth (NDSU, 2022). The pathogen persists between seasons in infected tubers left behind during harvesting, seed potatoes, cull piles, and volunteer plants (Cornell, 2014; NDSU, 2022; UC IPM, 2019). Late blight infected seed decays before plant emergence or shortly afterwards, causing early season plant losses (NDSU, 2022). The pathogen also produces airborne spores on infected seedlings, which can spread the disease rapidly to nearby seedlings if conditions are conducive, i.e., moderate temperatures with high humidity (NCSU, 2018; NDSU, 2022; UC IPM, 2019). Even certified seed must be treated because it can contain a low percentage of late blight infection, which can be enough to cause severe problems if conditions are conducive for disease (Cornell, 2014).

To reduce the risk of early season late blight outbreaks and the risk of disease transmission during seed handling operations, growers are advised to treat seed pieces with fungicides, including mancozeb (Cornell, 2014; NDSU, 2022; NDSU, 2023; Oregon State et al., 2023).

<u>Fungal Diseases</u>

In addition to the above non-fungal diseases, mancozeb is effective on a number of seedborne fungal pests of potato, including dry rot (*Fusarium* spp.), black scurf (*Rhizoctonia solani*), and silver scurf (*Helminthosporium solani*) (MSU, 2009; NDSU, 2023; UC IPM, 2019). These diseases reduce plant establishment by killing developing potato sprouts (MSU, 2011). If disease-free seed is not used, growers are advised to use fungicide seed treatments that contain mancozeb, plant more seed per acre to ensure stand uniformity and promote yield, or reject the seed lot if disease is too substantial to be suppressed using seed treatments (MSU, 2011).

Dry rot
Dry rot is one of the most common storage and seed piece diseases, and even certified seed cannot be guaranteed to be fully disease-free, highlighting the importance of seed treatments including mancozeb (Miller et al., 2019; MSU, 2011; Oregon State, 2020). MSU (2009) specifically recommends fungicides containing mancozeb for dry rot control. Stakeholder information from the National Potato Council via MTF (2021) reports that dry rot is mancozeb's primary target disease for potato seed treatments.

Black scurf
Black scurf is caused by *Rhizoctonia solani*, a common soil pathogen with a broad host range (Oregon State, 2020). Early black scurf infection caused by soilborne or seedborne inoculum can girdle and kill developing sprouts, reducing plant stand and eventual yields (Oregon State, 2020). Silver scurf, like other seed rots, is a common disease of potato and is present in all major production areas of the U.S. (Cornell, 2021b). While silver scurf symptoms only affect the skin of the potato, seed potato infections can spread to daughter potatoes, resulting in tuber discoloration or disfiguration (i.e., quality losses) (Oregon State, 2020). Fungicide seed treatments, particularly mancozeb, are often recommended for black scurf. Often other

fungicides are combined with mancozeb to provide greater control of scurf and control of seedborne late blight (Miller et al., 2019; MSU, 2011; NDSU, 2023; Oregon State, 2020; UC, 2019; UMaine, 2019).

Mancozeb Alternatives in Potato

Table 1 lists registered seed treatments for potato, their risk of fungicide resistance development, and the diseases they control and denotes where fungicide resistance has been detected in these target diseases. In addition to its broad spectrum of control, mancozeb, as a multisite fungicide, can be used as part of a resistance management program to prevent or delay the development of resistance to single-site fungicides in its target pathogens (FRAC, 2010; FRAC, 2018). Mancozeb as a potato seed treatment is particularly important for resistance management for *Fusarium sambucinum* (dry rot), *Phytophthora infestans* (late blight), and *Rhizoctonia solani* (black scurf) because these pathogens have developed resistance to single-site fungicides commonly used as potato seed treatments (Abuley et al., 2023; FRAC 2020).

Table 1: Fungicides Registered for Potato Seed Piece Treatment and Disease(s) Controlled

FRAC group	Active ingredient(s)	Risk of resistance[1]	Labeled diseases[2]				
			Dry rot	Black scurf	Silver scurf	Late blight	Common scab
M03	Mancozeb	Low	X	X	X	X	X
1	Thiophanate-methyl	High	$\boldsymbol{X_R}$	$\boldsymbol{X_R}$	$\boldsymbol{X_R}$		
3	Difenoconazole, prothioconazole	Medium	X	$\boldsymbol{X_R}$	X		
7	Flutolanil, penflufen, sedaxane	Medium to high		X	X		
11	Azoxystrobin, fenamidone	High		$\boldsymbol{X_R}$	X		
12	Fludioxonil	Low to medium	$\boldsymbol{X_R}$	X	X		
40	Mandipropamid	Low to medium				$\boldsymbol{X_R}$	

[1]FRAC, 2024. Resistance risk determination is based on mechanism of action and prevalence of resistance in target pathogen(s).

