Indian Journal of Weed Science (2022) **54**(4): 370–375
http://dx.doi.org/10.5958/0974-8164.2022.00068.5

ANALYSIS ARTICLE

Risk associated with the weed seeds in imported grain

M.C. Singh*, V.C. Chalam, Dhruv Singh[1], Sushilkumar[2] and S. Gnansambandhan[3]

Received: 13 November 2022 | Revised: 27 November 2022 | Accepted: 29 November 2022

ABSTRACT

The risk of introducing weeds to new areas through grain (cereals, oilseeds and pulses) intended for processing or consumption is considered less than that from seed or plants for planting. However, within the range of end uses for grain, weed risk varies significantly and should not be ignored. There is a need to examine the association of weed seeds with grain commodities throughout the production process from field to final end use, and inspection of representative samples for grain crops commonly imported to India. In the field, weed seed contamination of grain crops is affected by factors such as country of origin, climate, biogeography, production and harvesting practices. As it moves toward export, grain is cleaned at a series of elevators and the effectiveness and degree of cleaning are influenced by grain size, shape and density as well as by grade requirements. In cases where different grain lots are blended, uncertainty may be introduced with respect to the species and numbers of weed seed contaminants. During transport and storage, accidental spills and cross-contamination among conveyances may occur. At the point of import to India, inspection data show that grain shipments contain a variety of weed seeds including seeds of regulated weeds. However, grain cleaning and processing methods tailored to end use at destination also affect the presence and viability of weed seeds. For example, grains that are milled or crushed for human use present a lower risk of introducing weed seeds than grains that undergo minimal or no processing. Risk analysis allows each of these stages to be evaluated in order to characterize the overall risk of introducing weeds with particular commodities, and guide regulatory decisions about trade and plant health.

Keywords: Dissemination, Grain shipments, Interception, Plant Quarantine, Risk analysis, Weed seeds

INTRODUCTION

Import of plant material in bulk like food grains is always of high plant quarantine risk. Increasing trade and globalization coupled with liberalized policies further increase the risk of introduction of exotic weeds through bulk imports. Grain is defined as “seeds intended for processing or consumption and not for planting” (IPPC 2015) and grain commodities consist of bulk shipments of cereal, oilseed or pulse crops destined for use as human food, livestock feed or industrial products. Many weed seeds associated with grain crops in the field are harvested along with the crop and can be difficult to remove due to similarities in shape and size of the seeds. Depending on the destination and intended end use of the grain some of these seeds may be introduced into new environments suitable for growth and establishment. Because large volumes of grain are traded internationally each year, this pathway may represent a considerable contribution to the spread of new weeds around the world. Several studies have reported large numbers of weed species found in sampled grain commodities and a number of globally important weeds of agriculture are thought to have been spread as contaminants in grain (Singh *et al.* 2005, 2014; Nagaraju *et al.* 2021; Dasari *et al.* 2022).

Regulating the spread of weeds via this pathway is the responsibility of individual countries under the guidelines of the International Plant Protection Convention (IPPC), and many countries have legislation and import requirements that mitigate the risk of introducing new weed species to some degree. However, according to the principles of the IPPC, regulations must be based on risk analysis and characterizing the risk associated with complex pathways such as this one remains a challenge. International standards for pest risk analysis are well developed for addressing individual species in terms of the likelihood they will enter, establish and spread in a new area, and the impacts they may have. In this

ICAR-National Bureau of Plant Genetic Resources, New Delhi-110012, India

[1] Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut Uttar Pradesh 250110, India

[2] ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

[3] Directorate of Plant Protection, Quarantine & Storage, NH IV, Faridabad, Haryana 121001, India

* Corresponding author email: moolchand.singh@icar.gov.in

paper we discuss the association of weed seeds with imported grain from point of origin to end use at destination, and provide a qualitative description of the pathway that can be used as a framework for weed risk analysis (Pheloung *et al.* 1999, Singh *et al.* 2014). We identify six points, or events, along the pathway that have relevance for weed risk, namely: crop-weed associations at the point of origin; farming practices; grain handling practices; transport and storage; import requirements; and end use of grain in the country of import.

