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Public Perceptions about Glyphosate Use in Australian Agricultural Value Chains

Kate McCabe

Postgraduate student, Centre for Global Food and Resources, University of Adelaide.

Abstract

Glyphosate safety has been subject to significant public attention following classification of glyphosate as "probably carcinogenic" in 2015 by the International Agency for Research on Cancer, and recent litigation in the United States, against its founder, Monsanto. There are a number of countries that have banned or restricted the use of glyphosate. This paper uses a systematic literature review to consider studies of public perceptions surrounding glyphosate use and safety. The review focuses on consumer preferences and expectations, trust and information sharing and draws conclusions on the impacts for Australian agricultural value chains. It is shown that farmers' understanding and views of glyphosate differ from those of consumers. Hence, understanding public perceptions is important in product development decisions. Farming practices, chemical residues, traceability and provenance all impact consumer preferences which are essential considerations for value chain actors. Education and information sharing have a strong impact on consumer perceptions of food safety risk with social media campaigns proven to be highly influential. Innovative means of conveying scientifically-based research findings on glyphosate usage to the public are important considerations for Australian agricultural value chain actors.

Key words: glyphosate, public perception, trust, agriculture, value chains

Introduction

Glyphosate has been responsible for significant changes in global cropping systems since its introduction in the 1970's. It is an essential element in the uptake of many genetically-modified (GM) crops grown globally and in Australia it has been associated with the successful application of no-till and conservation farming which now dominates Australian cropping systems.

The International Agency for Research on Cancer's (IARC) classification of glyphosate as "probably carcinogenic" in 2015 has focused attention on the safety of this chemical. Regulators around the world were forced to justify their safety assessments and basis for approval. Examinations of the regulatory positions unveil the volume of scientific publications that are considered; for the Australian Pesticides and Veterinary Medicines Authority (APVMA) alone, 1183 publications have been considered (APVMA, 2019b). A number of countries placed restrictions on glyphosate use and the European Union was faced with strong public opposition resulting in only a five year renewal of approval (rather than the standard 15 years) and promises of greater transparency (European Union,

2017). Recent court cases in the United States have dominated media reporting of glyphosate safety including criticisms of the molecule's developer, Monsanto. Further bans and restrictions have ensued in many countries.

There are a number of issues relating to public perceptions that potentially impact the value chains of Australian agriculture. Safety concerns impact consumer preferences and provide product differentiation opportunities. Trust in our food systems also impacts public perceptions and should be considered in relation to key value chain actors: chemical manufacturers, producers (farmers), regulators and government. Information and education have been shown to have a significant influence on food safety views and need to be considered in relation to trust of our food systems.

Background

The herbicide glyphosate is a non-selective and broad-spectrum weed killer. It does not discriminate between plant types unless they have been genetically modified (GM) to be resistant. The scientific name of glyphosate is N-(phosphonomethyl) glycine. Glyphosate functions by inhibiting the shikimic acid pathway which is observed only in plants. There are approximately 500 glyphosate based herbicide (GBH) products registered in Australia (APVMA, 2019a).

Glyphosate was developed and patented by Monsanto with their formulation 'Roundup' first sold commercially in 1974 (Benbrook, 2016). The herbicide has both agricultural and non-agricultural uses but this review will focus on agriculture applications which now account for over 90 per cent of global use (Table 2). Glyphosate was initially used in agriculture as a post-harvest knock down, however when herbicide tolerant GM varieties of soybean, cotton and maize were introduced to the United States in 1996, the usage increased substantially (Benbrook, 2016). Table 1 below shows the significant increases since initial approval in 1974 and the impact of GM herbicide resistant adoption in 1996. Data on global usage is not available prior to 1994 but Table 2 shows globally the substantial impact of the adoption of GM herbicide tolerant varieties. No-till farming accounted for early increases in global use (IARC, 2015, p. 323) and then when glyphosate came off patent around 2000, resulting in falling prices, a 107 per cent increase in global usage was observed over the following five years (Table 2).