[2]An X denotes that the fungicide is registered for the disease. An $\boldsymbol{X_R}$ denotes that the fungicide is registered on the disease but that populations of the causal pathogen have developed resistance to the corresponding FRAC group (Abuley et al., 2023; FRAC, 2020).

<u>Late blight</u>

There are only two recommended fungicide seed treatments for control of late blight in potato: mancozeb and mandipropamid (Table 1). Mandipropamid, a single-site oomycete-specific fungicide, is classified as low to medium risk of resistance; however, FRAC (2023) advises users to implement resistance management strategies when using group 40 fungicides (mandipropamid) to manage late blight. While *P. infestans* lineages in the U.S. have not yet developed resistance to mandipropamid, *P. infestans* populations insensitive to mandipropamid have been isolated from potato fields (Abuley et al., 2023). FRAC (2019) classifies *P. infestans* as a medium resistance risk pathogen. In particular, the *P. infestans* lineages dominant in the Pacific Northwest have already developed resistance to mefenoxam, a commonly-used single-site foliar fungicide for *P. infestans,* demonstrating the potential for these populations to also develop resistance to other single-site fungicides, including mandipropamid (Abuley et al., 2023; Oregon State et al., 2023).

If unable to use mancozeb, growers would need to use mandipropamid for prevention of late blight transmission during seed cutting processes. Sole reliance on mandipropamid would increase the risk of *P. infestans* developing resistance which would compromise late blight control.

Dry rot

Potato seed fungicides recommended for control *Fusarium* dry rot are mancozeb, fludioxonil, thiophanate-methyl and the demethylation inhibitors (DMIs), prothioconazole and difenoconazole (Table 1; Oregon State et al., 2023; Miller et al., 2019; NDSU, 2023). Fludioxonil is a highly effective fungicide for sensitive *Fusarium* populations, but fludioxonil resistance in dry rot-causing *Fusarium* spp. has become increasingly common throughout the U.S. (Miller et al., 2019; Christy, 2023). Similarly, due to widespread resistance in thiophanate-methyl's target diseases, including dry rot, its use has declined, and it is no longer recommended (Miller et al., 2019; NDSU, 2023; Oregon State et al., 2023; UMaine, 2019). While there is no known DMI resistance in dry rot-causing *Fusarium* spp., there is a risk of resistance development. There are several *Fusarium* spp. that do not cause dry rot that are resistant to DMI fungicides, i.e., the genus is prone to developing DMI resistance (Christy, 2023; FRAC, 2020). If growers were unable to use mancozeb, they may need to rely more on DMI fungicide seed treatments for dry rot control, especially where *Fusarium* populations are resistant to fludioxonil. Increased reliance on DMIs could increase the risk of fungicide resistance development in dry rot-causing *Fusarium* populations, which could make dry rot difficult to control in the absence of mancozeb.

Black scurf

Rhizoctonia solani, while classified by FRAC as a low resistance risk pathogen, has developed resistance to multiple classes of fungicides, including several used as potato seed treatments, such as thiophanate-methyl, DMIs, and Quinone outside Inhibitors (QoIs; FRAC group 11) (FRAC, 2019; Table 1). Consequently, most recommended seed treatments for black scurf include mancozeb, fludioxonil (FRAC group 12), or FRAC group 7 (sedaxane, flutolanil) fungicides, to which *R. solani* has not developed resistance (FRAC, 2020; Miller et al., 2019; Oregon State et al., 2023; UC IPM, 2019). In particular, increased resistance on FRAC group 7 fungicides may further exacerbate resistance issues, as these fungicides are classified as medium to high risk for resistance development (Table 1). On the other hand, increased reliance on fludioxonil for black scurf control in the absence of mancozeb could have the unintended consequence of promoting resistance in *Fusarium* spp., the causal agent of dry rot.

BEAD finds that the benefits of mancozeb in potato seed pieces are high because it is broadly recommended by extension publications and stakeholders, it is effective on the most important potato seed diseases, and it can help delay the development of resistance in target pathogens. Without mancozeb, growers treating potato seed pieces would need to use multiple fungicides to replace it, as mancozeb is the only seed fungicide in potato that controls both late blight and fungal diseases.

Impacts of Potential Cancellation in Potato

To reduce the human health risks to occupational handlers and ecological risks to non-target taxa from use of mancozeb seed treatments, the Agency is considering the cancellation of all potato seed treatment uses of mancozeb. The benefit of mancozeb seed treatments in potato seed pieces is high, so the impacts of cancellation would be high.

If growers were unable to use mancozeb on potato seed pieces, they may need to use multiple fungicides to control mancozeb's primary target diseases. In particular, growers would likely need to use several single-site fungicides for diseases such as dry rot, black scurf, and silver scurf, and mandipropamid to reduce the spread of seedborne late blight. Information received from stakeholders indicates that if producers who use mancozeb for potato seed piece treatment needed to replace it with alternatives, adequate seed treatments could be two to three times more expensive per acre (USDA OPMP, 2022).

BEAD does not have sufficient data with which to fully assess quantitatively the cost of mancozeb seed treatment compared to its alternatives. However, the National Potato Council (MTF, 2021) stated that mancozeb is "the most cost-effective way to control Fusarium and seed borne late blight"; this claim is supported by USDA OPMP (2022). Available data products also indicate that mancozeb is relatively low cost when compared to other commonly used fungicide potato seed treatments (Ben Kirk, 2022).

BEAD reviewed various potato crop budgets from different states with a goal of conducting a partial budget analysis for mancozeb seed treatments on potato seed pieces (Eborn, B. 2019a; Eborn, B. 2019b; CSU, 2021; Sánchez, et al, 2023a; Sánchez, et al, 2023b; UK, 2022; Robinson et al, 2018; WSU, 2019). There were some issues that made this difficult. While potatoes are grown all over the US, not every state has publicly available and relatively recent crop budgets. Also, while nearly all budgets found provided cost information for pesticide applications, only a subset of these provided sufficiently disaggregated information on seed treatment costs for potatoes. Additionally, some budgets lumped seed treatment and seed cutting, or fungicide and insecticide applications (all application types: foliar, in-furrow, seed treatment, etc.) into a single line item in the budget. And lastly, another important issue was that the specific active ingredient(s) or pesticide type(s) for a seed treatment, were not always provided. Taking note of these issues, BEAD used a partial budget approach to perform a sensitivity analysis with a subset of crop budgets, using the per acre gross revenue, operating costs, and seed treatment costs from the budgets with seed treatment costs presented as a line item, rather than as a footnote for the pesticide or seed costs.

In the sensitivity analysis, the seed treatment costs were doubled and tripled, since stakeholder feedback indicated that replacing mancozeb would cost two to three times more per acre (Table 2). In this analysis, when the seed treatment costs were doubled and tripled, the result was a decrease in net operating revenue of 1 to 3% per acre (Eborn, B. 2019a; Eborn, B. 2019b; UK, 2022; Robinson et al, 2018; Sánchez, et al, 2023a; Sánchez, et al, 2023b). There were a few notable exceptions in the analysis, with estimated net revenue declines of up to 16% per acre (UK, 2022; Robinson et al, 2018). However, this higher range of impacts only includes budgets with potato seed treatments within aggregated costs, e.g., wherein seed treatment and cutting were lumped together or all fungicide seed treatments were lumped together, thus the more appropriate range of impacts is a net revenue decline of 1 to 3%.

Table 2. Partial Budget Sensitivity Analysis for Potatoes, multiple U.S. states and years

Potato Growing State	Gross Revenue ($/acre)	Seed Treatment (ST) cost ($/acre)	Operating Costs ($/acre)	Baseline Net Revenue ($/acre)	Net Revenue (2X ST cost)[1]	Net Revenue % Change (2X ST cost)	Net Revenue (3X ST cost)	Net Revenue % Change (3X ST cost)[1]
Idaho (Eastern Region)[2]	$2,738	$15	$1,534	$1,188	$1,174	-1.2%	$1,159	-2.5%
Idaho (Southwestern Region)[3]	$4,040	$17	$2,402	$1,621	$1,605	-1.0%	$1,588	-2.1%
Kentucky[4]	$4,125	$60	$3,302	$763	$703	-7.9%	$643	-15.7%
North Dakota (all fungicide STs)[5]	$2,889	$39	$2,041	$809	$770	-4.9%	$730	-9.7%
North Dakota (mancozeb ST only)[5]	$2,889	$11	$2,069	$809	$798	-1.4%	$787	-2.7%
Pennsylvania (conventional)[6]	$8,625	$62	$3,237	$5,327	$5,265	-1.2%	$5,204	-2.3%
Pennsylvania (plasticulture)[7]	$10,313	$62	$4,397	$5,854	$5,792	-1.1%	$5,731	-2.1%

Sources: USDA OPMP, 2022[1]; Eborn, B. 2019a[2]; Eborn, B. 2019b[3]; UK, 2022[4]; Robinson et al, 2018[5]; Sánchez, et al, 2023b[6] ; Sánchez, et al, 2023a[7]

Overall, in the short term, potential impacts to growers would be a large increase in seed treatment costs (2 to 3 times). However, seed treatments are a relatively small percentage of the per acre operating costs for potato production in many states as presented above, so the net revenue declines would be a relatively modest 1 to 3% (Table 2). In the medium to long term, fungicide resistance could increase, and control of the pests covered in this memo could decrease, in part due to reliance on single-site alternative fungicides, many of which have a medium to high risk of resistance developing. The potential of alternatives developing resistance is particularly important for diseases with fewer alternatives such as dry rot and late blight. Reduced control of these pests due to fungicide resistance development would likely have the consequence of reducing seed tuber emergence after planting and contributing to early-season disease establishment, which could result in yield or quality losses, which can range from 25 to 60% (Tiwari, et al, 2020), depending on the disease, level of inoculum in the field, and environmental conditions.

IMPACTS OF MITIGATION TO OTHER SEED TREATMENT USES

The Agency is considering the cancellation of all mancozeb seed treatments except for sorghum, on-farm liquid treatments for field corn, cotton, flax, safflower, and tomato, and on-farm dust treatments for safflower, with additional PPE. BEAD expects any restrictions on non-potato use sites to be less impactful than in potato because these sites were found to have a lower benefit with a smaller spectrum of seed pests and a greater number of alternatives (NDSU, 2023).

CONCLUSION

Mancozeb has high benefits in potato because it has a broad spectrum of control, including both fungal and non-fungal diseases, reduces the risk of fungicide resistance development, and it is inexpensive relative to potential alternatives. Potato seed piece treatment is essential to reduce disease spread during cutting and because diseases such as dry rot, late blight, and silver scurf can cause seed to decay before emergence or cause damping-off of emerging seedlings, reducing initial stand development and increasing initial disease pressure. Mancozeb, as the only multisite fungicide used for potato seed treatment, is particularly important for reducing the development and spread of fungicide resistance, particularly for resistance-prone diseases or diseases with few effective alternatives, including dry rot, late blight, and black scurf. Mancozeb's broad spectrum also makes it one of the only effective potato seed piece treatments for late blight and common scab.

If unable to use mancozeb, potato growers would need to use multiple single-site products to replace it, which would greatly increase costs of potato seed piece treatment. However, seed treatments are a relatively small percentage of the per acre operating costs for potato production in many states, so a large increase in seed treatment cost (i.e., double or triple) alone would not lead to large declines in per acre operating net revenue for potato growers. In the near term, economic impacts may be primarily limited to an increase in pest control costs (1 to 3% per acre), but if resistance develops in the alternative fungicides, such that these pests cannot be adequately controlled, then high yield losses (25 to 60%) are possible in the future.

Mancozeb is also registered as a seed treatment in barley, corn, cotton, flax, oats, peanuts, rice, rye, safflower, sorghum, tomato, triticale, and wheat. BEAD concludes that benefits in these sites are likely low because, where surveyed, there has been low to no mancozeb usage, stakeholders indicate that it is generally not used in these sites, and/or it is typically not recommended as a seed treatment. Some use sites, like flax or safflower, do not have any usage data available, so the impact to these sites is uncertain; however, impacts are still expected to be lower, due to the availability of a broader variety of disease-resistant cultivars, a smaller spectrum of seed pests compared to potato, and a greater number of registered fungicides. While no mancozeb usage was reported for rice seed, the USA Rice Federation claims that mancozeb is important for rice seed treatment, particularly for kernel smut, in Texas. However, BEAD concludes that there are likely low benefits in rice because mancozeb is not recommended by publicly available rice seed treatment guidelines, there has been no reported usage, and there are multiple efficacious alternative treatments.

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