CROP-WEED ASSOCIATIONS AT THE POINT OF ORIGIN

The weed seed dispersal in grain begins in the field where the crop is grown in the country of origin. Weed communities and species assemblages are determined by geography and vary according to the crop species and conditions (e.g. climate, soils) in the country or area of origin. Although the exact species and numbers of weeds present will vary from field to field and season to season in response to local conditions, farming practices and weather, it is possible to use this type of information to develop a preliminary understanding of the weeds likely to be associated with the crop at the point of origin. The risk of introducing new weed species to India depends not only on the number of weed seeds contaminating imported grain, but on the particular species assemblages present, and the likelihood of their dissemination to a suitable environment for establishment and spread (Nagaraju *et al.* 2021; Dasari *et al.* 2022). Many contaminants moving in the international grain trade may be common weeds that are already present in India, and thus do not present a risk of new species introductions. Information about the point of origin allows for generalizations about risk. For example, the risk of new species introductions is generally considered lower from countries with similar weed floras or different climates, and higher from countries with different weed floras and similar climates.

FARMING PRACTICES

Crop production

Prior to planting, factors such as previous land use, crop rotation, pre-planting tillage, herbicide application, seed bank composition and crop seed purity can play a role in characterizing a field's weed flora for a particular year. At planting time, farmer decisions about crop type, planting date and planting density will influence the crop's ability to compete with weeds. Throughout the growing season, climatic factors, fertilization and weed control methods can further affect the performance of both weeds and crops. In general, weeds with similar biology and requirements to those of crops tend to be favoured, with well-known examples including jointed goatgrass (*Aegilops cylindrica* Host) in wheat, Johnson grass (*Sorghum halepense* (L.) Pers.) in sorghum, and wild mustard (*Sinapis arvensis* L.) in canola. Some crops and crop cultivars are more competitive than others. Crop competitive ability varies from region to region, but a general ranking puts cereals first, followed by canola and then pulses (Blackshaw *et al.* 2002). Highly competitive crops are able to germinate, emerge and accumulate biomass more rapidly than weeds and have an advantageous height and canopy structure for intercepting light. Chemical weed control options also vary by crop. In general, broad-leaved weeds are easier to control in cereals and other monocot crops, while grass weeds are easier to control in broad-leaved crops. For some crops, such as flax and pulses, herbicide options tend to be more limited than those for others, such as cereal grains or corn. Herbicide tolerant cultivars of crops such as corn, soybean and canola allow more comprehensive weed control than many conventional varieties, reducing the number of weeds in the field (Shaw and Bray 2003) and changing the species composition of weed communities. On the other hand, the rise of herbicide resistant weeds may reduce the advantages of herbicide tolerant cultivars over time, as herbicide resistant weed seeds are disseminated as seed and grain contaminants around the globe (Shimono *et al.* 2010). In the case of organically grown crops, a variety of non-chemical weed control options, such as mechanical and thermal methods, mulching and intercropping, may be employed to keep weeds in check. As a result, the quantity and composition of weed seeds in organic grain can differ significantly from that which is conventionally grown.

Harvest

At harvest, critical factors contributing to weed contamination levels include timing, weather conditions, crop vs. weed height, weed maturity and combine settings. Grain crops are usually harvested by direct combining and weeds most likely to be harvested with the crop are those that are taller than cutting height at the time of harvest, with mature seed retained in the seed heads. Early maturing weed species shed most or all of their seeds prior to harvest. In taller crops, seeds from short species are generally eliminated during harvesting for example, sunflower is one of the cleanest grains taken into a mill when the combine is set high at harvest. On the other hand, pulse crops are low-growing and harvested close to the ground, making them more likely to be contaminated with weed seeds. The action of the conventional combine includes reaping, threshing and winnowing. Weed seeds that have a pappus are easily dislodged and dispersed at harvest time and are more readily eliminated during the cleaning process (Shimono and Konuma 2008). The amount of weed seeds in grain can be reduced at harvest with correct combine sieve and fan adjustment (Humburg *et al.* 2009).