Table 1. Glyphosate active ingredient use, United States, 1974 -2014

	1974	1982	1990	1995	2000	2005	2010	2012	2014
Glyphosate Use (1000kg)	635	3,538	5,761	18,144	44,679	81,506	118,298	118,753	125,384
Agricultural	363	2,268	3,357	12,474	35,720	71,441	106,963	107,192	113,356
Non-agricultural	272	1,270	2,404	5,670	8,958	10,065	11,335	11,562	12,029

Source: Benbrook (2016)

Table 2. Global glyphosate active ingredient use, 1994 – 2014

	1994	1995	2000	2005	2010	2012
Glyphosate Use (1000kg)	56,296	67,078	193,485	402,350	652,486	718,600
Agricultural	42,868	51,078	155,367	339,790	578,124	648,638
Non-agricultural	13,428	16,000	38,118	62,560	74,362	69,962

Source: Benbrook (2016)

Glyphosate Use in Australia

Glyphosate use commenced in Australia in the 1970's (APVMA, 2016). Data on Australian glyphosate use is not available but global usage patterns give us some insight into the local application trends. The only GM crops with herbicide resistance in Australia are canola and cotton (Office of the Gene Technology Regulator, 2018). Globally glyphosate usage on GM canola and cotton in 2012 was only 3 per cent and 1.5 per cent respectively, of total glyphosate use on all crops with GM soybeans accounting for 41 per cent and GM maize 11 per cent (Benbrook, 2016, p. 9). As Australia does not grow GM soybeans or maize, the substantial increase from 1996 onwards shown in the global data would not have been expected. However, an increase in usage due to lower prices when glyphosate became available off patent around 2000 would have been expected.

Capacity for no-till farming was one of the substantial benefits of glyphosate to Australian agriculture (Heard, 2018). Weed control could be managed over summer and use as a pre-sowing knockdown eliminated the need for cultivation which enabled the retention of moisture and prevented erosion (Heard, 2018). In 2017, 78 per cent of Australian crops were managed under no-till practice (Australian Bureau of Statistics, 2017) showing the high prevalence of this production system and reliance of glyphosate in Australian agriculture.

Crop production statistics give us some insight into the markets in which products subject to glyphosate application are sold, as shown in the tables below. Given that wheat accounts for over 50 per cent of cropping land use (ABARES, 2019), analysis of markets has focused on this crop type. Table 3 highlights the high proportion of Australian wheat that is exported (over 70 per cent) with Asia the destination for 70 per cent of the export market.

Table 3. Australian wheat markets

Australian wheat sales 2010-2018 average	Sales kt	%
Domestic sales	6,879	27
Export sales	18,707	73

Export markets by continent	%
Africa	5
Asia	70
Middle East	14
Oceania	5
Other	6

Asia - Top 5 markets 2010-2018 average	Sales kt
Indonesia	4,033
Vietnam	1,641
Bangladesh	1,437
Korea, Rep. of	1,289
China	1,288

Source: ABARES (2019)

Safety of Glyphosate

The safety of glyphosate is considered in three spheres: occupational safety, environmental impact and food safety. A summary of the latest evaluations by World Health Organisation (WHO) agencies and regulatory agencies in the United States, Europe and Australia is provided below.

International Regulation and WHO agency evaluations

International Agency for Research on Cancer (IARC)

The IARC is an agency of the World Health Organisation aiming to "promote international collaboration in cancer research" (IARC, 2019). In 2015 IARC classified glyphosate as "probably carcinogenic group 2A" with the following evaluations of "limited evidence in humans for the carcinogenicity of glyphosate" but "a positive association has been observed for non-Hodgkin lymphoma" and "sufficient evidence in experimental animals for the carcinogenicity of glyphosate" (IARC, 2015, p. 398).

Joint FAO/WHO Meeting on Pesticide Residues (JMPR)

This body is jointly administered by the Food and Agriculture Organisation of the United Nations (FAO) and WHO to provide risk assessments on pesticide residues and evaluate acceptable pesticide residue limits (JMPR, 2019).

JMPR called a meeting in May 2016 and concluded the following in regard to glyphosate: "unlikely to be genotoxic at anticipated dietary exposures", "not carcinogenic in rats, but was unable to exclude the possibility that glyphosate is carcinogenic in mice at very high doses", "unlikely to pose a carcinogenic risk to humans via exposure from the diet" and "some evidence of a positive association between glyphosate exposure and risk of NHL from the case–control studies" but noted that the AHS being the "only cohort study and is large and of high quality, found no evidence of association at any exposure" (JMPR, 2016b, pp. 255-257).

JMPR provides explanations of the differences in the assessments of the two WHO agencies (JMPR, 2016a). In the IARC evaluation "hazard identification" is the first step, which considers if at some level an agent could increase the risk of cancer. JMPR conducts the next step of "risk assessment" where exposure level is considered to establish a safe intake level but their evaluation considers safety at levels it is used in agriculture or may occur in food.

