DISS. ETH NO. 27080

Chemophobia Today: Determinants, Consequences and Implications for Risk Communication

A thesis submitted to attain the degree of
DOCTOR OF SCIENCES of ETH ZURICH

(Dr. sc. ETH ZURICH)

Presented by
RITA SALEH

MA. Health Sciences, University of Lucerne

born on *09.01.1993*

Lebanese

Accepted on the recommendation of
Prof. Dr. Michael Siegrist
Dr. Angela Bearth
Prof. Dr. med. Martin Wilks

2020

This thesis was funded internally by the Consumer Behavior Group at ETH Zürich

During my three years of doctoral studies in Switzerland, the Lebanese people were battling political unrest, unprecedented economic crisis, fear of famine and war, the coronavirus pandemic, and the aftermath of a massive chemical incident. I had found it painful that I could not contribute to help my people in the way that I had wanted to. Therefore, I would like to dedicate my doctoral thesis to the Lebanese people who have faced a lot of turbulences and survived them on their own. I dedicate it to the victims of the August 2020 chemical incident and their grieving families. I dedicate it to those who opened their homes for the affected ones, to those who did what they can to help. To me, you are heroes. I also dedicate it to the October 2019 Lebanese revolution, to those who were and continue to fight for the country's unity, basic civil rights and freedom. This dedication does not undo the disasters that occurred nor does it alleviate the suffering and the losses endured by the Lebanese people. This dedication is a mere promise that those who fought, those who suffered, those who died, will not be forgotten.

To my father Mohammed Saleh who have passed away in 2018. I still remember how you sold what you owned to give me what I wanted. I still remember how you were so proud of me that you used to talk to people about me and what I am achieving. There are people to this day whom I don't know, would approach me to talk about all your kindness and generosity with them. You are forever my inspiration. I want you to know that I still carry your letters to me in the books you have gifted me. Most importantly, I still carry you in my heart, forever.

To my mother Iltaf Banat who gave up (and still) much more than she ever had, to ensure I have a proper education. I see how you fight for me, how you protect me and stand by me even when I don't make it easy for you. Truly, words fall short to describe how amazing you are. I want you to know that I hold my head high whenever I say I am your daughter. I want you to know that without you, I wouldn't have accomplished anything. You are my motivation and my idol. I know you are tired now, I am going to take care of you, I promise.

Summary

The present thesis aimed to empirically investigate the public's irrational fear of chemicals, which is generally termed "chemophobia." In an effort to understand the public's perceptions of chemicals, the associations evoked by the term "chemicals" were identified. The results indicated that chemicals tend to be associated with both negative images (e.g., death, poison) and negative affect (Chapter II). Additionally, several misconceptions in relation to the basic toxicological principles (e.g., the dose-response insensitivity) seemed to exist among consumers. These misconceptions appeared to be the most important and consistent determinants of chemophobia (Chapters II and III). Other determinants of chemophobia were identified (e.g., health concerns), although some (e.g., trust in regulators) were not found to be related to chemophobia in all the European countries investigated (Chapter III). Moreover, regarding the consequences of chemophobia, evidence was found that chemophobia impacts not only the public's acceptance of chemical products but also their acceptance of technologies. In the case of agriculture (Chapter IV), chemophobics were identified as being more likely to reject the use of pesticides and biotechnologies (i.e., gene technology) as crop protection measures. This rejection could be due to the perceived low degree of naturalness of the two types of measures. Ultimately, the findings of this thesis suggested that chemophobia is not a psychological disease. Rather, it is an irrational fear of entities perceived to be synthetic, characterized by a set of misconceptions regarding the risks of natural and synthetic chemicals. Communicating information regarding basic toxicological principles to the public can serve to mitigate chemophobia and thus, facilitate informed decision-making regarding chemicals (Chapter V). However, regional differences and psychological factors (e.g., ideational beliefs) must be accounted for if the success of the information provision strategy is to be ensured.

Résumé

L’étude approfondie de la peur irrationnelle du public des produits et des substances chimiques ou en d’autres termes la chimiophobie est l’objectif de cette thèse. Afin de mieux comprendre les perceptions du public des produits chimiques, les entités associés au terme “substances chimiques” ont été identifiées. Les résultats ont indiqué que les substances chimiques sont souvent associées à la fois à des images (par exemple, la mort, la poison) et sentiments négatifs. De plus, plusieurs fausses idées concernant les principes toxicologiques de base existent chez les consommateurs et qui sont responsables de cette chimiophobie (Chapitres II et III). D'autres déterminants de la chimiophobie ont été identifiés, par exemple les soucis concernant la santé, la confiance dans les régulateurs des produits chimiques, bien que cette dernière ne soit pas un important déterminant de la chimiophobie dans tous les pays européens étudiés (Chapitre III).

Il a été démontré que la chimiophobie a un impact sur l’acceptation par le public des produits chimiques et des technologies. Par exemple les chimiophobes ont été identifiés comme étant plus susceptibles de rejeter l'utilisation de pesticides et de biotechnologies comme mesures de protection des cultures (Chapitre IV). Ce rejet pourrait être dû à leur perception de ces deux types de mesures comme non naturelle.

Les résultats de cette thèse suggèrent que la chimiophobie n'est pas une maladie psychologique. Il s'agit plutôt d'une peur irrationnelle des entités perçues comme synthétiques et des fausses idées concernant la toxicité des substances chimiques naturelles et synthétiques.

La communication au public des principes toxicologiques de base pourra servir à atténuer la chimiophobie (Chapitre V) et ainsi faciliter la prise de décisions éclairées concernant les produits chimiques. Cependant, les différences entre les régions et les facteurs psychologiques (par exemple, les éléments idéationnels (croyances, valeurs)) doivent être pris en compte si l'on veut garantir le succès de la stratégie de communication.

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Abbreviations

TCDD	2,3,7,8-Tetracholorodibenzodioxin
DDT	Dichlorodiphenyltrichloroethane
MMA	Mental Models Approach
PCA	Principal Component Analysis
CA	Correspondence Analysis
MSA	Mokken Scale Analysis
ANOVA	One-way Analyses of Variance
CH	Switzerland
AT	Austria
FR	France
DE	Germany
IT	Italy
PL	Poland
SE	Sweden
UK	United Kingdom
Agri-biotech	Agricultural Biotechnology
GM	Gene Modification

Chapter I General Introduction

1.1.Introduction

The use and development of chemicals has led to many innovations, which have formed the building blocks of modern life (Michaelis, 1996; Sense About Science., 2006). For example, without chemicals, neither cellphones, cars, nor airplanes would exist. Additionally, the use of chemicals has helped to address many challenges worldwide, from the eradication of diseases (e.g., smallpox) following the development of vaccines to the potential for mass food production through the use of agricultural chemicals (Koplow, 2003; Sense About Science., 2006).

Besides the benefits brought about with the use of chemicals, it is important to note that the use of chemicals can pose certain health and environmental risks, depending on the doses and exposure levels involved (Schiefer, Irvine, & Buzik, 1997). However, chemicals are subjected to an extensive risk assessment process prior to being approved for use in consumer goods or services (Leeuwen & Hermens, 1995; Schiefer et al., 1997). For instance, after determining if a given chemical may cause harm to human health or the environment by referring to epidemiological and toxicological studies, experts calculate the dose(s) at which illness or death usually occurs. This calculation allows the experts to establish the safe dosage at which the relevant chemical can be used (Leeuwen & Hermens, 1995). Yet, the public might not be aware of the extensiveness of the risk assessment process performed in relation to chemicals, which is designed to ensure that the chemicals used in products are under the safe limits (Bearth, Cousin, & Siegrist, 2014; Dickson-Spillmann, Siegrist, & Keller, 2011; Shim et al., 2011). In fact, the public's concerns regarding the risks associated with the use of chemicals in consumer products and services have been well-documented over the years (Bearth, Miesler, & Siegrist, 2017; Dickson-Spillmann et al., 2011; Jansen, Claassen, van Kamp, & Timmermans, 2020a, 2020b; Kraus, Malmfors, & Slovic, 1992; MacGregor, Slovic, & Malmfors, 1999; Mertz, Slovic, & Purchase, 1998; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997). The risks posed by chemicals tend to be exaggerated and feared, while the individual and societal benefits that stem from the use of chemicals appear to be disregarded or unrecognized (Michaelis, 1996; Ropeik, 2015). As a result, the public's concerns seem to have developed into an irrational fear of chemicals, which is loosely termed "chemophobia" (Entine, 2011b; Gribble, 1991, 2013; Kauffman, 1989; Lee et al., 2019; Michaelis, 1996; Ropeik, 2015). Chemophobia is thought to have been generally present in societies for around two centuries, with its catalyst being the misbelief that chemicals are inherently dangerous and should be avoided at all costs (Entine, 2011b; Gribble, 2013; Kraus et al., 1992). In fact, chemophobia could explain the public's ongoing skepticism and opposition with regard to the use of chemicals and related innovations in domains ranging from consumer goods to food technologies (Entine, 2011a, 2011b; Gribble, 2013; Ropeik, 2015). For instance, chemophobia might lead laypeople to boycott and even protest against consumer products and services (e.g., vaccines) simply for being chemicals (Entine, 2011b). Chemophobia might thus, be hindering laypeople from making informed decisions regarding chemicals and consumer products. However, this link between chemophobia and the public's decision-making regarding chemicals is purely anecdotal, as it has not yet been explicitly examined. Most prior studies concerning chemophobia have been theoretical and offered a descriptive analysis of the possible origins and consequences of chemophobia (Entine, 2011b; Gribble, 2013; Kauffman, 1989, 1991).

Therefore, the aim of the present thesis is to provide an empirical understanding of chemophobia, its determinants and implications for the public's decision-making regarding chemicals. The question of whether and, if so, how chemophobia could be mitigated is another aim of this thesis. Chapters II-VI altogether address these aims, while Chapter I mainly serves to describe the phenomenon of chemophobia in terms of its characteristics (section 1.2), hypothetical drivers (section 1.3) and possible consequences (section 1.4).

1.2. Who are the chemophobics?

Research conducted in relation to public's risk perceptions has shown that there is divergence between experts' and the public's judgements concerning the use of chemicals (Kraus et al., 1992; Mertz et al., 1998; Slovic et al., 1995; Slovic et al., 1997). While experts rely on a quantitative risk assessment process to evaluate the risks associated with chemicals, laypeople tend to view chemicals more simplistically as either safe or dangerous. Kraus et al. (1992) described the public's appraisal of chemicals as "intuitive toxicology," which refers to the reliance on senses and intuitions when judging the risks of chemicals. This reliance is characterized by dose–response insensitivity, which indicates a lack of familiarity with the basic toxicological principle that "the dose makes the poison" (Kraus et al., 1992; Slovic et al., 1995). This dose–response insensitivity is exemplified by the belief that harm will definitely result from any level of exposure to toxic or carcinogenic chemicals (MacGregor et al., 1999). From a toxicological perspective, the risk posed by a given chemical is the probability of adverse consequences occurring based on a certain level of exposure to that chemical. A chemicals' risk is differentiated from the hazard posed by that chemical, which refers to its potential to cause adverse consequences (Scheer et al., 2014). However, this difference might not appear to be salient for chemophobics (Kraus et al., 1992; Monro, 2001; Stone, 2014), as the mere ability to detect small traces of chemicals in consumer products or the human body can be perceived to indicate a health hazard (Entine, 2011b). For instance, the small amounts of agricultural chemicals found in water samples, which are lower than the acceptable/safe levels, are commonly equated with definite adverse health consequences by chemophobics (Entine, 2011a). Chemophobics tend to seek the elimination of chemical-related risks at all costs (Francl, 2013; Gribble, 1991; Kauffman, 1991; Kraus et al., 1992), especially since the health risks of chemicals are mostly associated with the development of cancer, a dreadful health consequence (MacGregor et al., 1999; Ropeik, 2011, 2015). Furthermore, the term "chemical" seem to be mainly associated with artificially-produced or man-made chemicals. While chemicals of natural origin might not necessarily be perceived or considered as a chemical entity by chemophobics (Entine, 2011b), despite the fact that by definition, a chemical is a form of matter with constant chemicals composition and properties (Schiefer et al., 1997). In other terms, everything is, or contains chemicals (from the air to consumer products). However, chemophobics seek to reduce their exposure to chemicals by avoiding artificial chemical-containing products (Chalupa & Nesmerak, 2019; Dickson-Spillmann et al., 2011; Entine, 2011b; Gribble, 2013), even though experts have continuously demonstrated that these chemicals are under the safe limits in products through the risk assessment process (Schiefer et al., 1997). It is undeniable that there are certain chemical products (e.g., descalers, bleach, etc.) that should only be used with caution because excessive use or any mishandling could have serious negative consequences. However, chemophobics might even avoid beneficial, safe and non-substitutable products (e.g., vaccines) simply because these products contain (artificial) chemicals and thus, are perceived to be dangerous (Entine, 2011a, 2011b).