Overall, knowledge of crop production and harvesting practices can be helpful for considering their effect on weed seed contamination at source. Although weed levels and species complexes vary from farm to farm, with different agronomic, harvesting and cleaning practices, generalizations can be made based on the information available and applied to the evaluation of risk. For example, crops that are typically more competitive, treated with herbicides, harvested at a greater height or have large seeds might be expected to harbour less weed seed contaminants than crops that are less competitive, grown organically, harvested close to the ground, or that have small seeds that are difficult to separate from weed seeds.

Grain handling

Cleaning

Cleaning removes dockage, which is material that can readily be removed from grain prior to grading, such as stones, straw, chaff, broken grains, contaminant seeds, dust and hulls. Conventional seed cleaning includes the use of aspirators, screens, gravity tables and other separators to remove debris and weed seeds from the crop based on size, shape or weight. As with harvesting, larger-seeded crops are relatively easier to clean than smaller-seeded crops, as they tends to be less overlap with weed seeds in terms of seed dimensions and weight (Salisbury and Frick 2010).

Grading

The percentage of foreign material allowed in a grade can be an indicator of the level of contamination with weed seeds. Using import data by grade, it is possible to estimate the maximum amount of foreign material that might be imported along with the crop.

Table 1. Plants currently regulated as quarantine weeds under plant quarantine (regulation of import into India - order 2003)

S. no.	Scientific name	Common name
1.	*Alectra vogelii*	Yellow witch weed
2.	*Allium vineale*	Crow garlic/ Wild garlic
3.	*Amaranthus blitoides*	Prostrate pigweed
4.	*Ambrosia maritime*	Sea ambrosia
5.	*Ambrosia psilostachya*	Perennial ragweed
6.	*Ambrosia trifida*	Giant ragweed
7.	*Anthemis cotula*	Dog fennel
8.	*Apera spica-venti*	Loose silky bent grass
9.	*Bromus secalinus*	Rye brome
10.	*Cenchrus incertus* (Syn. *Cenchrus tribuloides*)	Spiny burr grass
11.	*Centaurea diffusa*	Diffuse knapweed
12.	*Centaurea maculosa*	Spotted knapweed
13.	*Centaurea solstitialis*	Yellow starthistle
14.	*Centrosema pubescens*	Butterfly pea
15.	*Chrysanthemoides monilifera*	Bone seed
16.	*Cichorium pumilum*	Dwarf chicory
17.	*Cichorium spinosum*	Spiny chicory
18.	*Cirsium vulgare*	Spear thistle
19.	*Conyza sumatrensis*	Tall fleabane
20	*Cordia crassavica*	Black sage/Wild sage
21.	*Cuscuta australis*	Australian dodder
22.	*Cynoglossum officinale*	Hound’s tongue
23.	*Digitaria velutina*	Velvet finger grass
24.	*Echinochloa crus-pavonis*	Gulf cockspur grass
25.	*Fallopia japonica* (Syn. *Polygonum cuspidatum*)	Japanese Knotweed
26.	*Froelichia floridana*	Florida snake cotton
27.	*Fumaria officinalis*	Common fumitory
28.	*Galium aparine*	Cleavers
29.	*Helianthus californicus*	California sunflower
30.	*Helianthus ciliaris*	Texas blueweed
31.	*Heliotropium amplexicaule*	Blue heliotrope
32.	*Leersia japonica*	Cut grass
33.	*Lolium multiflorum*	Italian ryegrass
34.	*Lonicera japonica*	Japanese honeysuckle
35.	*Matricaria perforata*	False chamomile
36.	*Orobanche cumana*	Sunflower broomrape
37.	*Orobanche minor*	Common broomrape
38.	*Oryza longistaminata*	Perennial wild rice
39.	*Pennisetum macrourum*	African feather grass
40.	*Polygonum lapathifolium*	Pale persicaria
41.	*Proboscidea louisianica*	Devil’s claw
42.	*Pueraria Montana var. Montana*	Rhodesian Kudzu
43.	*Raphanus raphanistrum*	Wild radish
44.	*Richardia brasiliensis*	While eye – Australia
45.	*Salsola vermiculata*	Mediterranean saltwort
46.	*Senecio inaequidens*	African ragwort
47.	*Senecio jacobaea*	Common ragwort
48.	*Senecio madagascariensis*	Fireweed
49.	*Solanum carolinense*	Horse nettle
50.	*Striga aspera*	Witch weed
51.	*Striga hermonthica*	Witch weed
52.	*Thesium australe*	Austral toadflax
53.	*Thesium humiale*	Dwarf thesium
54.	*Thlaspi arvense*	Field pennycress
55.	*Urochloa plantaginea (*Syn. *Brachiaria plantaginea)*	Plantain signal grass
56.	*Veronica persica*	Creeping speedwell
57.	*Viola arvensis*	Field pansy

Blending

In commercial trading, the quality of grain in demand fluctuates with changing markets and intended uses. Producers, handlers and exporters must balance the costs of cleaning grain against the value it will have on the market. To achieve this, many grain elevators use the practice of blending to produce grain with the desired level of foreign material; that is, rather than cleaning all grain delivered, a portion of high- foreign material grain is cleaned to a level well below the desired limit and then blended with the rest to achieve the targeted level in the final product. It is unclear to what extent grain lots from different origins are blended prior to export, but this could create highly unpredictable weed assemblages in blended grain shipments. Overall, the variation in composition of foreign material and the practice of blending are significant sources of uncertainty with respect to the potential numbers and species of weed seeds found in grain. Blending of grain lots from different origins with distinct weed seeds has the potential to greatly increase the number of weed species in the resultant lot. Unfortunately, information on whether or not a particular grain lot has been blended and the origins of the original grain lots is very difficult to obtain.

Transport and storage

Transport and storage of grain at every stage along the pathway introduces the possibility of cross-contamination and spills. The pathway may be simple or complex in terms of the number of transfers and conveyances prior to arrival at destination. From the point of origin, grain may be moved by truck, rail car and/or ship as it moves towards export and final destination, and may be unloaded and reloaded at a series of intermediate elevators and storage facilities along the way. Each step contributes to uncertainty with respect to the potential for cross-contamination and the risk of spillage post-import.

Cross-contamination

Good sanitation requires the thorough cleaning of all grain harvesting, transporting, and handling equipment between loads. Practically, however, the cleaning of combines, transportation vehicles and storage facilities between different lots of grain is difficult and often incomplete, resulting in some carry over (Shimono and Konuma 2008). The different lots may represent different grades, origins or even crop types. Howell and Martens (2002), reported that after careful cleaning of a combine, three bushels of red corn (the original crop harvested) were found in the subsequently harvested yellow corn. In a similar way, weed seed contaminants can get trapped in machinery and end up in subsequent loads of grain.

Accidental spills

Accidental spills are also an unfortunate reality of the grain handling system, as evidenced by the weed and volunteer grain flora along railway tracks, roadsides, ports and around mills and other grain processing facilities.

As with grain cleaning and blending, the possibility of cross-contamination of conveyances and spills during the transport and storage of grain illustrates the complexity of the pathway and introduces a significant element of uncertainty with respect to the species of weed seeds that might be found in imported grain.

Import requirements

Import requirements are an important means by which countries can reduce the risk of introducing new pests and protect their agriculture and environments. Currently, all grain imported to India is expected to arrive free of soil and regulated pests, and a range of different requirements (e.g., import permits, phytosanitary certificates, treatment certificates) exist for particular crops and countries of origin (PQ Order 2003). Pests of concern in imported grain include a number of crop pathogens, nematodes and storage pests in addition to weeds (PQ Order 2003)). Regulated weeds include 57 taxa that have been identified as quarantine weeds under Schedule VIII of Plant Quarantine (Regulation of Import into India) Order (2003), based on weed risk analysis (**Table 1**).

End use of grain in the country of import

The end uses of grains, unprocessed or minimally processed screenings present the highest risk for containing viable weed seeds, and potentially large numbers of them. The weeds seeds in screenings can be unintentionally spilled in a variety of environments conducive to germination, including areas around mills, bins and farm fields.

Interception of weed seeds in imported grain consignments

Compliance with import requirements is monitored through inspection and sampling at the point of import (Nagaraju *et al.* 2021). During the period 2015– 2021 an import sampling and inspection program focussed on weed seeds in grain was initiated to monitor for regulated weed species in

Table 2. Imported grain, sample size, number of samples examined, range of contamination, other crop seeds and weed seeds reported in imported grain during 2015-2021

Imported grain	Samples		Range of weed species reported per sample	Total number of other crop seeds and weed species reported in all samples			
	Size (kg.)	Number(s)		No. of other crop seeds	Indigenous weeds	Exotic weeds	Total
Corn	1.0	198	0–11	29	14	7	50
Rice	1.0	11	2–12	5	18	4	27
Soybean	1.0	70	3–26	35	19	10	64
Wheat	1.0	223	5–35	55	28	24	107
Pulses	1.0	251	6–36	36	20	4	60
Canola	1.0	52	3–18	18	17	3	38
Sunflower	1.0	42	0–14	22	15	2	39
Flax	1.0	7	0–13	5	11	3	19
Millet	1.0	69	0–18	17	12	3	32
Sorghum	1.0	24	1–16	12	13	2	27
Total		947		234	167	62	463

Table 3. Exotic weed species intercepted in imported grain crops during 2015-2021

Name of weed species	Frequency	No. of crops	Name of weed species	Frequency	No. of crops
Agrostemma githago	130	6	*Neslia paniculata*	46	7
Amaranthus caudatus	30	8	*Papaver hybridum*	03	8
Ambrosia trifida	17	5	*Phalaris paradoxa*	28	4
Ambrosia psilostachya	05	9	*Polygonum convolvulus*	39	3
Apera spica-venti	60	3	*Polygonum cuspidatum*	04	2
Avena barbata	16	4	*Polygonum lapathifolium*	11	1
Avena sterilis L.	112	6	*Polygonum persicaria*	02	6
Bromus diandrus	85	7	*Raphanus raphanistrum*	24	5
Bromus catharticus	50	5	*Rapistrum rugosum*	130	4
Bromus secalinus	18	2	*Reseda lutea*	89	9
Bromus sterilis	50	5	*Rumex crispus*	78	8
Carrichtera annua	98	7	*Rumex maritimus*	101	6
Carthamus lanatus	33	3	*Salva verbenaca*	128	7
Cenchrus pauciflorus	84	8	*Sida rhombifolia*	130	5
Cenchrus tribuloides	91	9	*Sylibum marianum*	29	3
Centaurea diffusa	126	7	*Sisymbrium officinale*	28	2
Centaurea melitensis	32	7	*Vicia villosa*	11	7
Centaurea solstitialis	18	6	*Vulpia bromoides*	65	9
Cynoglossum officinale	79	3	*Thlaspi arvense*	07	6

imported grain. In total, 947 samples were taken from imported shipments of the 10 grain commodities most commonly imported to India, and analyzed for presence of weed seeds (**Table 2**).

The number of weed species per sample ranged between 0 and 16 (**Table 3**). Overall, 58 different weed seeds were reported in the samples analysed, 20 weeds are already present in India, and 38 weed species are not reported from India. All intercepted weed species were identified up to species level on the basis of their morphological characters. There was a significant and positive correlation between the number of samples taken for each crop and the total number of contaminant species reported, indicating that in general, more sampling is likely to result in more weed species reported.

CONCLUSIONS

In summary, imported grains represent a very complex pathway for the possible introduction of new weed species to India. Weed-crop associations at the point of origin, along with crop production and harvesting practices, can be researched to develop predictions of what weed species might be associated with which imports; however, subsequent steps along the pathway such as grain cleaning, blending, and the potential for cross-contamination in transport and storage mean the weeds found in import sampling programs are not always the ones that might be expected. Import interception data presented here shows that all imported grain commodities sampled were a source of associated weed contaminants, however information about end use indicates that grain destined for human food or industrial purposes in India likely presents a negligible risk of introducing new weeds into the agriculture, due to extensive cleaning and processing at destination. Further research on the effects of specific processes on weed seed viability would be useful to confirm this. However, the greater risk lies with imported grain that is direct-fed or minimally processed for livestock feed, and the fate of dockage or screenings that are removed from grain during the cleaning process.

The risk analysis approach provides a useful framework for characterizing the nature of a pathway, identifying events that affect weed risk, and highlighting possibilities for risk reduction or mitigation (Dasari *et al.* 2022). In this case, a qualitative description of the pathway from point of origin to end use at destination provides a better understanding of the multiple interacting factors that may affect weed seed contamination in grain imports, and this may help to focus plant protection efforts in future. For example, future risk analyses on specific grain commodities may call for less focus on the analysis of crop-weed associations at the point of origin and production and harvesting practices and more focus on end use. Likewise, risk mitigation efforts might be most usefully focused on grain used for livestock feed and management of screenings, as compared to grain for human consumption or industrial purposes which present little risk of introducing new weeds to the environment.

REFERENCES

Blackshaw RE, O'Donovan JT, Harker KN and Li X. 2002. Beyond herbicides: New approaches to managing weeds. *ICESA* **2002**: 305–312.

Dasari S, Pawar D, Chethan CR, Singh PK, Sondhia S, Chander S and Singh MC. 2022. Indian quarantine weeds invasiveness assessment using bio-security tool: Weed Risk Assessment. *Indian Journal of Weed Science* **54**(2): 110–115.

Howell M and Martens K. 2002. Harvesting high-quality organic grain. Part 3-Corn. ACRES USA, *A Voice for Eco-Agriculture* **32**(12).

Humburg DS, Nicolai RE and Reitsma KD. 2009. Corn grain harvest. In: Clay DE, Clay SA, Re-itsma KD (Eds) Best management practices for corn production in South Dakota. South Dakota State University, Brookings, 1–127.

IPPC 2015. International Plant Protection Convention – International Standards for Phytosanitary Measures, ISPM 5: Glossary of phytosanitary terms. Food and Agriculture Organization of the United Nations, Rome.

Nagaraju DK, Iyyanar D, Singh M, Esakkirani B, Venkatareddy, Keshavamurthy GM, Kapoor KS, Verma OP, Prakash R and Singh M.C. 2021. Interception of non-indigenous weed seeds in lentil and lentil husk shipments imported from Australia, Canada, U.S.A., and Sri Lanka to India. *Indian Journal of Weed Science* **53**(4): 417–420.

Pheloung A, Swarbrick J and Roberts B. 1999. Weed Risk Analysis of a Proposed Importation of Bulk Maize (*Zea mays*) from the USA. DAFF, Weed Technical Working Group, Canberra, 78 pp.

PQ Order .2003. Plant Quarantine (Regulation of Import into India) Order (2003). Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India.

Salisbury T and Frick B. 2010. Seed cleaning for grain growers. *The Canadian Organic Grower Winter* **2010**: 32–33.

Shaw DR and Bray CS. 2003. Foreign material and seed moisture in glyphosate-resistant and conventional soybean systems. *Weed Technology* **17**(2): 389–393.

Shimono Y and Konuma A. 2008. Effects of human-mediated process on weed species com-position in internationally traded grain commodities. *Weed Research* **48**: 10–18.

Shimono Y, Takiguchi Y and Konuma A. 2010. Contamination of internationally traded wheat by herbicide-resistant *Lolium rigidum*. *Weed Biology and Management* **10**: 219–228.

Singh MC and Madhu B. Priyadarshi. 2014. Predicting invasive plants using weed risk assessment. *Indian Journal of Weed Science* **46**(1): 91–95.

Singh MC, Gnansambandham S and Chandurkar PS. 2005. Weeds as quarantine pests. *Plant Protection Bulletin.* **57**: 1–3.