United States

In 2015 the Environmental Protection Agency (EPA) reviewed glyphosate registration and classified glyphosate as "not likely to be carcinogenic to humans" (EPA, 2016, p. 13). The EPA uses a broader range of studies, including registrant studies, compared to the IARC and JMPR who primarily rely on peer reviewed research (Benbrook, 2019).

Europe

Glyphosate regulation in the EU (European Union) is a complex process as you may expect with the number of countries involved, all with different priorities. The European Food Safety Authority (EFSA) is responsible for risk evaluation of the existing science and offers scientific guidance on food chain risks to the European Commission (EC) and European Parliament (APVMA, 2016). EU glyphosate approval is the responsibility of the EC but the formulated products are authorized by

each of the member states. Germany is the currently appointed Rapporteur Member State (RMS) so the Federal Institute for Risk Assessment (BfR, 2019) was required to assess glyphosate risks and report to the EFSA. The subsequent EFSA assessment was published in November 2015 concluding that glyphosate was "unlikely to pose a carcinogenic hazard to humans and the evidence does not support classification with regard to its carcinogenic potential" (APVMA, 2016, pp. 23-24).

In 2017 the EC approved glyphosate for a further five years (European Union, 2017). Ministers representing agriculture or environment from France, Belgium, Greece, Luxembourg, Slovenia and Malta have written to the EC Vice-President, following the renewal, reiterating their concerns surrounding glyphosate risks and invited the EC to "prepare the exit plan for glyphosate" with reference to the European Citizen's Initiative (ECI) demands (Michalopoulos, 2018).

Australia

In Australia, APVMA is responsible for regulating the use of glyphosate and its formulations. The APVMA works with Food Standards Australia New Zealand (FSANZ) to establish maximum residues limits (MRL's) which are the maximum chemical residues that are permitted in foods in Australia (FSANZ, 2019).

Following the IARC assessment in 2016, the APVMA considered glyphosate and published a report which outlined their position that there were no scientific grounds for putting glyphosate under formal reconsideration. The APVMA found that on the scientific weight of evidence "exposure to glyphosate does not pose a carcinogenic risk to humans"(APVMA, 2016).

The APVMA highlights that in assessing chemical risk both "hazard assessment" and "exposure assessment" are considered. Similar to the JMPR's comparison with IARC, the APVMA takes risk assessment of glyphosate a step further than the IARC's "hazard identification" by considering real-world exposures and the likelihood and potential seriousness of harm if a chemical is used according to label instructions (APVMA, 2019a). The APVMA also provides some context around the IARC classification process by providing examples of other "probably carcinogenic group 2A" risks such as frying at high temperatures, red meat and some shift work while "carginogenic group 1" risks include consumption of alcohol and processed meat (APVMA, 2019a).

FSANZ's 25th Australian Total Diet Study was released in June 2019 and had some interesting results on glyphosate residues including the following (FSANZ, 2019):

- 23 per cent of food samples tested had detectable glyphosate residues;
- All detections were significantly under the MRL with FSANZ estimating that for Australian consumers, estimated glyphosate exposure through the diet is less than 1 per cent of internationally recognized safe levels; and
- The highest detection was 0.080 mg/kg which from a dietary perspective would require a consumer of average body weight to eat more than 370 loaves of bread per day across their lifetime before they would become close to exceeding safe levels of exposure.

Current status of international glyphosate approval

Table 4 shows the current approval status of countries with bans in place and other regions of significance.

Table 4. Summary of key glyphosate restrictions and bans by country

Country /region	Full ban	Partial ban/ restrictions	No restrictions (outside MRL's)	Further detail on restrictions
Europe				EU Commission re-authorised for 5 years in 2017. Member countries approve use of formulations (APVMA, 2016)
Austria	✖			Effective 1st January 2020 once bill passes upper house (Murphy & Schwarz-Goerlich, 2019)
Belgium				EC "Exit plan" request (Michalopoulos, 2018) Banned for individual use (Johansson, 2017)
Czech Republic		✖		Ban use as a desiccant and limit blanket use (Phys Org, 2018)
Denmark		✖		Restriction on desiccation (Pesticide Action Network, 2018)
France		✖		Banned Roundup 360 (Phys Org, 2019) EC "Exit plan" request (Michalopoulos, 2018)
Italy		✖		Restrictions in public places and ban for use as desiccant (Pesticide Action Network, 2016)
The Netherlands		✖		Ban for non-commerical use (Walia, 2015)
Australia			✖	(APVMA, 2019a)
Brazil			✖	Reinstated in 2018 after temporary registration suspension (Reuters, 2019)
Canada		✖		Risk reduction measures (APVMA, 2016)
Sri Lanka		✖		Full ban lifted in 2018 and now restricted to tea and rubber industries (Daily FT, 2018)
United States			✖	(EPA, 2016)
Vietnam	✖			Ban on import of all glyphosate based herbicides (Viet Nam News, 2019)

Source: information collated from a number of sources with reference detail in "Further detail" column

Litigation

In the United States there have been three successful lawsuits against Monsanto linking RoundUp with Non-Hodgkin's lymphoma (NHL). The first, in 2018, saw a California jury find that RoundUp caused the cancer of a former groundskeeper and that Monsanto had not disclosed the health risks

connected to its use, awarding US$289 million. In the second case, the US federal court awarded US$80 million to a residential user claiming NHL was caused by RoundUp use on his properties. In the third case, a jury again found that NHL was caused by RoundUp which they had used extensively over decades on their property, awarding US$2 billion (Houston & Vedelago, 2019).

In Australia the first lawsuit has been filed in the Supreme Court against Monsanto by a Melbourne gardener who claims his NHL is linked to 18 years exposure to glyphosate (Houston & Vedelago, 2019).

These lawsuits have resulted in extensive media coverage regarding glyphosate safety, and considering the timing of restrictions and bans imposed in a number of countries (Table 5), it is possible these cases have been influential in regulatory decisions.

Systematic Literature Review

Public perceptions are an important consideration as they will potentially influence consumer preferences and policy decisions globally. Value chain actors must be aware of factors that impact these perceptions and how resulting changes to consumer preferences and regulation or policy will effect value chain profits.

Purpose and methodology

A systematic literature review (SLR) has been undertaken to consider studies of public perceptions surrounding glyphosate use and safety to provide insights into possible implications for Australian agricultural value chains. The structure developed for SLR's for supply chain management by Durach, Kembro and Wieland (2017) has been broadly applied to this review.

Research criteria for inclusion and exclusion of studies

"Web of Science" and "Scorpus" databases were utilized to source relevant literature. After an initial scan of the literature, the final keyword searches, in various combinations, included the following terms to establish a preliminary literature sample: "glyphosate", "herbicide", "pesticide", "residue", "public perception", "public opinion", "public concern", "consumer", "preference", "behaviour", "expectations", "societal demand" "trust", "regulators", "conflict of interest", "media coverage", "ghostwriting" and "supply chain".

Review and exclude process

The preliminary literature sample was reviewed and sources included if the abstract incorporated reference to glyphosate or pesticides and public perception or an issue that impacts public perception. Peer reviewed journals were given priority. Journals limited to critiquing the science and not considering public perceptions were excluded. Global studies were considered based on their impact on international debate and Australia markets while all Australian studies were focused on with an emphasis on consumer preferences and expectations, trust in the value chain and information sharing.

Synthesize the literature

The 28 papers in the final list were reviewed and it was found that they could be categorized into three distinct classifications: "Consumer preferences", "Trust" and "Information and education". Appendix 1 details the final literature sample, coded into these categories.

Reference has also been made to a University of Adelaide survey, the results of which have not yet been made public while the journal paper peer review is being finalized (Umberger et al., 2020). As this survey shows such current findings, following increased media coverage from United States court cases, it was essential to include due to their relevance and current insights into all three categories of this SLR.

Results

Consumer preferences

There is a strong trend towards "identity-based" eating in the developed world, where a consumer's food preferences will be dictated by the product's conformance to a particular identity or morality (Saitone & Sexton, 2017). This identity may take a variety of forms but of particular interest here are health and environmental motives (Orlando, 2018).

Contributing to this trend is the difficulty faced by mass produced foods in maintaining provenance due to long and complicated food chains (Richards, Lawrence & Burch, 2011).These factors have contributed to growth in the areas of farmers' markets, certifications, niche market labelling and retailer-driven quality control programs.

Pesticide use has been of primary concern to consumers in relation to health and environmental impacts. In fact, numerous studies have shown that in relation to health, contaminants such as pesticides and sprays, are of higher concern than nutritional value or other risk attributes (Brantsaeter, Ydersbond, Hoppin, Haugen & Meltzer, 2017; Cranfield, Deaton & Shellikeri, 2009; Gempesaw & Toensmeyer, 1991). A University of Adelaide study found that 65 per cent of respondents were concerned to some degree over the use of glyphosate in agriculture and food production and 26 per cent indicated they had changed their food consumption due to these concerns (Umberger et al., 2020). The level of concern seems to have grown compared to a government study identified in a 2010 journal finding that 26 per cent of participants viewed pesticides, sprays and residues as a risk to food safety (Buchler, Smith, & Lawrence, 2010).

Certification and labelling

Globally the organic market is growing rapidly due to consumers' views that such foods confer health and environmental benefits (Brantsaeter et al., 2017). As organic food is widely understood to mean lower pesticide use it will be a food preference for consumers concerned about the potential health and environmental risks associated with glyphosate.

There are a number of other certifications appearing in the market aimed at attracting customers concerned about pesticide use. For example, in the United Kingdom the "Tesco Nuture" certification stipulates environmental criteria including "rational use of chemical" (Richards et al., 2011). In Switzerland "IP-Suisse"(Böcker, Möhring & Finger, 2019) is a label accreditation program which promotes integrated agriculture which is environmentally and animal friendly. While food labelled under these programs is not organic, it provides consumers with glyphosate safety concerns with a visible option.

Traceability

Traceability has been identified as an important measure in food safety (Lusk & McCluskey, 2018) and plays an integral role in accreditation schemes (Richards et al., 2011). New technologies such as blockchain are emerging that are able to support traceability, and could potentially add customer value.

Willingness to pay

When considering implications on the value chain of negative public perceptions of glyphosate we should contemplate whether consumers are willing to pay for food produced without glyphosate. The model shown in Figure 1 maps the scope for adding consumer value against the activity's relative environmental impact (Bonney, Clark, Collins, Dent & Fearne, 2009, p. 18).

Figure 1. Bonney model for mapping consumer value against environmental impact

Scope for adding consumer value High	Innovate to create value; avoid increasing environmental impact	Focus for innovation to add value; and simultaneously reduce environmental impact
Low	Limited scope for adding value or reducing environmental impact	Chain only invests to reduce cost; May require government intervention to ensure environmental improvement
	Low **Relative environmental impact** High	

Source: Bonney et al. (2009)

Application of this model can determine the priorities and expectations that should be considered for investing in glyphosate-free product development by plotting the scope for the consumer to pay more for glyphosate-free products in relation to the degree that reduced glyphosate usage delivers positive health and environmental outcomes. The debate over glyphosate safety has generated uncertainty hence the environmental and health impact cannot definitively be plotted, however, given the trends in organic produce and consumer concerns over glyphosate (Umberger et al., 2020), the scope for adding consumer value appears to be high. This would place mapping for value chain actors, such as grain producers and food manufacturers, for glyphosate-free food production, to sit within the top two quadrants "Innovate to create value: avoid increasing environment impact" or "focus for innovation to add value: and simultaneously reduce environmental impact". In Europe and the United States there are policies and subsidies in place that promote reduced pesticide or organic produce (Saitone & Sexton, 2017). Application of the Bonney model suggests for Australian producers that even without subsidies there is scope for differentiating their product based on environmentally friendly attributes.

An additional consideration in determining consumers' willingness to pay is the that food is becoming a smaller proportion of the household budget in the developed world (Saitone & Sexton, 2017). This gives consumers greater capacity to embrace identity-based eating. There is evidence of traditionally low cost supermarkets such as Walmart in the United States now offering high quality food options (Lusk & McCluskey, 2018).

In considering the scope for product differentiation the limitation that survey participants will often exaggerate the willingness to pay (Janssen & Hamm, 2012) must be kept in mind. It is important that such research is validated with observed trends or quantitative market data.

Trust of value chain actors

Public perceptions in regard to glyphosate usage and safety are closely related to the trust of various actors in the value chain and in particular chemical manufacturers, agricultural producers (farmers), regulators and government.

Chemical manufacturers: Monsanto (now Bayer)

There have been a range of claims surrounding Monsanto, the developer of the first commercially formulated glyphosate product, RoundUp. The "Monsanto Papers" is a collection of documents, obtained under freedom of information including "internal Monsanto emails, manuscript drafts, peer review reports, deposition testimony, powerpoint presentations and text messages" (McHenry, 2018, p. 194). There are a number of studies providing evidence through internal emails of persistent ghostwriting (Gillam, 2017; Krimsky & Gillam, 2018; McHenry, 2018) and incidence of such papers being cited by the EPA (Krimsky & Gillam, 2018). Claims of interfering in the scientific process include the intervention in a peer reviewed journal resulting in its retraction by the journal due to inconclusiveness (McHenry, 2018, pp. 199-200). It has also been suggested that Monsanto were aware of mutagenic risks as a result of an external expert review it had commissioned (Foucart & Horel, 2018). The public have become aware of these claims through court cases and subsequent media reporting and it can be assumed this has impacted on the public trust as well as making it "difficult for consumers to know whom to trust and what to believe" (Gillam, 2017, p. 114).

Further research into public perceptions of Monsanto, following the court cases and release of the "Monsanto Papers", and implications for attitudes towards glyphosate safety, would complement this SLR.

Farmers

Evidence in regard to the trust of farmers is varied and differs between countries. A 2009 Australian survey found consumers overwhelmingly trusted farmers with 93 per cent trust level compared to media 52 per cent, supermarkets 66 per cent and politicians 44 per cent (Henderson, Coveney, Ward & Taylor, 2011, p. 322).

In contrast, a lack of trust of farmers in Europe has been observed (Ghosh, 2014) which researchers attribute to globalisation and the increasing separation between farms and the consumer (Pellizzoni, 2005, p. 568) along with the criticisms of farming practices in the media following food safety incidents such as mad cow disease (Henderson et al., 2011, p. 323). In the United States innovations that have been responsible for productivity growth, such as chemical inputs, are negatively perceived by consumers (Lusk & McCluskey, 2018, p. 8) and it has again been questioned whether the disconnect been food production and the consumer is a contributing factor to distrust in farming practices (Lusk & McCluskey, 2018).

Proactive stewardship in glyphosate use has been identified as essential to ensure responsible use and efficacy (Clarke, 2018). Such activities include training on best practice (including spray drift, record keeping and personal protection equipment), continuing to improve technology and equipment for application and embracing opportunities for integrated weed management (Clarke,

2018). Promotion of such stewardship to the public can only help to improve public trust of farming practices.

Regulators and World Health Organisation agencies

IARC and JMPR

The debate on the 2015 classification of glyphosate as "probably carcinogenic" is ongoing. There is substantial literature on the methodology and results of IARC assessment but only a small number of studies questioning integrity or trust of this agency. This includes claims that the IARC classification is flawed, that conflicts of interest existed and that bias due to the selection criteria for the Working Group membership (Tarone, 2018). Monsanto criticized the finding claiming "they had failed to carry out their studies properly" and that the conclusions reached were "largely contradictory to published research" (Torretta, Katsoyiannis, Viotti & Rada, 2018). Conversely, there are claims that corporate interests had interfered with the science by lobbying US Congressional Respresentatives to discredit IARC's review process (Infante, Melnick, Vainio & Huff, 2018).

The distinction between "hazard identification" and "exposure assessment", as described in the background information on IARC and JMPR, has been at the centre of differing views and debate surrounding the scientific evidence about glyphosate safety (Saracci, 2017). Such controversy and ambiguity in the published science has the potential to impact on confidence in these agencies.

International regulators

During the initial literature review it was evident that there is substantial literature surrounding debates about the processes and science relied on in glyphosate approval by the United States EPA and the EFSA, however this is beyond the scope of this SLR so only brief observations from the SLR literature have been made.

The influence of Monsanto on the EPA's regulatory processes has been questioned and calls for an inquiry into misconduct into the EPA's review of glyphosate were made by a congressman in 2017 (Gillam, 2017).

The EFSA has been criticized for basing decisions on unpublished proprietary studies rather than peer viewed research by independent scientists (Landrigan & Belpoggi, 2018). The German Federal Institute for Risk Assessment (BfR) who have a significant contribution to the EFSA regulatory process, have rejected claims regarding lack of independence in their assessments and stipulated that "possible interests of the applicants, politics or other interest groups cannot and must not play any role in a scientific assessment" (BfR, 2019).

Australia

Overall there is a high level of trust in food governance in Australia but there are suggestions it is simply "taken for granted" and habitual, due to less frequent food safety incidents than other developed countries (Ghosh, 2014, p. 1). This is consistent with results of the University of Adelaide study indicating that 40 per cent of respondents were unaware that GM foods were subjected to safety assessments before they are approved for sale in Australia (Umberger et al., 2020). There are a number of agencies involved in regulation for food safety with the two relating to glyphosate use being APVMA and FSANZ. Perhaps surprisingly, given the overall high level of trust in Australian food supply, FSANZ has been found to enjoy only a moderate level of consumer trust (Ghosh, 2014, p. 2).

Trust of the APVMA has also been questioned, in particular relating to its independence (Senate Rural, Regional Affairs, & Transport References Committee, 2019).

Court cases in the United States and media reporting on the "Monsanto Papers" prompted public interest in Australia and precipitated a Senate enquiry into "Independence of regulatory decisions made by the Australian Pesticides and Veterinary Medicines Authority (APVMA)" (Senate Rural et al., 2019). The APMVA is funded by levies from chemical companies which the review recognized "is perceived by some as a conflict of interest". The review found that "the authority's clearly legislated regulatory responsibilities do not allow for industry to unduly influence the decisions of the regulator, by the fact that it is industry funded" (Senate Rural et al., 2019).

In Australia consumers ultimately expect government to be responsible for food safety (Ghosh, 2014, p. 2; Henderson, Coveney & Ward, 2010, p. 347).

Impact of public perceptions on glyphosate regulation

The strongest reaction to public opinion is in Europe. Public perception is very mobilized, with support of NGO's, in relation to food safety and had a strong influence in glyphosate renewal (Bozzini, 2017).

The ECI has influenced glyphosate regulation and policy in a number of ways. Firstly, the European Commission's renewal period for glyphosate is only for five years rather than the standard 15 years (European Union, 2017; Jale, Herman & Trevelyan, 2019). Secondly, a promise of transparency has been secured from the European Commission (European Union, 2017). Finally, the ECI were influential in the European Parliament putting forward a resolution to phase out glyphosate (European Parliament, 2017). While this proposal has not been adopted, a number of leaders from member countries are investigating measures for phasing out.

The "precautionary principle" is significant in relation to the EU's policies regarding food safety and the environment, with views amongst researchers and commentators that the public opinions communicated through the ECI should be more influential in regulatory decisions (Bozzini, 2017; Leonelli, 2018; Torretta et al., 2018).

Information and education

Given the wide ranging views regarding glyphosate safety, it is interesting to consider, in relation to public perception, what type of information influences consumers.

Information plays a key role in consumer perceptions. There is significant evidence that consumers are not informed in relation to technologies such as gene technology (Lusk & McCluskey, 2018; Umberger et al., 2020). As shown in the University of Adelaide study, respondents who felt insufficiently informed regarding genetically modified foods tended to be more averse to food safety risks and believed genetically modified food was unsafe. This suggests that they could be influenced in regard to food safety by information from trusted sources (Umberger et al., 2020).

The academic community is the most trusted source for information concerning food safety with the media the least trusted according to a US study (Gempesaw & Toensmeyer, 1991, p. 5) although it was noted that such content is not easy to distribute.

Social media has changed the way global issues are communicated and opinions influenced in recent years and there have been examples of "social pressure" being more effective than traditional educational campaigns (Lusk & McCluskey, 2018, p. 9).

In the media, stark variations have been identified in the focus on glyphosate reporting in publications targeting different readerships. A German study found a standard weekly newspaper, targeting a broad audience, highlighted the scientific debate and possible health risks compared to a publication aimed at the agriculture industry which focused on the harmless nature of glyphosate (Villnow, Rombach & Bitsch, 2019). If similar patterns apply in Australia, the potential for consumers and farmers to have different understandings and views of safety regulation and the research surrounding safety of glyphosate should be evident.

Conclusions

The controversy surrounding the safety of glyphosate has resulted in substantial debate globally in relation to regulation. A number of countries have banned the use of glyphosate and many others face significant public and political pressure to restrict their use or conduct more research. Although the Australian agricultural industry cannot influence these regulations, there are a number of considerations suggested by this review into public perceptions of glyphosate usage, which may assist producers in preparation for the future in this environment of uncertainty.

It has been observed in research on media reporting that farmers' understanding and views regarding glyphosate may differ from those of their customers. Even if they do not share views on glyphosate health and environmental risks, they will not maximize value chain profits if they ignore these views in product development decisions.

Use of pesticides, and specifically glyphosate, is a concern for many consumers. In Australia some consumers have acted on this concern, as observed with increasing organic food consumption. European consumers are showing they are willing to pay for product differentiation where certain environmental or health attributes can be guaranteed.

Australian producers should consider product differentiation with reference to how this would impact on their production systems. They should determine the product attributes that domestic and export customers are looking for: in relation to glyphosate are they looking for "glyphosate-free production systems", "glyphosate-residue-free produce" or "responsible use of pesticides"? Additional research is required to break down further customer preferences in regard to glyphosate. There are a variety of options from organic certification, development of "glyphosate free" or other "environmentally friendly" labelling and accreditation schemes and the enabling of traceability.

If consumers are hypersensitive to risk and opportunities for such market niches exist, producers should examine the challenges involved in "glyphosate-free production systems" or the other variants discussed above. The costs of changing the production system should be calculated for determining viability. This should be considered alongside the fixed nature of such a change given the inability to quickly convert in and out of such production systems.

The proportion of agriculture produce that will be exported and to which destinations should also be considered, as this will impact consumer preferences. For example, for wheat, due to its significance to Australian agriculture (53 per cent of farm land) and reliance on no-till farming systems and glyphosate (Heard, 2018), it is important to note that over 70 per cent is exported with Asia the largest market (70 per cent of exports) as per Table 3. Consumer attitudes in Asian markets (particularly Indonesia where 22 per cent of wheat exports are destined (ABARES, 2019) towards

glyphosate need to be analysed. Organic food demand has been stronger in developed countries where food expenditure is a lower proportion of household income, which would suggest product differentiation opportunities would be lower in developing Asian countries. The ban on glyphosate use in Vietnam (not effecting imported grain at this stage) is an interesting development and it will be intriguing to observe potential flow on effects into Asia or import restrictions in relation to glyphosate use or revised residue limits.

Provenance and traceability have been compromised in mass-produced food manufacture with the long and complex value chains now involved. The popularity of Farmers' Markets is an indication of the value consumers place on provenance. Technology is continuing to make traceability more achievable with the development of platforms such as blockchain.

This review has identified two distinct areas in which education and information sharing is required: regulation and testing of food system safety in Australia, and research conclusions about the safety of glyphosate.

Information has become increasingly accessible with smart phones making a Google search accessible within seconds. Social media has also changed the way the public source information. This SLR does not explore the effectiveness of the different mediums but the review of public perceptions has raised some interesting insights. In terms of trust, academic sources rate most highly and this suggests our messaging should be related back to peer reviewed sources whenever possible. Another key finding was the effectiveness of public pressure rather than traditional education campaigns to convey information so innovation is required in how communication is approached. Further reviews of literature, specific to trusted sources in the digital age, would be useful including analysis of consumer perceptions of data obtained from Monsanto (now Bayer) or other corporates with perceived vested interests.

Farmers must focus on stewardship in glyphosate use to ensure efficacy is maintained. Best practice in relation to chemical applications, such as personal protection equipment and avoiding spray drift, protects farm workers and their communities, while responsible use is essential for managing residues and resistance issues. Australian farmers already enjoy strong levels of trust from the public, but promotion of responsible use of glyphosate and stewardship employed in farming practices will further influence public perceptions.

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[1]Abbreviations - APVMA: Australian Pesticides and Veterinary Medicines Authority; EFSA: European Food Safety Authority; EPA: United States Environmental Protection Agency; FSANZ: Food Standards Australia New Zealand; IARC: International Agency for Research on Cancer, JMPR: Joint FAO/WHO Meeting on Pesticide Residues

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Appendix 1. SLR sources by category

Source	Category	Inclusion as cited from a SLR included source
Böcker, Möhring and Finger 2019	Consumer preferences	
Bozzini 2017	Trust	
Brantsaeter et al. 2017	Consumer preferences	
Buchler, Smith and Lawrence 2010	Consumer preferences	Cited
Clarke 2018	Trust	
Cranfield, Deaton and Shellikeri 2009	Consumer preferences	
Foucart and Horel 2018	Trust	
Gempesaw and Toensmeyer 1991	Consumer preferences, Information and education	
Ghosh 2014	Trust	
Gillam 2017	Trust	
Henderson et al. 2010	Trust	
Henderson et al. 2011	Trust	Cited
Infante et al. 2018	Trust	
Jale, Herman and Trevelyan 2019	Trust	
Janssen and Hamm 2012	Consumer preferences	Cited
Krimsky and Gillam 2018	Trust	
Landrigan and Belpoggi 2018	Trust	
Leonelli 2018	Trust	
Lusk and McCluskey 2018	Consumer preferences, Trust, Information and education	
McHenry 2018	Trust	
Orlando 2018	Consumer preferences	
Pellizzoni 2005	Trust	Cited
Richards, Lawrence and Burch 2011	Consumer preferences	
Saitone and Sexton 2017	Consumer preferences	
Saracci 2017	Trust	
Tarone 2018	Trust	
Torretta et al. 2018	Trust	
Villnow, Rombach and Bitsch 2019	Information and education	