1.3.How did chemophobia emerge and evolve?

It has been established that the public's perceptions of chemicals are generally negative (Gribble, 2013; Jansen et al., 2020a; Kraus et al., 1992; Mertz et al., 1998; Ropeik, 2015). There are a number of situational and psychological factors that are considered to represent the origins of, or to have contributed to the evolution of, chemophobia. Figure 1 (author's own representation) is an overview of the situational and psychological factors related to chemophobia, which are discussed in more detail in this section.

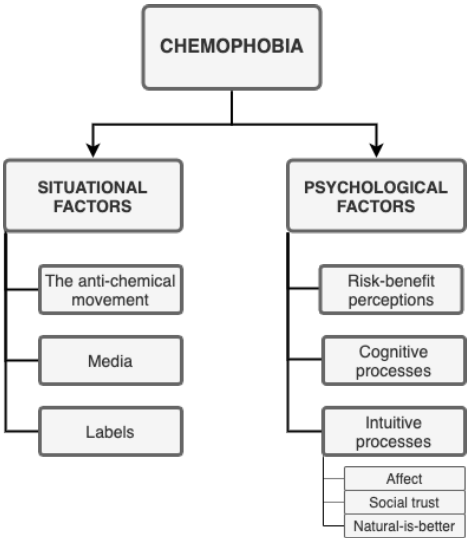

Figure 1. Overview of the situational and psychological factors possibly related to chemophobia

1.3.1. Situational factors

There are situational factors that arguably led to warranted fears of chemicals, and other factors that triggered irrational fears of chemicals (i.e., chemophobia). Section 1.3.1.1 represents some of the factors that possibly caused justifiable concerns regarding the use of chemicals. Other situational factors that can be attributed to chemophobia are discussed in section 1.3.1.2.

1.3.1.1.The horrifying history of chemicals

During the early 20th century, the public displayed excitement with regard to the use of chemicals due to the booming of chemical industries (e.g., dyes, pharmaceuticals, etc.), which brought about improvements to individuals' quality of life and also brought prosperity to wider societies (Entine, 2011b). However, certain events that occurred throughout the 20th century had tarnished the image of chemistry and possibly gave rise to real and justifiable fears concerning the use of chemicals. For instance, the use of chemicals as weapons during both World War I, which was infamously known as the "chemists' war," and World War II, resulted in the public perceiving chemistry to be a fearsome science (Hartings & Fahy, 2011; Schummer, Bensaude-Vincent, & Van Tiggelen, 2007). The public's concern with the toxic potential of chemicals increased, especially since the most prominent associations with chemicals during that period were “chemical warfare,” “mad scientists,” and “poisons” (Schummer et al., 2007).

Moreover, the number of severe industrial chemical incidents that occurred throughout the 20th and 21st centuries likely increased the public’s concern about the harmfulness of chemicals (Gribble, 2013). Table 1 details 10 of the worst chemical incidents to have occurred over the last 100 years worldwide (Brice, 2008; Organization for Economic Cooperation and Development., 2013). As can be seen from the table, the various chemical-related incidents have led to high numbers of human deaths, significant losses of wildlife, and severe environmental problems. The magnitude of the consequences of such incidents has arguably had a long-term impact on the public’s risk perception and acceptance in relation to the use of chemicals (Kher et al., 2013; Slovic, 1987). For example, the 1986 Chernobyl nuclear power plant disaster and the 2011 Fukushima nuclear power plant explosion are thought to partly explain the public’s ongoing skepticism and opposition regarding nuclear power (Bauer, Gylstorff, Madsen, & Mejlgaard, 2019). The fact that chemical incidents in general could not been prevented and continue to occur causing major damages and losses is likely to influence the public’s risk perception of chemicals. From the public’s perspective, chemicals and the chemical industries seem to entail serious risks that cannot be safely managed, which might explain the public’s negative perceptions of chemicals (Hartings & Fahy, 2011).

However, due to such disastrous events, important treaties as well as international and national measures have been implemented to prevent and/or mitigate the impacts of possible chemical incidents and deliberate releases of toxic chemicals (United Nations., 1992, 1996, 2017). More stringent regulations have been imposed on the chemical industries, including consumer goods companies, which must obtain authorization to use certain chemicals (European Chemicals Agency., 2007; Lokke, 2006). Yet, despite such efforts to ensure the safe use of chemicals, the public’s concerns regarding the use of chemicals have endured (Bearth et al., 2014; Jansen et al., 2020a; Kher et al., 2013) and may even have spiraled into chemophobia (Chalupa & Nesmerak, 2018; Entine, 2011b; Gribble, 2013; Ropeik, 2015).

Table 1. 10 of the worst chemical incidents worldwide

Location	Date	Chemical Incident	Consequences
Pointe d'Esny Beach, Mauritius	August 6, 2020	A spill of 1 180 tons of oil in the Indian ocean	Endangerment of corals, fish and other marine life under threat. Consequences are yet to unfold.
Beirut, Lebanon	August 4, 2020	An explosion of 2 750 tons of ammonium nitrate ill-stored at the port of Beirut	More than 200 deaths, 5 000 injured and 80% of the homes, infrastructure and buildings destroyed as far as 10 km, leaving more than 300 000 homeless
Toulouse, France	September 21, 2001	An explosion of 300 tons of ammonium nitrate at the Atofina's Grande Paroisse fertilizer plant	30 deaths, and more than 10 000 injuries, and 80% of the buildings destroyed within 3 km from the explosion site
Alaska, USA	March 24, 1989	The Exxon Valdez, an oil tanker, spilled 260 000 – 750 000 barrels of crude oil into the sea	The deaths of 100 000 – 250 000 seabirds
Prypiat, Ukraine	April 26, 1986	An explosion occurred during an unauthorized test at the Chernobyl nuclear power plant	Around 50 human deaths due to radiation as well as 3 940 human deaths due to radiation-induced cancer and leukemia
Basel, Switzerland	November 1, 1986	A major fire at the Sandoz chemical factory	The deaths of 500 000 fish and severe pollution to the Rhine
San Juanico, Mexico	November 19, 1984	A series of explosions at a liquid petroleum gas tank farm	Around 500 human deaths
Bhopal, India	December 2–3, 1984	A toxic methyl isocyanate gas leak at a Union Carbide subsidiary pesticide plant	Around 3 787 human deaths as well as 558 125 individuals left with temporarily or permanently disabling injuries
Seveso, Italy	July 10, 1976	A chemical manufacturing plant released dioxins, 2,3,7,8-Tetracholorodibenzodioxin (TCDD)	The deaths of 3 300 farms animals, while 80 000 animals had to be slaughtered later to prevent TCDD from entering the food chain
Texas, USA	April 16, 1947	The explosion of nearly 2 300 tons of ammonium nitrate onboard the Grandcamp ship caused by a fire	Around 581 human deaths

1.3.1.2. The rise of chemophobia

A number of situational factors might have exacerbated the public's risk perception of chemicals and provoked an exaggerated and unreasonable reactionary fear regarding the use of chemicals. First, some researchers have argued that chemophobia might be an outgrowth of the environmental movement that was ignited by the book called *Silent Spring* by marine biologist Rachel Carson in 1962 (Chalupa & Nesmerak, 2018; Entine, 2011b; Gribble, 2013; Hübner, 2014; Kovács, 2014; Ropeik, 2015). Carson criticized the environmental and health risks associated with chemicals, particularly pesticides. Her book led to important new legislation regarding chemical uses, as well as to environmental advances such as the banning of the controversial pesticide dichlorodiphenyltrichloroethane (DDT) in most countries due to its environmental toxicity (Dunn, 2012). However, Carson (1962) vilified all chemicals as "the sinister and little-recognized partners of radiation entering into living organisms, passing from one to another in a chain of poisoning and death." It is thought that her description of chemicals gave rise to anti-chemical movements and advocacy groups that were skeptical of the safety of chemicals, particularly artificial ones, used in consumer products and services (Entine, 2011b; Ropeik, 2015). This skepticism might have incited several unfounded chemical-related scares (e.g., concerning the E numbers found in food products, vaccines) and also nourished chemophobia (Chalupa & Nesmerak, 2018; Entine, 2011a, 2011b).

Second, the news coverage of chemical scares may well have played an important role in shaping the public's risk perceptions of chemicals, especially since the news media can exert a powerful influence on the public's risk-related judgements (McCarthy, Brennan, De Boer, & Ritson, 2008; Paek, 2017). In fact, the news media tend to exaggerate the risks of certain (artificial) chemicals that are regularly found in everyday products, particularly in food products. For instance, aspartame, an artificial sweetener widely used in food and beverages, was reported to be a possible cause of cancer, despite such reports being unfounded (e.g., a detailed examination of the aspartame issue and media coverage in the study by Lofstedt [2008]). The news media did not take into account the consensus of experts regarding the safe use of aspartame and instead presented a one-sided and negative story regarding its use. The media then disseminated the dubious story with embellished titles and headlines (e.g., *"Cancer is linked to sweetener – Risk in 6000 food and drink products"* and *"Crippled girl walks again after giving up sweetener,"* Daily Express newspaper in the UK, 2005), which stoked the public's fear concerning the use of aspartame in food (Lofstedt, 2008). Such media stories lacked information about doses and exposures levels, and were likely to have intensified people's desire to reduce their exposure to chemicals, especially in food (Entine, 2011b; Ropeik, 2015).

Lastly, the misleading labels, such as "nontoxic," "green," and "chemical-free," found on certain products might also have played a role in fostering chemophobia (Asioli et al., 2017; Gribble, 2013). Such labels imply that nontoxic chemicals exist and represent a safe alternative to the allegedly risky chemicals. While consumers might perceive these labels positively, the term "chemicals" became synonymous with toxicity and dangerousness (Ropeik, 2015; Rozin et al., 2004). For instance, several blogs and websites unwarrantedly have claimed that certain consumer products contain inherently risky "chemicals" (e.g., the aluminum found in deodorants) that can cause serious diseases such as Alzheimer's or cancer (Urban et al., 2016; Willhite, 2014). These claims could have needlessly instilled doubts and heightened publics' health-related risk perceptions of certain chemicals. Additionally, claims in relation to the replacement of products perceived to be risky with products that are labeled as being "chemical-free," could have contributed to the misperception that a chemical-free life is possible and further inflamed chemophobia (Entine, 2011b; Francl, 2013).

1.3.2. Psychological factors

In addition to the above-mentioned situational factors, there are certain psychological factors that exert an important influence on the public's evaluations of different issues and technologies. These factors might be relevant to the public's appraisals of chemicals, and they could also be determinants of chemophobia. This section presents some of the most important psychological factors known to guide laypeople's decision-making.

1.3.2.1. Risk–benefit perceptions

Risk–benefit perceptions are recognized as key psychological factors in relation to the public's judgements and decision-making regarding various issues (Alhakami & Slovic, 1994; Bearth & Siegrist, 2016; Frewer et al., 2011; Gupta, Fischer, & Frewer, 2012). For instance, risk–benefit perceptions are considered the major drivers of the public's acceptance of food technologies such as genetically modified food (Bredahl, Grunert, & Frewer, 1998; Kim, 2012; Siegrist, 2000) and the use of nanotechnology in food products (Stampfli, Siegrist, & Kastenholz, 2010). There exist research that has shown that benefit perceptions are more influential than risk perceptions in terms of the public's appraisals of hazards and technologies (Bredahl et al., 1998; Bronfman, Jimenez, Arevalo, & Cifuentes, 2012; Siegrist, 2000; Visschers & Siegrist, 2014). Other researchers revealed that risk perceptions are the important driver of the public's decision-making (Eiser, Miles, & Frewer, 2002; Greenberg & Truelove, 2011). Nonetheless, there is scientific consensus that the publics' judgements regarding the risks and benefits associated with given activities or technologies are not independent; rather, they are inversely related in people's minds (Alhakami & Slovic, 1994; Finucane, Alhakami, Slovic, & Johnson, 2000). Risk–benefit perceptions are, therefore, intuitively weighed up against one another. That is, the greater the perceived risk, the lower the perceived benefit, and vice versa (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978). This inverse relationship between risk–benefit perceptions suggests that certain degrees of risks might be tolerated or accepted, if the hazard in question is perceived to offer large benefits (Alhakami & Slovic, 1994). With regard to chemicals, the risks might not be tolerated because they tend to be perceived as high, while the benefits appear to be dismissed by the public (Mertz et al., 1998; Slovic, Kraus, Lappe, & Major, 1991; Slovic et al., 1995). Thus, a distorted risk–benefit perception concerning chemicals might influence the public's reaction to the use of chemicals and promote chemophobia (Entine, 2011a, 2011b). Furthermore, the way in which the risks and benefits are judged might also explain chemophobia. Generally, evaluations of the risks and benefits of hazards are based on both cognitive and intuitive processes that depend on certain contextual factors such as time pressure (Finucane et al., 2000). The cognitive processes are discussed in section 1.3.2.2, while the intuitive processes are discussed section 1.3.2.3.

1.3.2.2. Cognitive processes: The role of knowledge

The role of scientific knowledge in shaping the public's perceptions and attitudes remains controversial. Many empirical studies have investigated the influence of scientific knowledge regarding a given technology on laypeople's risk perceptions and acceptance of that technology. Among those studies, a few identified the positive effect of knowledge regarding certain technologies on people's evaluations of those technologies (Hayes & Tariq, 2000; Huang et al., 2013). However, other studies revealed that an understanding of a given activity does not necessarily lead to lower risk perceptions or greater acceptance regarding that activity (Connor & Siegrist, 2010; Jobin, Visschers, van Vliet, Arvai, & Siegrist, 2019; Renn, 2006; Wallquist, Visschers, & Siegrist, 2010). In fact, rather than having a positive influence, the provision of information might have a negative influence on the public's perceptions and evaluations. For instance, Sutterlin and Siegrist (2017) found that merely describing a form of geoengineering technology led to increased risk perceptions and decreased benefit perceptions concerning that technology and, therefore, reduced the public's support for its use in fighting climate change.

Thus, the findings of prior studies have not confirmed that knowledge, in general, has a linear relationship with the public's attitudes. In other words, knowledge is not absolutely reliable in terms of influencing the public's perceptions and decision-making, despite what the knowledge deficit model suggests (Hansen, Holm, Frewer, Robinson, & Sandoe, 2003). The model postulates that laypeople's perception of a certain technology differs from experts' perception due to the public's ignorance or lack of scientific knowledge. This model has been criticized as inadequate, as it fails to account for the way in which people perceive risks or how their perceptions are formed (Ahteensuu, 2012; Sturgis & Allum, 2004). Instead, the model ignores or neglects the public's opinions and beliefs and simply dismisses them as a knowledge deficit. Similarly, neglecting or dismissing the beliefs of chemophobics would be invalid. To understand chemophobia and its determinants, it is important to first understand the beliefs that chemophobics hold.

No prior studies have empirically examined the beliefs and misconceptions of chemophobics. However, it is possible that some of the misconceptions held by chemophobics might be related to dose–response insensitivities (i.e., the belief that chemicals are dangerous irrespective of their dose, etc.), which might prompt chemophobics to overestimate the risks and underestimate the benefits of chemicals (Entine, 2011b; Kraus et al., 1992; Ropeik, 2015). On the one hand, research has suggested that a basic understanding of the risk assessment process of chemicals might guide laypeople toward better assessing the risks and benefits of chemicals and reduce chemophobia (Bearth, Cousin, & Siegrist, 2016; Dickson-Spillmann et al., 2011; Monro, 2001; Shim et al., 2011; Siegrist & Bearth, 2019). For example, Bearth et al. (2016) found that the public's perception of food additives tended to be more positive when people were aware of the risk assessment process undertaken to ensure the safety of food additives. On the other hand, other researchers have indicated that emphasizing the societal benefits brought about by chemicals might help to address people's skepticism regarding chemicals and reduce chemophobia (Chalupa & Nesmerak, 2018; Hartings & Fahy, 2011). It certainly seems plausible that the suggested types or levels of knowledge (knowledge of the risk assessment process, knowledge of the benefits of chemicals) could exert different influences on chemophobia, since different types of knowledge can have different relationships with laypeople's evaluations and decision-making (Cuite, 2005; Wallquist et al., 2010). Therefore, it is important to understand whether and, if so, which types of knowledge might be relevant to laypeople's perceptions of chemicals as well as to chemophobia.

1.3.2.3. Intuitive processes: The role of heuristics

Due to resource constraints (e.g., lack of time, motivation, or attention), laypeople might not always rely on information or analytical risk evaluations (Slovic, Finucane, Peters, & MacGregor, 2002, 2004). Under these circumstances, people may instead rely on heuristics, which can be broadly defined as mental shortcuts used to judge the risks and benefits associated with a given activity or technology (Tversky & Kahneman, 1974). There are three important heuristics (i.e., the affect heuristic, the trust heuristic, and the natural-is-better heuristic) that people might rely on when judging the risks of chemicals, and might be related to chemophobia. Therefore, the subsequent sections examine the affect, trust, and natural-is-better heuristics as possible drivers of chemophobia.

The affect heuristic

The affect heuristic is considered to be one of the most important heuristics that laypeople rely on when making judgements. It involves a reliance on the feelings experienced regarding a given stimulus when judging whether that stimulus has a quality characterized by "goodness" or "badness" (Slovic et al., 2004). In other words, people's evaluations of an activity can be based on the "affect pool," which is the negative and positive tags associated either consciously or unconsciously with that activity (Finucane et al., 2000; Slovic, Finucane, Peters, & MacGregor, 2007). This heuristic is central to the experiential and intuitive mode of thinking (Slovic et al., 2007), which can be distinguished from the analytical mode of information processing (Epstein, 1994). In fact, Zajonc (1980) argued that the affective reactions to a given stimulus are automatic and fast and could be the first reactions that guide information processing and judgement. Relying on the affect heuristic can be easier and more efficient than analyzing the pros and cons of a given activity or technology, especially when an individual's mental resources and time are limited or when the decision at hand is complex (Finucane et al., 2000; Gigerenzer & Gaissmaier, 2011). However, other researchers have argued that relying solely on affective reactions might distort perceptions and even lead to biased judgements regarding certain products or technologies that are not necessarily in the individual's best interests (Ropeik, 2010; Slovic et al., 2002, 2004). Risk and benefit judgements concerning a given activity or technology can be guided by people's feelings toward that activity or technology (Alhakami & Slovic, 1994; Finucane et al., 2000). If a certain stimulus evokes positive feelings, the risks of that stimulus are perceived to be low, while the benefits are perceived to be high, and vice versa if the feelings evoked are negative (Alhakami & Slovic, 1994). There exists evidence that affect can determine the public's perception and acceptance of a wide range of technologies or issues, including nuclear power, nanotechnology-based food, and energy systems (Jobin & Siegrist, 2018; Leiserowitz, 2006; Peters & Slovic, 1996; Siegrist, Cousin, Kastenholz, & Wiek, 2007; Vastfjall, Peters, & Slovic, 2008). Generally, the more that technologies or issues evoke negative feelings or a sense of dread, the riskier they are perceived to be and the greater the need for their regulation is thought to be (Slovic et al., 2007). Similarly, chemophobia might be related to the types of images and feelings associated with chemicals. In fact, chemicals are heavily stigmatized and frequently associated with "cancer," "danger," and "death" (Flynn, Slovic, & Kunreuther, 2001), which provokes feelings of dread and so possibly exacerbates people's negative perceptions of chemicals, thereby leading to chemophobia. Therefore, it is plausible that the affect heuristic might drive chemophobia. Understanding the role played by the affect heuristic in chemophobia might prove valuable in relation to risk communication intended to address chemophobia and promote informed decision-making.

The trust heuristic

In the absence of knowledge, laypeople are unable to directly evaluate the risks and benefits of technologies. Instead, their decisions and risk–benefit judgements regarding technologies might be guided by social trust (Earle & Cvetkovich, 1995; Siegrist & Cvetkovich, 2000; Siegrist, Cvetkovich, & Roth, 2000). The higher the level of social trust, the more benefits and less risks an individual associates with a given technology (Siegrist et al., 2000). For instance, individuals who exhibit social trust in the companies and scientists involved in gene technology tend to perceive less risks and more benefits to be associated with such technology than those who do not exhibit social trust (Siegrist, 2000). Even the acceptance of technologies (e.g., energy technologies, nanotechnology applications, gene technology, nuclear power, and climate change measures) has been found to be related to social trust (Lu, Xie, & Xiong, 2015; Montijn-Dorgelo & Midden, 2008; Siegrist, 2019; Siegrist et al., 2007; Siegrist, Gutscher, & Earle, 2005; Viklund, 2003).

There are many stakeholders and institutions involved in the chemical sector, including the chemical industries, consumer goods companies, chemicals regulation and compliance organizations, and academic as well as non-affiliated scientists. The public's level of trust differs between stakeholders and institutions. For instance, on the one hand, it is arguable that the public's level of trust in the chemical industries is low (Flynn, 1993; Ricci, Bellaby, & Flynn, 2010). This might be due to the chemical incidents that previously occurred and to the chemical scares highlighted in the media (Entine, 2011b; Ropeik, 2015). The public might also perceive the chemical industries to be focused on profits rather than on important values. On the other hand, the public tend to express high levels of trust in regulators and scientists, especially when they are perceived to share the public's values or to have the publics' interests in mind (Earle & Cvetkovich, 1995; Lu et al., 2015; Siegrist, & Hartmann, 2020). This disparity in the public's trust in the involved stakeholders makes it difficult to determine who people should trust. In other words, it remains unclear which levels of trust in which chemical institutions or stakeholders are relevant to the public's evaluations of chemicals. Siegrist (2019) explained that in a context in which many stakeholders are involved, it is likely that rather than trust, the affect heuristic is employed. Yet, when a limited number of stakeholders are involved, trust is relied upon for decision-making. Therefore, it is important to determine whether or not, the trust heuristic is relevant for chemophobia.

The natural-is-better heuristic

While the term "chemicals" might be stigmatized (Ropeik, 2015), the term "natural" seems to have positive connotations even in context-free situations (Meier, Dillard, Osorio, & Lappas, 2019; Rozin, Fischler, & Shields-Argeles, 2012). People appear to believe that "natural" entities, or entities derived from nature, are better than man-made ones (Evans, de Challemaison, & Cox, 2010; Rozin et al., 2004). This belief likely represents the basic premise behind the natural-is-better heuristic. According to this heuristic, chemicals are evaluated based on their origins rather than on their risk assessments and toxicity profiles (Bearth et al., 2014; Dickson-Spillmann et al., 2011). Rozin et al. (2004) demonstrated that chemicals of natural origin are valued more highly than their synthetic counterparts due to ideational and instrumental beliefs. The latter suggest that natural entities are perceived to be inherently safer and healthier than synthetic ones, while the former indicate nature and natural entities to be morally superior to human interventions (Rozin, 2005; Rozin et al., 2004). In fact, some people express an affinity with nature, which is known as biophilia (Kellert & Wilson, 1993; Wilson, 1984) and could represent the origin of the natural-is-better heuristic. Such people perceive that man-made products cannot imitate the goodness or quality of natural products (Cotterill, John, & Teh, 2000; Rozin, 2005). Instead, man-made products tend to be perceived as contaminated by humans' inherent negative essence. This perception is known as the contagion principle, and it assumes that when two objects are in contact, their properties are permanently shared (Nemeroff & Rozin, 1994; Rozin & Royzman, 2001). For instance, a synthetic chemical could be perceived as a carrier of the negative essence of humans. The presence of even small amounts of that chemical within a product (e.g., food, pharmaceutical drugs, cosmetics, etc.) seems to transmit the negative essence of humans into the product (Rozin, 2005; Rozin & Royzman, 2001). Thus, synthetic entities seem to negatively influence the perceived naturalness and risks of a product (Apaolaza, Hartmann, Lopez, Barrutia, & Echebarria, 2014; Apaolaza, Hartmann, Lopez, Echebarria, & Barrutia, 2016; Green, Horne, & Shephard, 2013; Gribble, 2013; Meier et al., 2019; Meier & Lappas, 2016; Rozin, 2005; Watkinson, Chapman, & Horne, 2017). These beliefs influence the public's perceptions of chemicals, and can contribute to chemophobia.

1.4. What are the consequences of chemophobia?

A lack of knowledge and a reliance on both heuristics and misconceptions when judging the risks of chemicals can lead to biased decisions and over-reactions to chemical-related issues, which can ultimately lead to chemophobia. In turn, chemophobia can have consequences at the individual and societal levels, which can have implications for policy-making, science, and innovation. These consequences are discussed in the following sections.

1.4.1. Consequences for behaviors and risk estimations

Chemophobics generally engage in specific avoidance behaviors such as not eating food containing preservatives or artificial sweeteners (Bearth et al., 2014; Dickson-Spillmann et al., 2011; Gribble, 2013). They thrive on reducing their exposure to chemicals by only consuming "natural" products, especially since a natural entity and its synthetic counterpart might not be perceived to have the same chemical identity (Li & Chapman, 2012; Rozin et al., 2004). In other words, chemicals of natural origin, or that are perceived to be natural, might not necessarily be considered to be chemical entities. Chemophobics tend to prefer products that contain chemicals of natural origin over conventional products in various domains (e.g., food, cosmetics, cleaning products, etc.). For instance, in the pharmaceutical domain, chemophobics are likely to reject the use of pharmaceutical drugs due to the presence of synthetic chemicals, as the latter are perceived to be dangerous (Lynch & Berry, 2007; Meier et al., 2019; Meier & Lappas, 2016). Thus, such people can endanger their health by avoiding products that would be beneficial for them. Interestingly, in the domain of household chemical products, chemophobia might have a positive influence on people's handling of the relevant products. A recent study by Buchmüller, Bearth, and Siegrist (2020) revealed that chemophobia is related to the increased perceived severity of the risks of household chemicals and, therefore, possibly leads to the careful handling of such products. This finding could be of particular relevance to household chemical products (e.g., bleach, descalers) that are needed for usage and to which no "natural" alternatives exist. However, when they do exist, chemophobics are likely to prefer natural alternatives over conventional products (Cotterill et al., 2000; Lynch & Berry, 2007; Zaffani, Cuzzolin, & Benoni, 2006). These natural alternatives tend to be perceived as safe and beneficial (Rozin et al., 2012; Rozin et al., 2004), despite the fact that their toxicity profiles might not always be understood and could even be more dangerous or ineffective than those of conventional products (Sense About Science., 2006). Consequently, chemophobics might underestimate the risks of products they perceive to be natural and endanger themselves and others due to the less vigilant handling of such products (Entine, 2011b). For instance, products that are labeled as eco-friendly tend to be perceived as being safer than conventional cleaning products, which can lead to inappropriate or careless usage (Bearth et al., 2017). Therefore, addressing chemophobia might be needed to ensure an informed decision-making and safe handling of chemical-containing products.

1.4.2. Consequences for science and innovation

Chalupa and Nesmerak (2020) have argued that chemophobia might indirectly lead to the science of chemistry becoming marginalized, especially when compared with physics and biology. In fact, in a number of cases, the names of the chemistry departments of colleges have been changed to escape the stigma associated with chemistry. The science of chemistry has been assigned more attractive labels such as "green chemistry," "material science," and "molecular science" (Schummer et al., 2007). Therefore, chemophobia is thought to prevent the public from understanding the value of chemistry and, thus, from recognizing and supporting chemical-related innovations. For example, the COVID-19 pandemic that has hit worldwide have pushed concerned people, including chemophobics, to turn to chemical-based products (e.g., disinfectants, protective masks, etc.) to protect themselves (Chalupa & Nesmerak, 2020). It is unclear however, whether chemophobics recognize these products as chemicals or not. Additionally, how they would react to the development of vaccines and drugs needed to protect the public from the virus is yet to unfold. There is anecdotal evidence that suggest that chemophobics might disregard the importance of vaccines and reject them simply due to being chemicals (Entine, 2011b). Chemophobia might hence threaten public health. Furthermore, chemophobia-driven rejection of safe and needed products can lead national authorities to unnecessarily spend funds on further research into the relevant products, and more strictly regulate the products in order to alleviate the public's concerns (Monro, 2001; Ropeik, 2012). Chemophobia is, therefore, thought to have implications for policy-making, particularly due to issues related to the public's acceptance of chemical products. To better illustrate the possible implications of chemophobia in relation to the public's acceptance of chemical products and innovations, and thus for policy-making, a concrete example is presented in section 1.4.2.1.

1.4.2.1. Chemophobia in the agriculture sector

An important example of the consequences of chemophobia in relation to policy-making can be seen in the public's opposition to certain agricultural practices, particularly the use of pesticides to protect crops from infestations. It is true that pesticides are associated with several health and environmental risks (Ntzani, Ntritsos, Evangelou, & Tzoulaki, 2013; van Lexmond, Bonmatin, Goulson, & Noome, 2015; Williamson, 2011); however, such pesticides are heavily regulated due to both their toxicity and the public's concerns regarding their use (Eyhorn, 2015; Lamichhane, Dachbrodt-Saaydeh, Kudsk, & Messean, 2016). Entine (2011a) has argued that the public's opposition to the use of pesticides and agricultural chemicals partly stems from chemophobia. Even miniscule traces of pesticides in food frighten people (Dunlap & Beus, 1992; Peterson, 2000; Williams & Hammitt, 2001), despite them being under the acceptable/safe level (Lamichhane et al., 2016). For chemophobics especially, there is zero tolerance of any level of pesticide residue in food. Thus, they might support initiatives to ban the use of pesticide, particularly synthetic ones (Entine, 2011a). For example, there are currently two citizen-led initiatives in Switzerland calling for the banning of all synthetic pesticides due to health and environmental concerns and to transition toward a solely organic food production system (Swiss Federal Council, 2020a, 2020b). These initiatives seem to mainly target synthetic pesticides and to disregard pesticides of natural origin, which could still be dangerous to health or the environment (e.g., copper-based pesticides that can accumulate in and harm the soil; Eyhorn, [2015]). Therefore, the chemophobia-driven support for such initiatives could erroneously maneuver agricultural policies into banning pesticides based on their origins rather than on a risk assessment or on the known risks and benefits of the relevant chemical. Additionally, bans could result in there being only a limited number of measures available in the agriculture sector. Thus, the measures left might not suffice to protect crops, especially if innovative crop protection measures such as agricultural biotechnology applications are not considered acceptable (Lamichhane et al., 2015; Lucht, 2015). In this context, biotechnology applications refer to tools and techniques employed to genetically modify plants, animals, and microorganisms. Prior research has shown that such applications are generally perceived negatively, especially since they tend to be perceived as unnatural (Gaskell, 2001; Kronberger, Wagner, & Nagata, 2014; Mielby, Sandoe, & Lassen, 2013; Miles, Ueland, & Frewer, 2005; Tenbült, de Vries, Dreezens, & Martijn, 2005). In terms of chemophobics, it remains unclear how they perceive, and subsequently whether they accept, biotechnology applications in the field of agriculture when compared with pesticide use. Therefore, evaluating the influence of chemophobia on the public's acceptance of pesticide use and innovative biotechnological measures intended to protect crops could help to establish the extent of consequences of chemophobia.

1.5. Chapters overview

As discussed above, there are many aspects of chemophobia, which all require an empirical investigation. Therefore, the present thesis involved an in-depth examination of chemophobia in terms of its prevalence, determinants, and consequences. Communication strategies to mitigate chemophobia are also investigated. This section provides an overview of the remaining chapters included in this thesis.

Chapter II

In Chapter II, laypeople's perceptions of chemicals based on the Mental Models Approach was investigated. In a first step, the public's beliefs regarding chemicals were identified via semi-structured interviews conducted with both laypeople and experts. The findings of the interviews formed the basis for the development of a survey distributed to a representative sample of the Swiss population to identify the public's misconceptions concerning chemicals. The associations and affect that the term "chemicals" evoked among the public were determined and a scale for measuring knowledge of basic toxicological principles was tested. Moreover, psychological factors (i.e., trust in regulators, affect, risk–benefit perceptions, knowledge, health concerns) were examined in terms of their relationship with chemophobia. The findings are presented and discussed with regard to their implications for risk communication.

Chapter III

In Chapter III, the prevalence of chemophobia was determined by examining the levels of chemophobia in eight European countries (i.e., Switzerland, France, Germany, Austria, the United Kingdom, Italy, Poland, and Sweden). A large-scale survey was conducted, which involved the measurement of laypeople's knowledge of basic toxicological principles, trust in regulators, chemophobia, health concerns, and health-related worry. The results of the survey indicated the areas in which misconceptions regarding chemicals are prevalent. Regional differences in the determinants of chemophobia are discussed in light of their implications for communication between toxicologists and laypeople.

Chapter IV

In Chapter IV, the consequences of chemophobia in relation to the public's acceptance of chemicals and technologies was investigated. Two online between-subject experiments involving two Swiss convenience samples were conducted on the public's acceptance of pesticide use and biotechnology applications in the agriculture sector. In the first experiment, the public's acceptance of pesticide use, gene editing, and genetic transfer between same-species plants as crop protection measures was examined. The relationships between chemophobia, naturalness perceptions and the public's acceptance were compared across the crop protection measures. In the second experiment, the public's acceptance of biotechnology applications in agriculture was investigated in light of the different labels (e.g., gene editing, gene technology labels) used for the applications. This experiment allowed to highlight the influence of terminologies and process descriptions on the public's naturalness perceptions and acceptance of technologies. Implications of the findings of the two experiments for risk communication and policy-making in agriculture are discussed.

Chapter V

From Chapters II-IV, the need to address chemophobia was revealed. Therefore, in Chapter V, different risk communication strategies were compared in terms of their impacts on both chemophobia and people's preferences for natural chemicals in different consumer products. An online between-subject experiment was conducted on a convenience sample from the general Swiss population. Two important approaches were used, namely an informational approach that provided knowledge of basic toxicological principles and an affect-based approach that focused on the benefits of chemicals. The effects of the two approaches on the public's chemophobia, preferences for natural products, knowledge, benefit perceptions, and affect toward chemicals were compared. The results provided insights into the efficacy of the informational approach, which appeared to be a promising risk communication strategy for addressing chemophobia.

Chapter VI

In the final chapter, the findings of the present thesis are summarized and the main conclusions are drawn in light of the practical implications for both agricultural practices and risk communication. The strengths and limitations of the thesis are also discussed.

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Chapter II Chemophobia Today: Consumers’ Knowledge and perceptions of Chemicals

Manuscript published as:

Saleh, R., Bearth, A., & Siegrist, M. (2019). "Chemophobia" Today: Consumers' Knowledge and Perceptions of Chemicals. *Risk Analysis, 39 (12)*.

doi:10.1111/risa.13375

Abstract

This mixed-methods study investigated consumers' knowledge of chemicals in terms of basic principles of toxicology and then related this knowledge, in addition to other factors, to their fear of chemical substances (i.e., chemophobia). Both qualitative interviews and a large-scale online survey were conducted in the German-speaking part of Switzerland. A Mokken scale was developed to measure laypeople's toxicological knowledge. The results indicate that most laypeople are unaware of the similarities between natural and synthetic chemicals in terms of certain toxicological principles. Furthermore, their associations with the term "chemical substances" and the self-reported affect prompted by these associations are mostly negative. The results also suggest that knowledge of basic principles of toxicology, self-reported affect evoked by the term "chemical substances," risk-benefit perceptions concerning synthetic chemicals, and trust in regulation processes are all negatively associated with chemophobia, while general health concerns are positively related to chemophobia. Thus, to enhance informed consumer decision-making, it might be necessary to tackle the stigmatization of the term "chemical substances" as well as address and clarify prevalent misconceptions.

2.1. Introduction

Laypeople's perception of chemicals tend to be rather negative and are generally founded on misconceptions and fear (Kraus, Malmfors, & Slovic, 1992). In previous studies involving British and Canadian consumers, specific misconceptions were identified concerning the dose-response relationship, the exposure assessment, and the use of animal testing (Kraus et al., 1992; Neil, Malmfors, & Slovic, 1994; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997). Additionally, previous studies have shown that laypeople often perceive "natural" chemicals more positively, meaning that they are considered to be less risky when compared to synthetic chemicals (Hartmann, Hübner, & Siegrist, 2018; Rozin, Fischler, & Shields-Argeles, 2012; Rozin et al., 2004; Siegrist, Hübner, & Hartmann, 2018). Moreover, other studies have investigated consumers' risk perceptions concerning chemicals and their preferences for natural products, particularly chemicals found in food and household cleaning products (Bearth, Miesler, & Siegrist, 2017; Dickson-Spillmann, Siegrist, & Keller, 2011; Kraus et al., 1992). Furthermore, it has been suggested that chemophobia, which is defined as the irrational fear of chemicals, could fuel laypeople's negative perceptions of chemical-containing products and their fear of synthetic chemicals (Entine, 2011; Francl, 2013). This fear could lead to individuals rejecting certain beneficial innovations and products (e.g., vaccines) or even endanger themselves by disregarding other risks (e.g., eco-labelled cleaning products) (Bearth et al., 2017; Ropeik, 2012). However, there is currently a lack of research regarding chemophobia and its determinants (Entine, 2011; Michaelis, 1996). Thus, understanding factors that can reduce chemophobia might help address laypeople's negative perceptions and reactions to chemicals. Therefore, this study aims to extend upon prior research by investigating consumers' knowledge of natural and synthetic chemicals in terms of basic toxicological principles and then relating that knowledge to their attitudes toward these chemicals. Overall, the findings of this study could help communicators and regulatory bodies plan and implement risk management strategies and messages concerning the risks of chemicals by addressing laypeople's misconceptions and irrational fears of chemicals.

2.2. Theoretical background

2.2.1. Risk perceptions and affect

Laypeople's risk perceptions (e.g., concerning innovative technologies) are not solely based on facts, with affect having been shown to play an important role (Alhakami & Slovic, 1994; Finucane, Alhakami, Slovic, & Johnson, 2000; Slovic et al., 1997). The affect heuristic postulates that consumers' feelings regarding a given product drive their risk evaluations (Finucane et al., 2000; King & Slovic, 2014). Indeed, if consumers experience positive affect toward a certain hazard, they are inclined to judge its benefits as high and its risks as low and vice versa (Finucane et al., 2000; King & Slovic, 2014; Slovic, Finucane, Peters, & MacGregor, 2004).

The use of affect is both automatic and quick and can prove more efficient than analytical and cognitive evaluations (Finucane et al., 2000; Gigerenzer & Gaissmaier, 2011). However, relying on affect for decision-making does not necessarily produce decisions that are in the individual's best interests, and it might, in some cases, even lead to biased and dangerous behavior (Ropeik, 2011; Slovic, Finucane, Peters, & MacGregor, 2002; Slovic et al., 2004). For instance, some consumers could be influenced by irrelevant individual or environmental stimuli (Slovic et al., 2004; Slovic, Finucane, Peters, & MacGregor, 2007) that could fuel misconceptions and over- or under-estimations of a product's risks. Additionally, this could even lead to the inappropriate handling of certain consumer products (Wilkinson, Rowe, & Lambert, 2004). For products containing chemicals, consumers might regard irrelevant cues featured on a given product's labelling as indicators of its risk level. For example, eco-labelled cleaning products are generally perceived as being safer than conventional cleaning products, which might lead to individuals being less careful in terms of using these products (Bearth et al., 2017). This indicates that consumers might not always, or solely, refer to the textual and graphical safety information featured on the packaging of products when judging the risks associated with those products (Bearth et al., 2017; Hinks et al., 2009; Riley, Fischhoff, Small, & Fischbeck, 2001). Several individual factors (e.g., misconceptions, attitudes, etc.) and situational cues (e.g., packaging of consumer products, distractions, etc.) are thought to comprise part of the reason why consumers do not always comply with the instructions and safety information found on potentially dangerous chemical-containing products (Basso et al., 2014; Kovacs, Small, Davidson, & Fischhoff, 1997). Hence, to ensure the safe handling of consumer products, it is necessary to further understand laypeople's risk perceptions of chemicals as well as how such perceptions are formed.

2.2.2. Knowledge and trust

Research has shown that a significant proportion of laypeople associate even minor doses of, and exposure to, toxic chemicals with the almost certain likelihood of harm (Mertz, Slovic, & Purchase, 1998; Slovic et al., 1995), causing them to view chemicals as either safe or dangerous. Hence, consumers frequently express high levels of concern about the use of chemicals as well as a desire to reduce the risks associated with chemicals at any cost (Dickson-Spillmann et al., 2011; Kraus et al., 1992; Slovic et al., 1995). This dose-response insensitivity might influence consumer risk perceptions while also causing overreactions to stories featured in the media that lead to taking inappropriate actions (Wilkinson et al., 2004). When laypeople's concerns arise from a comparably minor risk, the risk management authorities will still have to respond and manage that risk, which could lead to detrimental societal and economic impacts such as increased public distrust of authorities and the wasting of financial resources (Monro, 2001; Ropeik, 2012). In fact, public distrust of the authorities managing the chemical risks might also hold implications for peoples' risk perceptions of these chemicals. When people do not possess sufficient technical knowledge for judging a certain risk, their trust in risk regulation bodies often guides their judgements and decisions instead (Earle & Cvetkovich, 1995; Siegrist, Connor, & Keller, 2012; Siegrist & Cvetkovich, 2000). If they trust these regulators, they are less concerned and less prone to overreact to chemicals because they believe the risk regulators do their work appropriately and provide accurate assessments (Ropeik, 2011; Siegrist & Cvetkovich, 2000). Nevertheless, if consumers become familiarized with the dose-response principle, their knowledge regarding chemicals might enhance, and limit their negative perceptions and overreactions to chemicals (Dickson-Spillmann et al., 2011). In fact, a greater understanding of the risk assessment process is associated with a lower risk perception of chemicals, particularly in the case of synthetic chemicals (Dickson-Spillmann et al., 2011; Kraus et al., 1992; Shim et al., 2011). Consequently, consumers probably require a basic knowledge of chemical and toxicology principles to enable them to make fact-based decisions regarding chemical-containing products (Bearth, Cousin, & Siegrist, 2016; Dickson-Spillmann et al., 2011; Dickson-Spillmann, Siegrist, Keller, & Wormuth, 2009; Kraus et al., 1992; Shim et al., 2011)

2.2.3. Chemophobia

When consumers express concerns about the chemicals used in consumer products, they may avoid or reduce their exposure, especially to synthetic chemicals such as artificial additives in food (Bearth, Cousin, & Siegrist, 2014; Dickson-Spillmann et al., 2011). Concerned consumers primarily associate chemicals with death, cancer, and toxicity and tend to be afraid of chemicals. This irrational fear has been called "chemophobia" (Entine, 2011; Ropeik, 2015; Rozin et al., 2004). On the one hand, chemophobia might cause people to avoid chemical-containing products that could actually prove beneficial (e.g., medication) or support groups that advocate for the removal of different chemicals from the market without considering the scientific evidence regarding those chemicals' safety (Entine, 2011). On the other hand, consumers might neglect the risks associated with chemicals of a natural origin due to perceiving them as being less threatening than synthetic chemicals (Ropeik, 2012; Rozin et al., 2012; Rozin et al., 2004). For example, consumers might endanger themselves via the less vigilant use of products with chemicals of a natural origin, such as natural personal care products, because they perceive such products to be free of hazardous substances (Hartmann & Klaschka, 2017). Hence, it might prove useful to address chemophobia in risk communications to limit its consequences and ensure informed consumer decision-making regarding chemicals.

2.2.4. Study aims

Previous studies have assessed laypeople's attitudes via knowledge questions related to their perceptions of toxicology principles (Kraus et al., 1992; Neil et al., 1994; Slovic et al., 1995). The present mixed-methods study aimed to extend upon prior research by investigating consumer knowledge of chemicals in relation to basic toxicology principles and chemophobia. Thus, the first objective of the study was to develop a scale that measures peoples' knowledge of basic toxicological principles. The second objective was to explore peoples' associations and affect evoked by natural and synthetic chemicals. The third objective was to determine how chemophobia is associated with knowledge, affect toward chemicals, risk-benefit perceptions of synthetic chemicals, trust in the regulation of consumer products, and general health concerns.

2.3. Methods

2.3.1. The Mental Models Approach

The Mental Models Approach offers a method to investigate laypeople's mental models regarding a certain risk, aimed at including their views in the development of risk communications (Morgan, Fischhoff, & Bostrom, 2002). It is comprised of five consecutive steps. In this study, only the first three steps in the MMA were followed to gather insights into laypeople's perceptions and knowledge of the risks of chemicals and experts' risk assessments. Furthermore, the first two steps of this method are qualitative, whereas the third step is quantitative.

First, in-depth, qualitative, semi-structured interviews were conducted with experts. This step was intended to gather information regarding the current practices of chemical risk assessment, the regulation process, and the principles of toxicology. In total, six experts were recruited and interviewed individually; three of whom were from governmental regulatory offices, one was a toxicologist working for an advisory and educational organization, another one was a toxicologist working in the chemical industry, and one was an expert from a poison prevention and emergency center. Second, ten consumers with different educational and vocational backgrounds were recruited (24–63 years old, 40% male) from Switzerland via convenience and snowball sampling. The aim of this step was to explore laypeople's perceptions and knowledge concerning toxicology principles and steps for the risk assessment and regulation of chemicals. This revealed potential misconceptions and gaps in the knowledge of laypeople in comparison to the experts. The interviews began with general, open-ended questions and shifted to more focused questions regarding chemicals in order to limit bias the responses of the interviewees. At the beginning of the interview, interviewees were asked about their first thoughts upon hearing the word "chemical substances". Then, they were shown pictures of different consumer products that are commonly found in households (e.g., cleaning products, medicine) and asked about their experiences, attitudes, and risk-benefit perceptions of these products (e.g., how beneficial these products are, which products they believe are the most and least harmful ones, etc.). The interviews continued with questions about how the interviewees assume the risk assessment and risk management processes for these products are performed. Moreover, the interviewees' trust in the regulation authorities, preferences, and safe handling practices of chemical-containing products were also discussed. Interviewees indicated factors (e.g., purpose of the consumer products, packaging of the products) that shape their judgements concerning the dangerousness of the products. Whether the product contains natural or synthetic chemicals was one of the most prominent factor interviewees discussed. They expressed more favorable perceptions of products with natural chemicals than with synthetic ones. Additionally, they had little to no knowledge regarding chemical risk assessment and regulation processes. The interviews lasted 60 minutes on average and were recorded to ensure accuracy during the transcription process. Third, the interview findings served as the basis for the design and development of the questionnaire used in the quantitative study, which was intended to provide information regarding the representativeness of the insights gained from the qualitative interviews (Morgan et al., 2002).

2.3.2. Quantitative study: Sample

For the quantitative step, an online survey was conducted via a consumer panel provided by a market research company in June 2018 in the German-speaking part of Switzerland. Respondents were not informed of the survey topic in the participation invitation and were compensated with a small financial incentive. Quota sampling was applied to ensure a balanced ratio of male to female respondents and age distributions. There was a total of 663 respondents to the survey. 74 respondents with missing values were excluded from the analyses. Additional 43 respondents were excluded due to their participation duration being too short (half the median) which could have increased their likelihood of potentially giving biased responses. The final sample was comprised of 546 respondents (52.7% females, M_{age} = 45 years, SD_{age} = 14, range: 18–70 years old). Furthermore, the sample was comparable to the general Swiss population in terms of both gender and age (50.4% females, M_{age} = 42 years) (Swiss Federal Statistical Office, 2017b). The respondents' self-reported education levels ranged between mandatory school, basic apprenticeship, prevocational school, or apprenticeship (45.6%), to high school or technical and vocational training (29.9%), and university (24.5%). The reported education levels were slightly higher than that of the general Swiss population (Swiss Federal Statistical Office, 2017a). Moreover, a total of 15 (2.7%) respondents worked in a chemical-related field (e.g., toxicology, chemical regulation).

2.3.3. Quantitative study: Materials

The survey questionnaire was divided into two sections. The first section was comprised of items intended to address the respondents' associations with the term "chemical substances", their affective responses, their knowledge of basic toxicology principles of, and their trust in the regulation of chemical-containing products. Furthermore, in the first section, respondents also answered questions about their risk perceptions, general health concerns, and chemophobia. Tables 2 and 3 and Figure 2 present all items included in the first section. In the second section of the survey, the respondents answered more specific questions regarding their preferences in terms of chemicals used in consumer products. The results of the second part of the survey are not discussed in the present paper. Finally, at the end of the survey, respondents answered sociodemographic questions (i.e., age, gender, level of education, profession), and were provided with information regarding the principles of toxicology and the regulation of chemicals to ensure their perceptions were not negatively affected by the content of the survey.

Table 2. Trust in the regulation of consumer products and synthetic chemicals' risk-benefit perceptions: Items-total correlations, items means (*M*), standard deviations (*SD*) and scales' Cronbach's alpha (α).

		Item-total correlation	M (SD)
	Trust in the regulation of consumer products**		**3.81(1.15)**
	How much trust do you have in the current regulation that monitors the safety of consumer products with chemical substances in Switzerland?		
	Synthetic chemicals' risk-benefit perceptions* (α = .74)		**3.11 (0.97)**
1	I believe that the benefits of synthetic chemical substances in consumer products outweigh the potential risks they pose for the environment.	.47	2.82 (1.29)
2	I believe that the use of synthetic chemical substances in consumer products is associated with greater benefits than health risks.	.56	3.00 (1.29)
3	I believe that the environmental risks associated with synthetic chemical substances in consumer products are more significant than the benefits for the consumers. (r)	.54	3.22 (1.31)
4	I believe that the health risks of synthetic chemical substances in consumer products outweigh their benefits. (r)	.54	3.39 (1.31)

* all scale items responses were within the range from 1 (strongly disagree) to 6 (strongly agree)
** item response was within the range from 1 (extremely low) to 6 (extremely high)
(r) indicates a reverse coded item

Table 3. General health concern and chemophobia: Items-total correlations, items means (*M*), standard deviations (*SD*) and scales' Cronbach's alpha (α).

		Item-total correlation	M (SD)
	General health concern* (α = .74)		**3.60 (0.97)**
1	Developing a chronic disease concerns me a lot.	.66	2.88 (1.42)
2	I worry a lot about getting a serious disease (e.g., cancer).	.64	3.12 (1.48)
3	I am very concerned about my health.	.65	3.58 (1.41)
4	I protect myself as much as possible from getting even slightly sick.	.29	3.83 (1.30)
5	I never worry about my health. (r)	.29	4.59 (1.32)
	Chemophobia* (α = .88)		**3.15 (1.19)**
1	I believe that chemical substances are the main reason why people suffer from cancer.	.72	2.90 (1.44)
2	I do everything I can to avoid in my daily life contact with chemical substances.	.71	3.08 (1.48)
3	I would like to live in a world where chemical substances don't exist.	.73	3.13 (1.58)
4	Chemical substances scare me.	.73	3.27 (1.39)
5	I believe that chemical substances are the reason for most environmental problems.	.65	3.39 (1.41)

* all scale items responses were within the range from 1 (strongly disagree) to 6 (strongly agree)
(r) indicates a reverse coded item

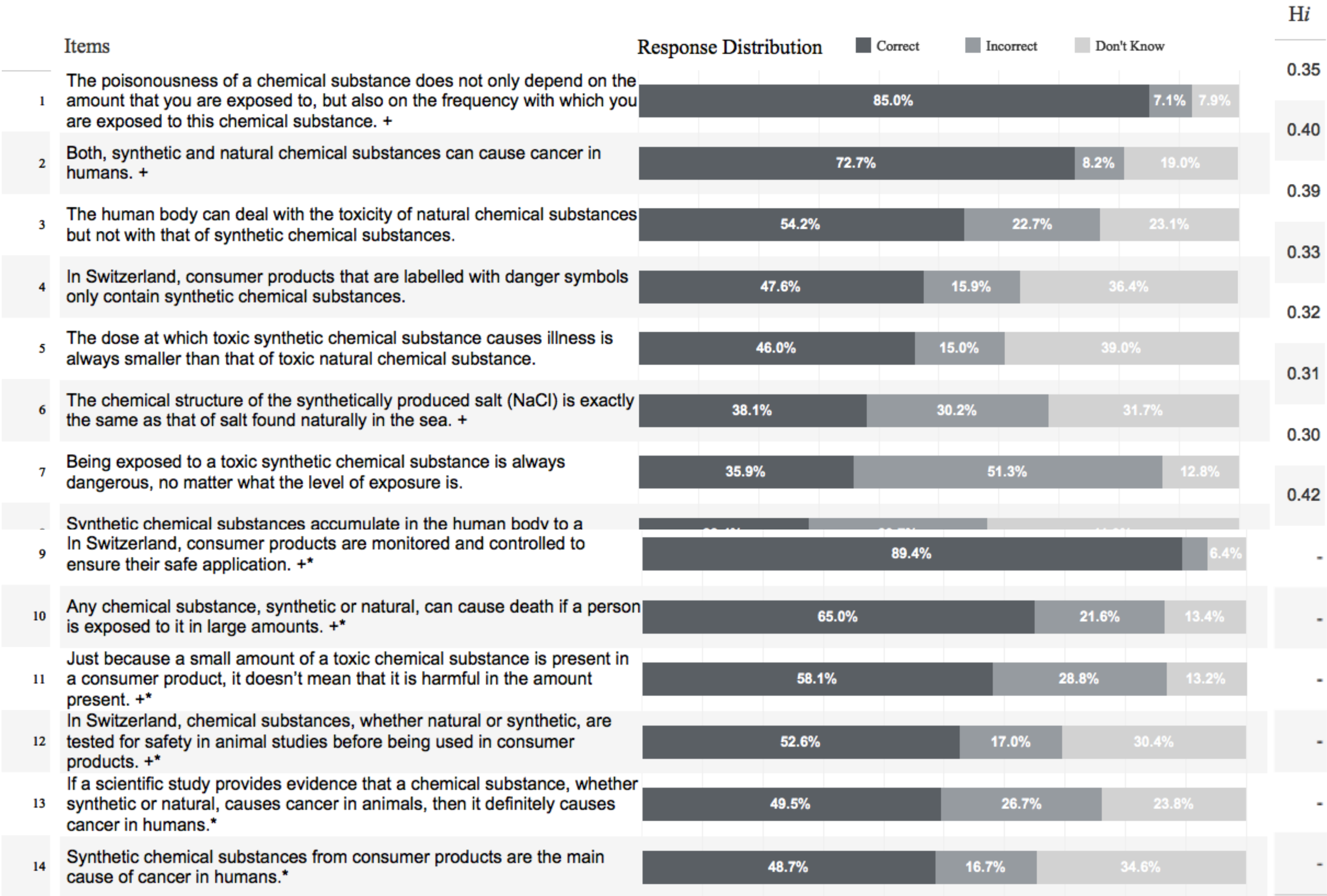

Figure 2. Knowledge of basic toxicological principles and regulation of chemicals: Response distribution nd Mokken scale scalability coefficients for each item (H*i*).

N = 546; Scalability coefficient of the whole scale H = 0.35 (SE = 0.02); Reliability of the Mokken scale Rho = 0.72. (+): items with a true statement. (*): items that are not part of the Mokken scale.

2.3.3.1. Free associations and affect

The free associations technique allows for the assessment of spontaneous subjective meanings that are associated with a given stimulus (Peters & Slovic, 1996; Slovic, Flynn, & Layman, 1991). First, respondents were asked to indicate the first two words, terms, or thoughts that came to mind when they heard the term “chemical substances.” They were then instructed to evaluate the feelings evoked by each association using a slider scale ranging between “extremely negative” (0), “neutral” (50), and “extremely positive” (100). Next, respondents were asked to read the following definitions of synthetic and natural chemical substances:

> ***Natural chemical substances*** *occur in nature, or are produced by plants and animals, without any human involvement, such as* <u>*vitamin C*</u> *(ascorbic acid), which is found in oranges.*
> ***Synthetic chemical substances*** *are made by humans to serve particular purposes. These chemical structures may or may not be found in nature, too. For example,* <u>*vitamin C*</u> *(ascorbic acid) can also be manufactured from glucose, while* <u>*Teflon*</u>*, which is used in non-stick pans, is man-made and cannot be found in nature.*
> ***Both synthetic and natural chemical substances*** *are used in a wide range of consumer products, including cleaning products, medicine, clothes, and cosmetics, to give these products certain desired features (e.g., colors, smell) and functions (e.g., waterproofing, disinfectant).*

The respondents were then asked to separately indicate their affective responses to synthetic and natural chemical substances on a slider scale ranging between “extremely negative” (0), “neutral” (50), and “extremely positive” (100).

2.3.3.2. Knowledge of basic toxicological principles and regulation of chemicals

The respondents’ knowledge of basic toxicological principles and regulation was measured using 14 statements (cf. Figure 2). Statements 4 and 9 measured regulation-related knowledge, while the remaining statements were related to aspects of toxicology and its principles. The latter included comparisons between natural and synthetic chemicals in terms of specific toxicological principles (e.g., dose-response, exposure scenarios, etc.) that act as the basis for the chemical risk assessment process. The items consisted of seven correct and seven incorrect statements and were based on a literature review and the interviews with both experts and laypeople. Only item 13 was adapted from the work of Kraus et al. (1992). All items varied according to their level of difficulty and were presented in a randomized order. The respondents were able to respond to each item with “correct,” “false,” or “do not know.”

2.3.3.3.Chemophobia, general health concerns, risk-benefit perceptions of synthetic chemicals, and trust in the regulation of consumer products

The respondents’ chemophobia, general health concerns (cf. Table 3), and risk-benefit perceptions of synthetic chemicals (cf. Table 2) were assessed via a six-point Likert scale (1 = strongly disagree, 6 = strongly agree). Furthermore, items 2 and 3 were adapted from the studies of Kraus et. al (1992) and Dickson-Spillman et. al (2011), respectively, to measure respondent chemophobia. The remaining items were formulated based on both a literature review and the findings of the qualitative interviews. For each of the investigated constructs, a scale was built by taking the mean value over the values of all items included in that construct. The chemophobia scale (five items) had a good Cronbach’s alpha of $\alpha = 0.88$, while the general health concerns scale (five items) and the risk-benefit perceptions scale (four items) each had a moderate Cronbach’s alpha of $\alpha = 0.74$. Respondents’ trust in the regulation of consumer products in Switzerland was assessed with one item (cf. Table 2) using a six-point Likert scale (1 = extremely low, 6 = extremely high). The item-total correlation, mean, and standard deviation for all items included in the above-mentioned scales are presented in Tables 2 and 3.

2.3.4. Quantitative study: Data analysis

To explore the associations evoked by and the affect associated with the term “chemical substances”, a correspondence analysis (CA) was conducted (Weller & Romney, 1990). Before being submitted to a CA, data is prepared in a two-way contingency table, which then the CA analyzes and reduces its complexity (Greenacre, 2010; Sourial et al., 2010). Next, CA provides factor scores for each category in the rows and columns of the contingency table. These scores are used as coordinates to visualize the rows and columns’ categories as points in a low-dimensional graphical map. The more similar the scores of the categories, the closer the points are to each other. Correspondingly, categories with different scores are represented by more distanced points (Clausen, 1998). Hence, the distance between points reflects the associations between the row and column variables.

A Mokken scale analysis (MSA) was used to scale respondent knowledge of basic toxicological principles. This scaling procedure considers item difficulty and is more suited to analyzing knowledge items than the classical test theory. The latter assumes that all items of a given scale will have similar distributions, thereby disregarding the different levels of knowledge individuals possess, which renders it unsuited to scaling knowledge items (van Schuur, 2003). MSA is a nonparametric, probabilistic version of the Guttman scaling process (van Schuur, 2003) and . It assumes that if an individual responds correctly to a difficult item, then that individual is more likely to respond correctly to the easier items of the scale (van Schuur, 2003). The scale is based on the assumption that each respondent’s probability of answering items correctly depends on both the item’s difficulty and the respondent’s knowledge (Molenaar & Sijtsma, 2000). The respondents are ranked according to their abilities, while the items are ordered according to their difficulty levels (Mokken & Lewis, 1982; Molenaar & Sijtsma, 2000). The degree of accuracy in terms of ordering respondents by the scales can be assessed using Loevinger’s coefficient H (Molenaar & Sijtsma, 2000). Hence, the coefficient H is an important indicator of the goodness of the formed Mokken scale, with H = .3–.4 suggesting a weak scale, and H = .5–1, suggesting a strong scale. The reliability of the Mokken scale is assessed with the Rho, which should be above .70. Additionally, the scalability coefficients for each individual item should be H*i* > .3. The knowledge items were recoded as 1 for correct responses and 0 for incorrect and "do not know" responses. The analysis was run on R version 1.1.456 using the Mokken package (van der Ark, 2007). Finally, to produce a knowledge score for each respondent, the correct responses to the Mokken scale items were summed. A high score indicated more knowledge, while a low score indicated less knowledge.

A regression analysis was conducted with chemophobia as the dependent variable. The following variables were used as independent variables: sociodemographic variables, respondent scores regarding their knowledge of basic toxicological principles, overall affect toward "chemical substances", trust in the regulation of consumer products, risk-benefit perceptions of synthetic chemicals, and general health concerns. The regression analyses and CA were conducted using SPSS version 25.0 (IBM Corp., 2017)

2.4.Results

2.4.1. Associations and affect

2.4.1.1.Free associations' content and affective ratings

The respondents were asked to provide two associations related to the term "chemical substances," which resulted in a total of 1092 associations. Approximately, 507 first associations and 492 second associations were considered meaningful and were assigned to one of the 18 categories listed in Table 4. The associations given by the respondents were originally in German and then translated into English. The English and German versions of the associations were coded via two independent coders. Moreover, the inter-rater reliability

(Cohen's kappa) was κ = .82. Disparities in the coding between the two raters generally occurred in relation to infrequent and non-meaningful associations and were all resolved by the first author. In terms of the first associations, the most prevalent categories were "science," "toxic," and "specific chemicals." Only the affective evaluations of the most prevalent associations (i.e., mentioned at least 60 times) are presented. The affective rating for "science" was approximately the midpoint (M = 54.39 [SD = 19.72]), whereas the affective rating for "toxic" was much more negative (M = 19.10 [SD = 15.56]), and the affective rating for "specific chemicals" was negative (M = 41.97 [SD = 26.54]). These three associations were also found to be dominant among the second associations (cf. Table 4). Additionally, "synthetic," "unnatural," "health danger," and "environmental danger" were relatively prevalent associations. It should be noted that only a minority of respondents associated chemical substances with benefits or a positive affective rating. The respondents also associated chemical substances with specific consumer products (i.e., medication, food, personal care products, cleaning products, and illegal drugs).

Table 4. Frequencies and examples of the main categories of respondents' associations with the term "Chemical Substances".

Main categories (examples of respondents' associations)	**Frequency of the first associations**	**Percent**	**Frequency of the second associations**	**Percent**
Science (e.g., chemistry, laboratory, experiments)	151	27.7	127	23.3
Toxic (e.g., poison, dangerous, death)	122	22.3	118	21.6
Specific chemicals (e.g., chlorine, oxygen, sulfur)	69	12.6	39	7.1
Medications (e.g., tablets, medications, pills)	44	8.1	42	7.7
Synthetic (e.g., synthetic)	24	4.4	20	3.7
Unnatural (e.g., unnatural)	17	3.1	13	2.4
Health danger (e.g., unhealthy, impairment to health)	16	2.9	32	5.9
Cleaning products (e.g., detergent, to clean)	15	2.7	4	0.7
Food (e.g., unwanted additives in food, eat, sweetener)	14	2.6	24	4.4
Illegal drugs (e.g., doping, ecstasy)	13	2.4	7	1.3
Chemical disasters (e.g., spillage, weapon, explosion)	6	1.1	14	2.6
Environment danger (e.g., pollution, ecological damage)	4	0.7	22	4.0
Personal care products (e.g., cosmetics, perfume)	4	0.7	3	0.5
Industry (e.g., chemical production, industry waste)	3	0.5	10	1.8
Natural (e.g., nature, natural)	3	0.5	1	0.2
Agriculture (e.g., fertilizers, pesticides, insect repellents)	1	0.2	12	2.2
Benefits (e.g., huge potential, endless opportunities)	1	0.2	4	0.7
Non-applicable*	39	7.2	54	9.9
Total	507	100.0	492	100.0

(*) indicates that these associations were not included in the analysis for their non-applicability or nonsensical meanings.

The respondents' affective ratings of the first associations with the term "chemical substances" were negative (M = 38.43 [SD = 25.02]). Moreover, respondents also reported negative affect in relation to the second associations (M = 36.75 [SD = 26.27]). The overall affect reported for all associations (i.e., both the first and second associations) was negative (M = 37.85 [SD = 22.26]) and had an acceptable Cronbach's alpha of $\alpha = .64$. The respondents' affective rating of the two sets of associations differed significantly from the scale's midpoint (50) based on a one-sample t-test, $t(522) = -12.46$, $p < .001$. Moreover, their affective reactions to "synthetic chemical substances" were negative, with M = 42.79 (SD = 17.41), whereas their affective reactions to "natural chemical substances" were positive, with M = 67.30 (SD = 19.40).

2.4.1.2.Correspondence analysis

The CA was only applied to the first set of associations to emphasize the first associations and minimize bias stemming from potential random fillings for the second associations. Only associations with $n > 10$ were included. Gender was also taken into account in this analysis, since women were found to be more concerned about chemicals than men (Kraus et al., 1992; Mertz et al., 1998). Hence, a two-way contingency table consisting of the first association as the column category (ten columns) and gender (female, male) combined with affective reaction to the association (1 = [0–45] as negative, 2 = [46–54] as neutral, 3 = [55–100] as positive) as the row category (six rows) was submitted for a CA. The overall chi-squared value was $\chi^2(45) = 217.66$, $p < .001$, while the total inertia was $\lambda G = 0.45$. The results of the CA showed that the first dimension explained 80% of variance, while the second dimension explained 9%. Moreover, the third dimension explained less than 5% of the variance and, therefore, a two-dimensional solution was used for the interpretation. Figure 3 presents a graphical display of the CA output.

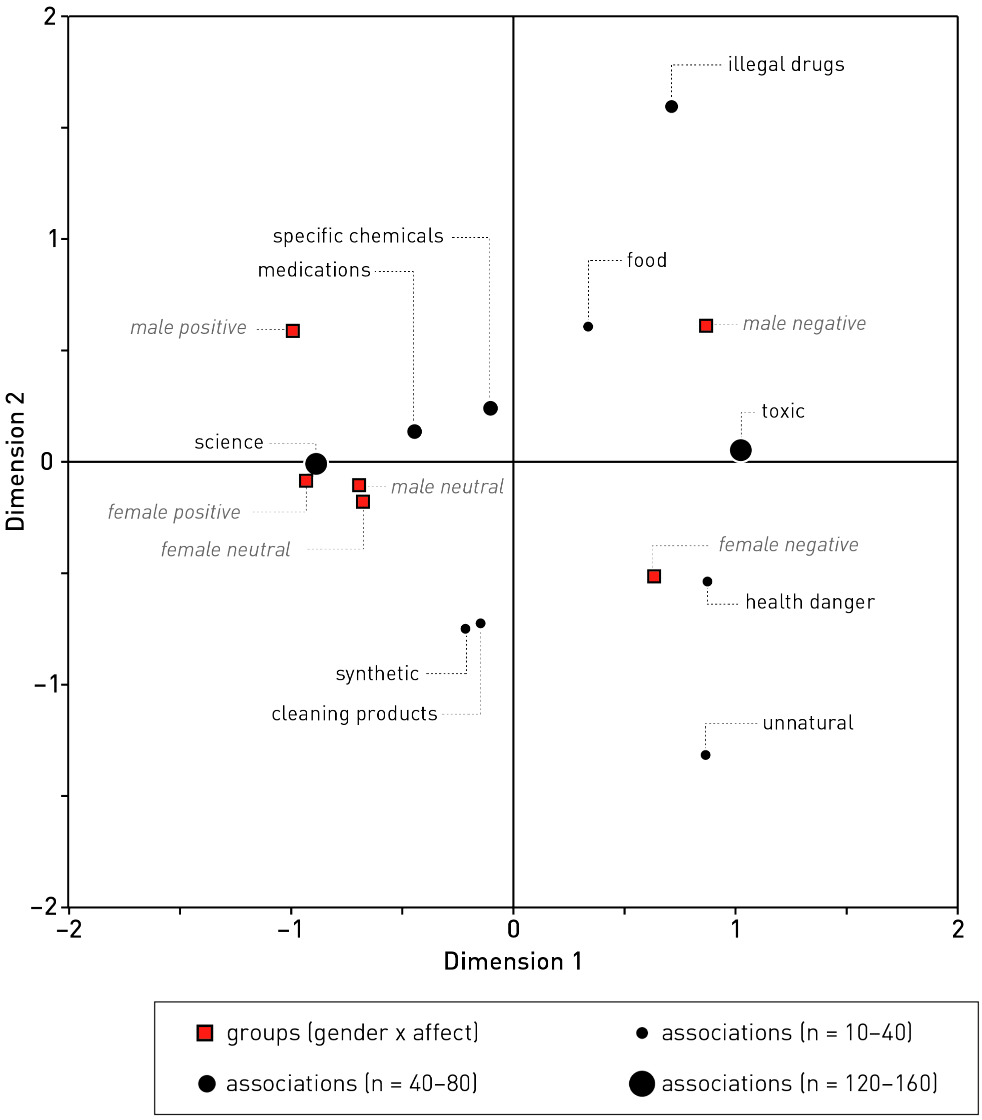

Figure 3. Content of the first free associations given by respondents (N = 485) to the term "chemical substances", in relation to gender and affect analyzed by correspondence analysis.

The first dimension illustrates the differences between the content of the associations in relation to the respondents' affective responses. The respondents with positive affect mentioned similar associations to the respondents with neutral affect. These associations were often related to "science," "specific chemicals," and "medication." In contrast, the respondents with negative affect mainly expressed associations related to "toxic," "health danger," "food," “unnatural,” and “illegal drugs.” The second dimension illustrates the differences between the female and male respondents. Both females and males mentioned “science,” “medication,” “specific chemicals,” and “toxic”; however, female respondents associated “health danger,” “unnatural,” “cleaning products,” and “synthetic” with “chemical substances”, whereas male respondents more often associated “illegal drugs” and “food.”

2.4.2. Knowledge of basic toxicological principles and regulation of chemicals

The response distributions of the 14 knowledge items are presented in Figure 2, differ according to difficulty, and differentiate between those with high and low levels of knowledge. The easiest items were related to the regulation of the use of chemicals in consumer products, with the harmfulness of chemicals depending on amount and frequent exposure levels. These items had the highest correct response rates (≥ 85%). The item regarding the deadliness of exposure to large doses of any chemical substance also had a relatively high correct response rate. However, the correct response rates of the items related to the dangerousness of small doses of chemicals in consumer products and the labelling of potentially dangerous products were relatively low (< 60%). Similarly, the correct response rate of the item regarding the role of animal testing in assessing the safety of chemicals was low. Items concerned with the chemical structure and toxicity of synthetic and natural chemicals (considering doses, exposure levels, and the ability of the human body to protect itself) had lower correct response rates (between 35% and 55%). The most difficult item referred to the accumulation of synthetic and natural chemicals in the human body and had the lowest correct response rate (< 30%).

One item (item 9) (cf. Figure 2) concerned peoples’ trust in Swiss regulatory bodies. To ensure the knowledge scale would only contain objective and knowledge-centric items, item 9 was excluded from the MSA. Hence, the MSA was run only with the remaining 13 items. Overall, it revealed that five of the items were unscalable and, therefore, were not included in the

Mokken scale. So, the final Mokken scale included eight items regarding natural and synthetic chemicals and basic toxicological principles (cf. Figure 2) while exhibiting an adequate scalability coefficient of H = .35 and a reliability of Rho = .73, which indicates a reliable, one-dimensional scale. The scalability coefficients for the individual items of the Mokken scale are shown in Figure 2. Furthermore, the mean knowledge score for all respondents was M = 4.08 (SD = 2.13) (range: 0–8, with 8 being the highest score, indicating high knowledge).

2.4.3. Regression analysis on chemophobia

Table 5 shows the correlation between respondents' chemophobia and their knowledge of basic toxicological principles, their overall affect toward "chemical substances," their trust in the regulation of consumer products, their risk-benefit perceptions of synthetic chemicals, and their general health concerns. All variables were found to be significantly correlated, although the strongest correlations were found in regard to chemophobia. Furthermore, there was a negative correlation between chemophobia and overall respondent affect toward "chemical substances" ($r = -.35$, $p < .001$, $N = 523$) and their risk-benefit perceptions of synthetic chemicals ($r = -.38$, $p < .001$, $N = 546$). Respondent knowledge of basic toxicological principles also exhibited a negative correlation with chemophobia ($r = -.36$, $p < .001$, $N = 546$). Moreover, knowledge exhibited a positive correlation with overall affect toward "chemical substances" ($r = .14$, $p < .01$, $N = 523$). However, this correlation was weak and similar to most of the correlations occurring between the independent variables.

Table 5. Pearson's correlations between chemophobia, overall affect towards "chemical substances", knowledge of toxicological principles, trust in consumer products' regulation, risk-benefit perceptions of synthetic chemicals and general health concern.

Variables	1	2	3	4	5
1. Chemophobia	-				
2. Overall affect towards "chemical substances" (N = 523)	-.35***	-			
3. Knowledge of toxicological principles	-.36***	.14**	-		
4. Trust in consumer products' regulation	-.29***	.20***	.19***	-	
5. Synthetic chemicals' risk-benefit perceptions	-.38***	.27***	.11**	.42***	-
6. General health concern	.44***	-.17***	-.13**	-.09*	-.19***

* p<.05, ** p<.01, *** p<.001
N = 546 (unless indicated otherwise)

Table 6 presents the results of the multiple regression analysis for respondent chemophobia. The model was found to be significant with $F (9,513) = 39.80$, $p < .001$ and explained 40% of the variance, with respondent knowledge of basic toxicological principles being negatively related to chemophobia. Respondent risk-benefit perceptions of synthetic chemicals, overall affect toward "chemical substances," and trust in the regulation of consumer products all displayed statistically significant negative relationships with chemophobia, whereas their general health concerns displayed a positive relationship with chemophobia. Furthermore, both gender and age had a significantly positive relationship with chemophobia, albeit a less important one compared to the above-mentioned factors. The respondents' education level was not significant.

Table 6. Regression analysis on respondents' chemophobia (N=523).

Independent variables	*B (se)*	*t*	*β*
Constant	3.16 (0.32)	10.04	
Gender (b)	0.18 (0.08)	2.10	.07*
Age	0.01 (0.00)	2.34	.08*
Low education (b)	0.08 (0.11)	0.73	.03
Medium education (b)	0.09 (0.11)	0.77	.03
Overall affect towards "chemical substances"	-0.01 (0.00)	-5.25	-.19***
Knowledge of toxicological principles	-0.13 (0.02)	-6.03	-.22***
Trust in consumer products' regulation	-0.10 (0.04)	-2.47	-.09*
Risk-benefit perceptions of synthetic chemicals	-0.22 (0.05)	-4.59	-.18***
General health concern	0.41 (0.04)	9.53	.33***

R^2 = 0.41, adjusted R^2 = 0.40
(b): indicates a binary variable. Gender (1 = female, 0 = male), Low education (1 = low level, 0 = high level), Medium education (1 = medium level, 0 = high level)
* p<.05, ** p<.01, *** p<.

2.5. Discussion and implications

One of the key goals of the present study was to develop a scale for measuring people's knowledge of basic toxicological principles. Applying the Mental Models Approach (Morgan et al., 2002) allowed for considering both expert knowledge and a broad range of laypeople's perceptions of the topic. Eight items measuring laypeople's knowledge of natural and synthetic chemicals in terms of basic toxicological principles formed a reliable Mokken scale. This provided a strong indication that the proposed scale is one-dimensional and reliable. The knowledge items were formulated based on qualitative interviews conducted in Switzerland; however, the items were not specific to Switzerland. Therefore, the scale may also be used to explore cultural differences.

A number of prevalent misconceptions among laypeople regarding both natural and synthetic chemicals were identified, including dose-response insensitivity and the underestimation of the toxicity of chemicals of natural origin. The insensitivity to dose-response relationships and exposure scenarios was also identified in previous research (Bearth et al., 2016; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Slovic et al., 1997). Rather than a dose-response function, laypeople tend to perceive a causal relationship between exposure to a chemical and inevitable consequences, especially in the case of chemicals associated with carcinogenicity (MacGregor, Slovic, & Malmfors, 1999). Furthermore, laypeople seem to consider the origin of a chemical (natural vs. synthetic) to be an indicator of its toxicity. Chemicals of a natural origin are considered to be healthier and safer than synthetic ones, since the latter involve human intervention and processing, which in turn negatively influences laypeople's perceptions of synthetic entities (Rozin, 2005; Rozin et al., 2004).

An inspection of the response distributions for the knowledge items and the revealed misconceptions suggests that the respondents were not familiar with the similarities between natural and synthetic chemicals in terms of basic toxicological principles. They might have been relying on their affect and associative imagery rather than referring to factual information in order to weigh the risks and benefits of synthetic and natural chemicals. Moreover, the experts do not differentiate between chemical substances of natural or synthetic origin. The laypeople, however, reported similar levels of negative affect regarding the terms “chemical substances” and “synthetic chemical substances,” while the term “natural chemical substances” was associated with a more positive affect. Respondents frequently mentioned risky associations (e.g., poison, death, dangerous), whereas only a small minority of them associated “chemical substances” with benefits. Hence, it appears that the advancements brought about by the synthesis of chemical substances might not be salient in laypeople’s minds. This could largely be explained by the different use of the terms “chemical substances” and “natural vs. synthetic” in everyday speech and in scientific language.

The negative relationship identified between knowledge and chemophobia indicates that a better understanding of (natural and synthetic) chemicals and the basic toxicological principles tends to mean laypeople are less afraid of chemicals. Previous research has shown that knowledge provision can influence people’s opinions and attitudes (Bearth et al., 2016; Gaskell, 1998; Shim et al., 2011). However, as is the case in other areas of risk research, the “knowledge deficit model” falls short when attempting to tackle chemophobia (Hansen, Holm, Frewer, Robinson, & Sandoe, 2003). Communication efforts have been undertaken, for example, the European Chemicals Agency’s (ECHA’s) website about chemicals in everyday life (e.g., chemicals in clothes and textiles, in personal care products), with the aim of improving people’s understanding and knowledge. However, laypeople’s resources are limited and, therefore, a lack of time or motivational, or other resource conflicts, might prevent them from seeking and processing complex information. It might prove more important to reduce the stigma associated with the terminology, as well as to clarify the differences between laypeople's and experts' use of the terms "chemical substance," "natural," and "synthetic." Furthermore, the advancements brought about by the inclusion of "chemical substances" in consumer products, medicine, or other beneficial applications should be rendered more salient in order to improve acceptance and informed decision-making. Prior studies have shown that communicating the benefits associated with a given technology or product may improve people's level of acceptance or promote more positive perceptions toward that technology or product (Bearth & Siegrist, 2016; Ueland, 2012). Mitigating chemophobia and its negative consequences on consumers could ensure peoples' informed decision-making. One possible approach to reduce chemophobia could be to stress the implications of the substitution of certain chemical substances with their counterparts of natural origin (e.g., a reduced range of products, higher costs, unknown risks due to impurities, medicine shortages). Moreover, people's trust in the communication agent represents a vital factor in relation to their acceptance of the communicated message (Breakwell, 2000; Siegrist, 2008). Thus, it is not only relevant to consider from whom the information originates, but also to understand what builds and destroys trust and then to implement measures accordingly.

A major limitation of this study is the fact that, due to its cross-sectional design, caution is warranted when stating the causal relationships. Future research should therefore attempt to test the directionality and strength of the relationships using longitudinal designs. For instance, changes in knowledge, perception, and chemophobia could be measured using the developed scale both pre- and post-information provision. Furthermore, there might be additional factors related to chemophobia that were not included in this study. There is evidence concerning the importance of worldviews (e.g., technological enthusiasm, economic growth, egalitarianism) in determining individuals' risk perceptions (Mertz et al., 1998; Slovic et al., 1995). Additionally, situational factors (e.g., labels, advertisements) (Basso et al., 2014) might also influence people's risk perceptions of chemicals and their chemophobia. Future studies should investigate the relationships between these factors and chemophobia in order to develop a better understanding of the factors that shape chemophobia and inhibit informed decision making. Lastly, the study was conducted in the German-speaking part of Switzerland and, therefore, the findings may not be generalizable to other cultural contexts. For instance, the public's views on chemicals in the French-speaking part of Switzerland might differ from the German-speaking part, since there is divergence in the socio-political orientations between the two parts of Switzerland (Eugster, Lalive, Steinhauer, & Zweimuller, 2011). This study should also be conducted in other countries to compare the findings regarding people's misconceptions and chemophobia.

2.6.Conclusion

In summary, this mixed-methods study contributes in several ways to the understanding of laypeople's perceptions of natural and synthetic chemicals in terms of basic toxicological principles. First, the Mokken scale helps reveal and quantify common misconceptions and knowledge gaps on the part of laypeople regarding chemicals. Second, the results suggest that chemophobia (i.e., people's irrational fear of chemicals) is largely fueled by negative associations and affect stemming from the stigmatized term "chemical substances." Finally, while greater knowledge is associated with lower levels of chemophobia, it might prove difficult to overcome the negative stigma associated with the term, particularly for synthetic chemicals.

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Chapter III Lay-people's knowledge about toxicology and its principles in eight European countries

Manuscript published as:

Bearth, A., Saleh, R., & Siegrist, M. (2019). Lay-people's knowledge about toxicology and its principles in eight European countries. *Food and Chemical Toxicology, 131*.

doi:10.1016/j.fct.2019.06.007

Abstract

The procedures of risk assessment related to substances consumed or used by consumers (e.g., food additives, cleaning products) are highly complex and there exists some controversy between experts in regards to the uncertainty linked to it. This contributes to the well documented divergence in experts and lay-people's judgments, particularly for synthetic or man-made chemicals. By investigating lay-people's knowledge gaps and misconceptions related to toxicology, we hope to contribute to facilitating the communication between experts and the lay public. For this, a large-scale survey measuring knowledge of toxicological principles, trust in regulators, the irrational fear of chemicals and health concern was distributed in eight European countries (Total: $N = 5631$). Results suggest that large gaps exist regarding people's knowledge of toxicological principles and that a lack of knowledge is significantly associated with higher levels of chemophobia. Particular attention for future communication efforts should be placed on the stigma associated with the terminology, principles of dose-response associations and the comparability of substances of natural and synthetic origin.

3.1.Introduction

In one of the articles on experts' and lay-people's perceptions of toxicological principles Kraus, Malmfors, and Slovic (1992) coined the expression "intuitive toxicology:" „Human beings have always been ‚intuitive toxicologists,' relying on their sense of sight, taste, and smell to detect harmful or unsafe food, water, and air" (p. 215). Due to the inadequacies of this "intuitive toxicology," the science of toxicology and health risk assessment have been developed to test the safety of chemicals. Chemicals consumed or used by consumers, such as food additives or cleaning products, are put through intensive risk assessments, maximum usage or consumption doses, and usage instructions are set before their approval (Fan, Khan, & Alexeeff, 2015). However, these procedures of risk analysis are highly complex and there is some controversy between experts in regards to the uncertainty linked to this risk assessment (Kraus et al., 1992; Slovic et al., 1995; Ueland et al., 2012). This complicates the communication between experts and lay-people, as the latter lack the necessary background information, time and motivation to judge the uncertainty linked to risk assessments themselves (Hartings & