Development of MY FRAM matrix to assess food safety risks in horticultural crops

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Abstract

A farm food safety risk assessment matrix (MY FRAM) was developed for horticultural farms. The tool enables farmers to carry out self risk assessments on the potential of food safety risks on the farm from site selection to post-harvest handling. MY FRAM was developed on Microsoft ASP. NET C# 4.5 with logical functions and utilised a semi-quantitative risk assessment approach (risk ranking of 1 – 9) for farmers. MY FRAM is an illustrative risk ranking tool to allow farmers to quickly identify potential food safety risks and risk summary and corrective actions are suggested to farms on how to reduce the risks. The tool can also be utilised as a training tool for farm workers to understand the importance of food safety at the farm level.

Keywords: farms; fresh produce; semi-quantitative risk assessment

1. Introduction

Fresh produce and sprouted seeds have been implicated in a number of documented outbreaks of illness in countries such as the US and within the EU. Powell and Chapman (2007) identified that since 1990 there have been over 500 outbreaks related to produce in US and argued that fresh fruits and vegetables are '*one of the most significant sources, if not the most significant source of foodborne illness today*'. The CDC reported that the incidence of outbreaks is greater for vegetables than for fruits and revealed salad greens, lettuce, sprouts, melons and tomatoes as the leading vehicles of illness. These fresh products have also received much attention by the FAO/WHO, which gave leafy green vegetables (including fresh herbs) the highest priority as commodities of global concern. Many of these commodities are vulnerable to contamination because they grow on or close to soil where contamination can potentially occur. Produce can also become contaminated with microbial pathogens by a wide variety of mechanisms. Contamination leading to foodborne illness has occurred during production, harvest, processing, and transporting, as well as in retail and foodservice establishments and in the home kitchen (FDA, 2010).

The likelihood of the edible parts of a crop becoming contaminated depends upon a number of factors which includes growing location, type of irrigation application and nature of produce surface. Some of the sources of pre-harvest contamination of produce include irrigation water (Steele and Odumeru, 2004), contaminated manure, sewage sludge, run-off water from livestock operations and wild and domestic animals (Beuchat, 2006; Delaquis,Bach and Dinu, 2007).

It is imperative to start reducing risk factors at farms, so this may reduce the contamination load into the processing and food preparation stage. A farm food safety risk assessment may be one of the many intervention strategies in reducing or preventing the food safety and disease risks from occurring. Hence, the development of MY FRAM is timely and can be utilised by horticultural farmers to identify potential food safety risks and to develop action plans or corrective actions.

2. Methods

2.1 Development of MY FRAM matrix

2.1.1 User interface

MY FRAM was developed using Microsoft ASP. NET C# 4.5 version framework and utilised standard mathematical and logical functions to calculate the risks. The database portion was handled using Microsoft SQL Server 2014 Express edition. To ease the development, Microsoft Language Integrated Query, or better known as LINQ was used to establish the connection between web application and database. On top of that, Microsoft AJAX Control Toolkit was also used to enable asynchronous communication between certain functions in MY FRAM to enhance users' experience. Users can go to http://umk.applyit.com.my and click on "Sign up new account" to register. Once registered as user, user can select go to Project > Create Project. Users are then prompt to name and describe the project. When a project has been created successfully, user will be allowed to add new Study into the project based on a period of time. After naming the study, users can go through the process to assess the risks for their crops.

The development and improvement of the MY FRAM matrix is similar to the Level 1 risk ranking proposed by van Gerwen et al. (2000) and the spreadsheet model of Soon et al. (2013) and Ross and Sumner (2002) but it estimates the risks according to the farm process flow (e.g. from site selection to harvest).

2.2 Delphi-based approach

2.2.1 Sampling and selection of experts

Expert panels were invited (Valeeva, Meuwissen, Oude Lansink, &Huirne, 2005) to take part in the Delphi study to identify and select the most relevant food safety hazards (and diseases) occurring at the fresh produce farms in UK. Here, the panellists were not selected randomly, so representativeness is not assured. The selection of experts for the Delphi study was made through:

- Personal contacts of the author and the research supervisory committee made in the course of the farm food safety research
- Participants in international food safety conferences
- Experts co-nominated by others (Scapolo&Miles, 2006)

A total of 86 experts on fresh produce safety were contacted and invited to participate in the Delphi survey. Sixteen percent of the invited experts responded to the Delphi survey. The reduced response rates is typical of Delphi studies as carried out by Grundy and Ghazi (2009), Stark et al. (2002) and Wentholt et al. (2010).

Experts were defined as having met two criteria: (1) currently teaching in a university level food science or agriculture/horticulture programme or working in the horticulture/agriculture (2) experience in the food safety, microbiology, chemical, toxicology, or risk assessment. The invitation contained a cover letter of a short description of the study and Delphi Round II questionnaire. Even though it is more advantageous to conduct a face to face interview in the first round to increase the response rates, it was not conducted in this study due to the limited financial resources and time. Three rounds of questions and answers were deemed to be optimal for this study (Soon et al. 2012):

Round (I)	Review and collate potential farm food safety hazards occurring in fresh produce farms
Round (II)	Experts' ranking of food safety hazards
Round (III)	Review feedback from Round II (and revise if necessary), review MY FRAM and suggest for improvements

2.3 Testing of MY FRAM matrix on farms

MY FRAM (spreadsheet version; Soon et al. 2013) was tested in 12 UK fresh produce farms. The on-farm visit was conducted in 4 steps and a total duration of 3 hours was targeted. Steps included (i) interview with the farmer or technical/farm manager to gather farm food safety practices data, (ii) briefing and explanation of MY FRAM, (iii) Testing of MY FRAM and collecting feedback from farms, and (iv) tour of farm and facilities with farmer.

3. Results and Discussion

3.1 Good Agricultural Practice (GAP) analysis

Most risk based models and standards for managing food safety at the farm level rely on the adoption of Good Agricultural Practice (GAP), therefore MY FRAM matrix required appropriate GAP to be embedded. The Good Agricultural Practice (GAP) Analysis self-assessment questions were developed for fresh produce production to encourage farmers to assess specific process during the primary production. A check-list containing 38 questions was drawn up according to Good Agricultural Practice (with an emphasis on food safety) and distributed under 8 sections according to the production process and inputs: (1) Process – Site selection; (2) Process – Seed/transplants; (3) Process – Sowing/planting; (4) Process – Crop harvest; (5) Process – Post-harvest handling; (6) Input – Irrigation water (Figure 1); (7) Input – Fertilizers and (8) Input – Pesticides (Knight 2009; Rangarajan et al. 2000). Figure 1 shows a snapshot of the self-assessment based on Good Agricultural Practices. Figure 1 does not illustrate GAP but was designed in a question and answer format to allow farmers to conduct their own self risk assessment of their current farm situation. These 38 questions were drawn up based on commercial systems such as GlobalGAP, Tesco Leafy Crop Assessment, Safeproduce.eu and FDA Produce Rule. The questions were selected on the basis of occurrences of potential hazards at the farm level and these 38 questions were summarised in order to allow farmers to focus on basic fresh produce safety criteria. A number of questions (> 40) may be too distracting for the farmers, while too few questions may not provide enough resolution for the farmers to conduct appropriate self-assessments. A more comprehensive and shorter version of assessment questions is more suited for small and medium farmers to enable them to focus their resources in prioritising food safety.

Figure 1. Self Risk Assessment (Question and Answer format) of Good Agricultural Practices

3.2 Process Flow

MY FRAM is then divided into different process flow ranging from site selection to postharvest handling and inputs such as irrigation water, application of fertilisers and pesticides. According to the processes, users are given scenarios of likelihood of occurrences (high, medium, low or no defined risk) to select from. For example, the risk factor for irrigation water sources is described. The low likelihood of occurrence for potential hazards to arise is defined as fresh produce farms using borehole/ground water or using tested (safe) surface water while higher likelihood of occurrence of food safety problems is associated with the use of surface water (Figure 2) with possible livestock access.

Figure 2. Example of likelihood scoring for 'source of irrigation water'

Farmers use MY FRAM based on their own judgment while assessing the likelihood of occurrences. Examples are given to enable users to select and determine the likelihood of selected/certain food safety hazards that could occur on their farms.

Risks are assessed on the probability of future occurrence; how likely is the risk to occur? How frequently has this occurred? (HSE 2008) Likelihood of occurrence is divided into low (1), medium (2) and high (3).

The criteria to help farmers to assess the likelihood of occurrence are:

High (3): This hazard has caused outbreak/recall on my farm

Medium (2): This outbreak/contamination has been reported in the local media or had occurred in other nearby farms

Low (1): Never occurred, but likelihood of occurrence is possible

3.3 Severity of food safety hazard

Criteria for the definition of each level of severity scoring for each risk factor were based on the review of literature and food legislation, vetted by consensus expert opinion from academia and industry experts.

The severity scoring is based on the following parameters (for general population unless stated otherwise):

Minor : Minor injury to consumer

Moderate : Consumer in hospital/Serious short term injury

High : May lead to severe health impact or death

3.4 Risk weight (severity × likelihood)

A risk matrix is developed to measure risk. The determination of risk is derived by multiplying the scores assigned for likelihood of occurrences and the severity of the hazards. The risk matrix consists of a 3 x 3 matrix of likelihood (high, medium and low) and severity (high, medium and low) to keep the risk assessment as simple as possible for farm operators' usage (Figure 3). There are other matrixes which use 4 x 4 or a 5 x 5 matrix depending on the risk assessor's requirements. According to Moses and Malone (2005), a typical 3 x 3 matrix do not provide enough resolution, while anything greater than a 5 x 5 was too distracting. This 3 x 3 matrix is adopted for its simplicity in translating practical risk ranking outputs for farm personnel.

The overall food safety risk can be categorised into high, medium or low based on the risk ranking score (1-9) when likelihood score multiplies with severity score. The scores used in FRAM matrix were based on a simple 1 to 9 scoring system to retain simplicity.

- Low risk (1-3)
- Medium risk (3-5)
- High risk (6-9)

Figure 3. Food safety risk (Risk weight) = Likelihood of occurrence × Severity of food safety hazard

3.5 Results presentation

The farm food safety risk assessment results is summarised in a tabular and radar format (Figure 4). First, the likelihood assessments are scored by the users based on their experiences and farm specificity. The relative ranking of risk scores will help farms to prioritise and optimize the allocation of resources or to request for technical assistance to reduce the likelihood of food safety hazards and diseases from occurring. However, the risk scores generated by the MY FRAM should be interpreted with caution. This is due to the generic nature of the tool and uncertainty associated with risks.

Figure 4. Example of results shown in radar chart format

3.6 Development of action plan and control measures

From the risk ranking output, farmers are then guided to develop their own action plan for improvement and control measures (Figure 5) are suggested according to Good Agricultural Practices section (HSE 2006; Knight 2009).

Figure 5. Action plan and corrective actions

3.7 Effectiveness as judged by the end user

End users (farmers) were asked to determine which part of the tool and topics were most useful or relevant to them. Developing their own action plan and using it as proof of assessment for future third-party audits were ranked the highest among the farms (Fig. 6). All the farms also agreed that ‘Sowing/Planting’ and ‘Irrigation Water’ topics were the most relevant and useful to them followed by ‘Plant Protection Products’ (92%) and ‘Harvesting’ (92%). A few topics such as waste handling and on-site packing (e.g. harvesting and bagging of fresh produce on rigs) were suggested to be included into MY FRAM. *Farm B* also stated that there should be less focus on wild animals’ assessment. Instead, more emphasis should be given to pesticides assessment as well as to expand the post-harvest handling assessment into individual washing, grading and packing assessments. *Farm C* noted that MY FRAM should specify the type of crops and risks of specific crops, e.g. Group I – leafy greens, tomatoes; Group II – carrots, onions; Group III – potatoes and Group IV – wheat, sugarbeet. More than half of the farms (58%) revealed that MY FRAM matrix has increased their interest in conducting farm food safety-risk assessment and 45% stated that after testing and using MY FRAM, it has improved their farm-food safety practices knowledge.

Figure 6. Most useful / relevant part of MY FRAM matrix (n=11 farms)

4. Role of MY FRAM in horticultural crops

The semi-quantitative scoring system of MY FRAM matrix to characterise risk is a good approach to help growers to understand that certain practices can be dangerous (e.g. surface water accessible by livestock). MY FRAM matrix can provide growers with a simpler means of assessing the level of produce safety in their farm based on general GAP requirements. Industry and/or commodity specific audits are extensive and costly and guidance from tools such as MY FRAM, Safeproduce.eu (http://www.safeproduce.eu/Login.aspx?ReturnUrl=%2fDefault.aspx) and the proposed rule for Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption (FDA, 2014) will facilitate farmers in identifying potential risk factors. The choice of food safety risk assessment model / matrix / tool is crucial to an organisation and MY FRAM can be utilised as a mechanism for assessing food safety risks and is an optional choice of self-risk assessment for farmers (Manning and Soon, 2013).

5. Limitations of MY FRAM

The general GAP requirements will be similar for all farms but some growers will require a more specialised GAP approach depending on their commodity or target consumers. In order to keep MY FRAM simplistic and to encourage farmers to carry out self-risk assessments; some of the risk factors were not specific enough and options given were limited, e.g. under risk factor for site selection: ‘Probability of site contaminated with run-offs from livestock farms’. Three scenarios likelihood of occurrences were given: (i) My farm is upstream from any sources of contamination; (ii) My farm is downstream from a well-managed livestock farm but may receive run-off during flooding; and (iii) My farm is downstream from at least one livestock farm and run-offs are commonly received. Since different farms faced different geographical environments, the options or scenarios given may not be specific enough for farms to select from. Hence this causes the farms to prompt further ‘what if’ questions – such as ‘What if I'm using borehole water and my neighbouring farm is a well-contained livestock farm?’ When using MY FRAM, farmers are provided with a guide to determine the level of risks involved in different processes.

6. Conclusion

MY FRAM matrix can be described as an illustrative risk ranking tool to facilitate horticultural farmers to identify potential risk factors during their crop production. It is best suited for small and medium enterprises (SMEs) to encourage farmers to identify food safety hazards and to help develop appropriate action plan for improvement. MY FRAM is a combination of semi-quantitative (matrix) and value-based criteria (based on farmers’ judgement of likelihood and experiences) to assess risks. An on-farm food safety risk assessment tool may be timely to encourage farms to assess potential hazards and to train both full-time and seasonal farm workers. MY FRAM focuses on risk reduction and not risk elimination.

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Figure Captions

Figure 1. Self-Risk Assessment (Question and Answer format) of Good Agricultural Practices

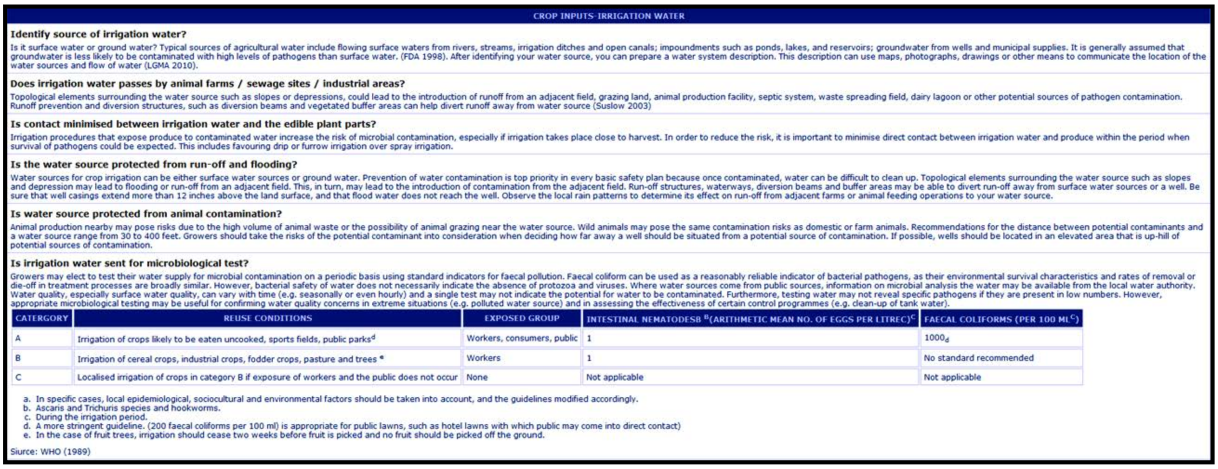
Figure 2. Example of likelihood scoring for 'source of irrigation water'

Figure 3. Food safety risk (Risk weight) = Likelihood of occurrence × Severity of food safety hazard

Figure 4. Example of results shown in radar chart format

Figure 5. Action plan and corrective actions

Figure 6. Most useful / relevant part of MY FRAM matrix (n=11 farms)



CROP INPUTS-IRRIGATION WATER

Identify source of irrigation water?

Is it surface water or ground water? Typical sources of agricultural water include flowing surface waters from rivers, streams, irrigation ditches and open canals; impoundments such as ponds, lakes, and reservoirs; groundwater from wells and municipal supplies. It is generally assumed that groundwater is less likely to be contaminated with high levels of pathogens than surface water. (FDA 1998). After identifying your water source, you can prepare a water system description. This description can use maps, photographs, drawings or other means to communicate the location of the water sources and flow of water (LGMA 2010).

Does irrigation water passes by animal farms / sewage sites / industrial areas?

Topological elements surrounding the water source such as slopes or depressions, could lead to the introduction of runoff from an adjacent field, grazing land, animal production facility, septic system, waste spreading field, dairy lagoon or other potential sources of pathogen contamination. Runoff prevention and diversion structures, such as diversion beams and vegetated buffer areas can help divert runoff away from water source (Suslow 2003)

Is contact minimised between irrigation water and the edible plant parts?

Irrigation procedures that expose produce to contaminated water increase the risk of microbial contamination, especially if irrigation takes place close to harvest. In order to reduce the risk, it is important to minimise direct contact between irrigation water and produce within the period when survival of pathogens could be expected. This includes favouring drip or furrow irrigation over spray irrigation.

Is the water source protected from run-off and flooding?

Water sources for crop irrigation can be either surface water sources or ground water. Prevention of water contamination is top priority in every basic safety plan because once contaminated, water can be difficult to clean up. Topological elements surrounding the water source such as slopes and depression may lead to flooding or run-off from an adjacent field. This, in turn, may lead to the introduction of contamination from the adjacent field. Run-off structures, waterways, diversion beams and buffer areas may be able to divert run-off away from surface water sources or a well. Be sure that well casings extend more than 12 inches above the land surface, and that flood water does not reach the well. Observe the local rain patterns to determine its effect on run-off from adjacent farms or animal feeding operations to your water source.

Is water source protected from animal contamination?

Animal production nearby may pose risks due to the high volume of animal waste or the possibility of animal grazing near the water source. Wild animals may pose the same contamination risks as domestic or farm animals. Recommendations for the distance between potential contaminants and a water source range from 30 to 400 feet. Growers should take the risks of the potential contaminant into consideration when deciding how far away a well should be situated from a potential source of contamination. If possible, wells should be located in an elevated area that is up-hill of potential sources of contamination.

Is irrigation water sent for microbiological test?

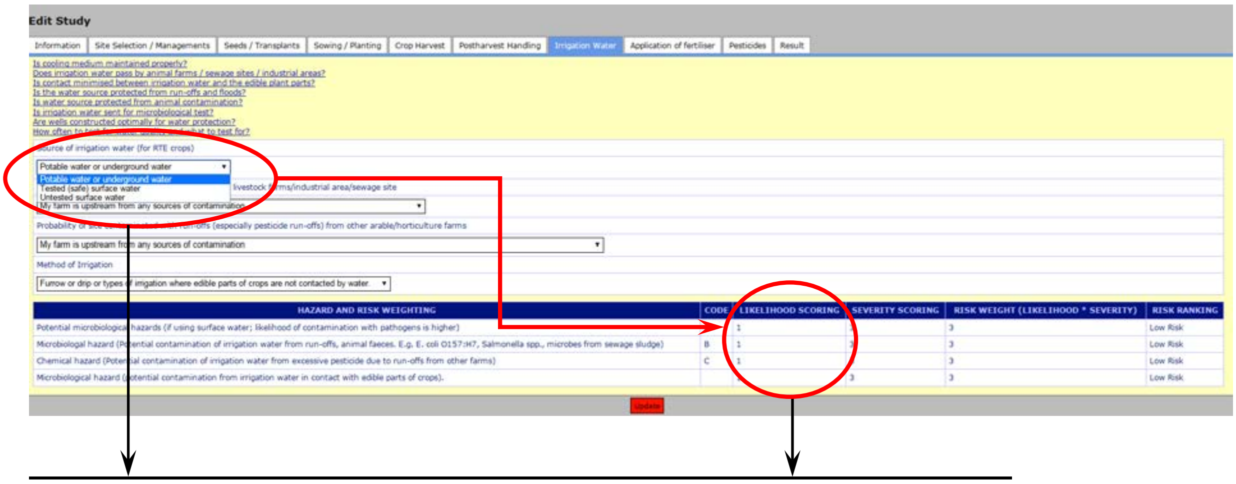
Growers may elect to test their water supply for microbial contamination on a periodic basis using standard indicators for faecal pollution. Faecal coliform can be used as a reasonably reliable indicator of bacterial pathogens, as their environmental survival characteristics and rates of removal or die-off in treatment processes are broadly similar. However, bacterial safety of water does not necessarily indicate the absence of protozoa and viruses. Where water sources come from public sources, information on microbial analysis the water may be available from the local water authority. Water quality, especially surface water quality, can vary with time (e.g. seasonally or even hourly) and a single test may not indicate the potential for water to be contaminated. Furthermore, testing water may not reveal specific pathogens if they are present in low numbers. However, appropriate microbiological testing may be useful for confirming water quality concerns in extreme situations (e.g. polluted water source) and in assessing the effectiveness of certain control programmes (e.g. clean-up of tank water).

CATERGORY	REUSE CONDITIONS	EXPOSED GROUP	INTESTINAL NEMATODESB [B](ARITHMETIC MEAN NO. OF EGGS PER LITREC)[C]	FAECAL COLIFORMS (PER 100 ML[C])
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	1	1000_d
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	1	No standard recommended
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable

a. In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
b. Ascaris and Trichuris species and hookworms.
c. During the irrigation period.
d. A more stringent guideline. (200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns with which public may come into direct contact)
e. In the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground.

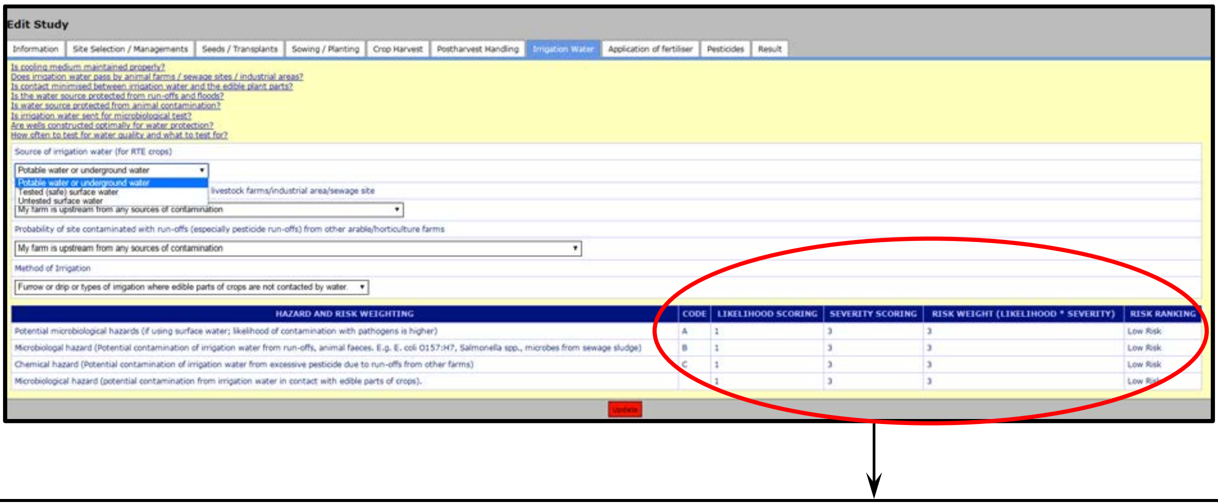
Siurce: WHO (1989)

Figure 1. Self-Risk Assessment (Question and Answer format) of Good Agricultural Practices



Source of irrigation water (for RTE crops)	Likelihood scoring
Potable water or underground water	1
Tested (safe) surface water	2
Untested surface water	3

Figure 2. Example of likelihood scoring for ‘source of irrigation water’



Source of irrigation water (for RTE crops)	Likelihood scoring	Severity scoring	Likelihood x severity scoring	Risk weight	Risk ranking
Potable water or underground water	1	3	1 x 3	3	(1 – 3) low
Tested (safe) surface water	2	3	2 x 3	6	(4 – 6) medium
Untested surface water	3	3	3 x 3	9	(6 – 9) high

Figure 3. Food safety risk (Risk weight) = Likelihood of occurrence × Severity of food safety hazard

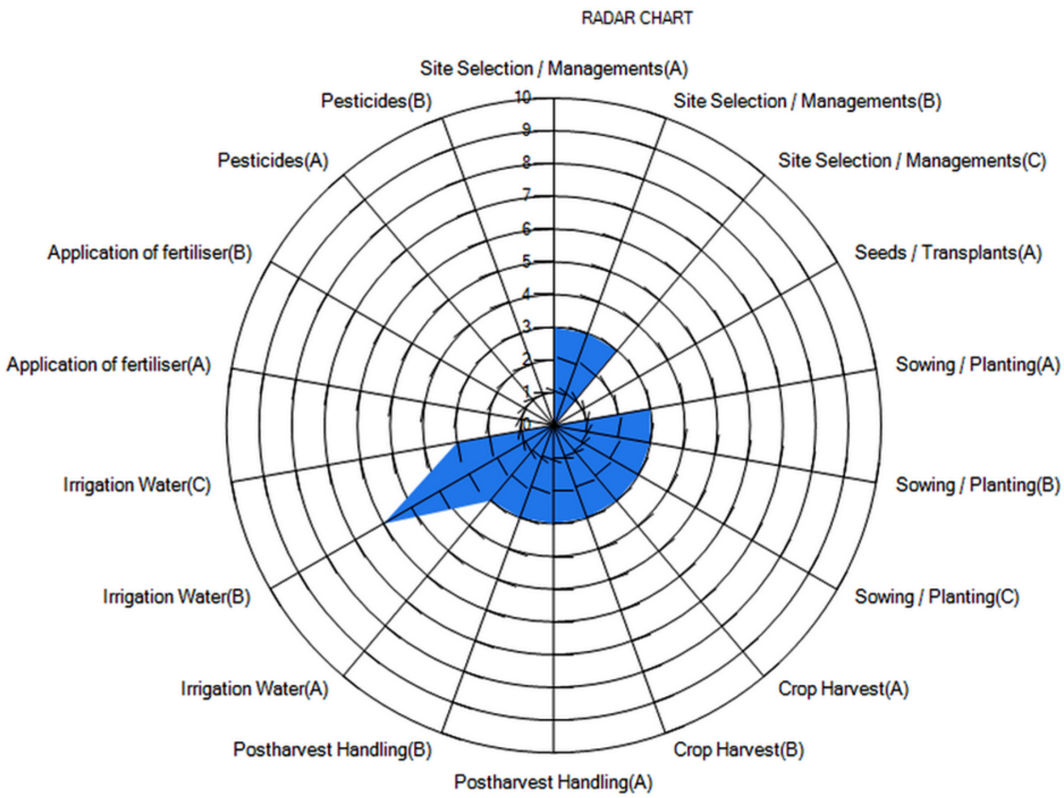


Figure 4. Example of results shown in radar chart format

Irrigation Water			
Microbiologal hazard (Potential contamination of irrigation water from run-offs, animal faeces. E.g. E. coli O157:H7, Salmonella spp., Crytosporidium parvum, Giardia intestinalis, Cyclospora cayetanensis, norovirus)	1 to 3	Low Risk	Well done. The risks posed to consumers from microbial contamination of your crop are low. Keep up with the good agricultural practices and HACCP based risk assessments conducted on your farm.
	4 to 6	Medium Risk	The risks posed to consumers from microbiological contamination of your crop is medium. They could be further reduced by considering: i. Runoff prevention and diversion structures, such as diversion beams and vegetated buffer areas can help divert runoff away from water source; ii. Minimise direct contact between irrigation water and produce within the period when survival of pathogens could be expected; iii. Wells should be located in an elevated area that is up-hill of potential sources of contamination; iv. Growers may elect to test their water supply for microbial contamination on a periodic basis using standard indicators for faecal pollution.
	7 to 9	High Risk	The risks posed to consumers from microbiological contamination of your crop is high. They could be further reduced by considering: i. Runoff prevention and diversion structures, such as diversion beams and vegetated buffer areas can help divert runoff away from water source; ii. Minimise direct contact between irrigation water and produce within the period when survival of pathogens could be expected; iii. Wells should be located in an elevated area that is up-hill of potential sources of contamination; iv. Growers may elect to test their water supply for microbial contamination on a periodic basis using standard indicators for faecal pollution.
Chemical hazard (Potential contamination of irrigation water from excessive pesticide due to run-offs from other farms)	1 to 3	Low Risk	Well done. The risks posed to consumers from chemical contamination of your crop are low. Keep up with the good agricultural practices and HACCP based risk assessments conducted on your farm.
	4 to 6	Medium Risk	The risks posed to consumers from chemical contamination of your crop is medium. They could be further reduced by considering: i. Using a plant strip or buffer to reduce potential of run-offs from other farms' areas to reduce pesticde run-offs; ii. Check the pesticide application procedure and training.
	7 to 9	High Risk	The risks posed to consumers from chemical contamination of your crop is high. They could be further reduced by considering: i. Using a plant strip or buffer to reduce potential of run-offs from other farms' areas to reduce pesticde run-offs; ii. Check the pesticide application procedure and training.

Figure 5. Action plan and corrective actions

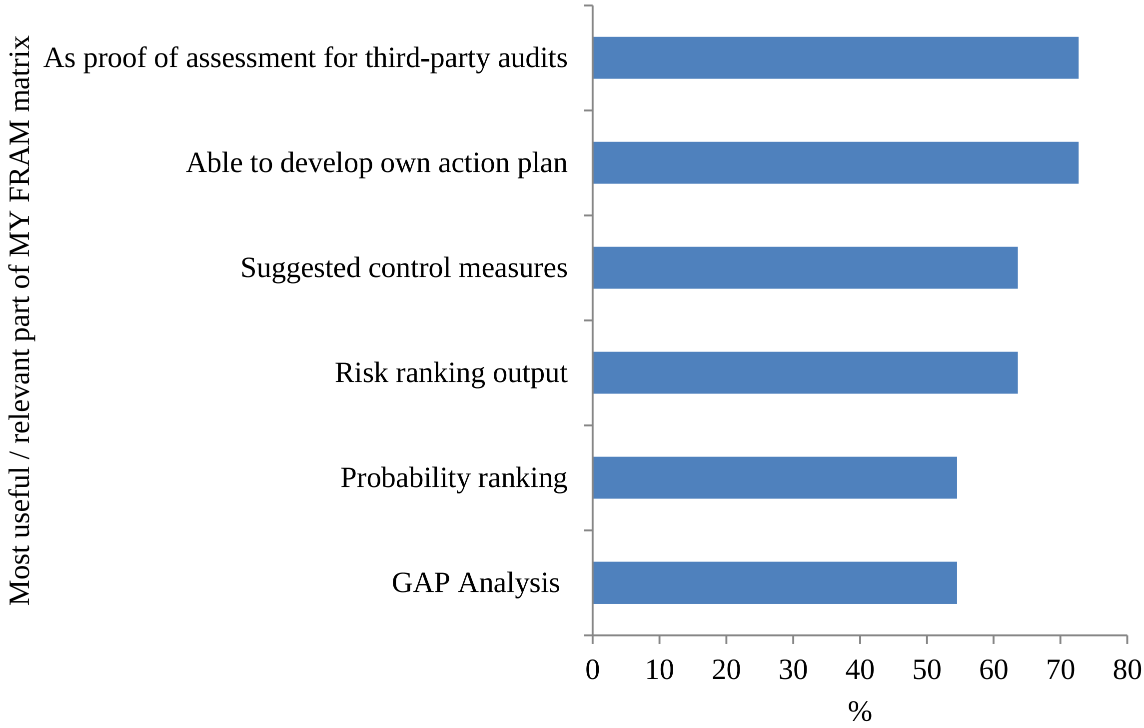


Fig.6. Most useful/relevant part of MY FRAM matrix (n=11 farms)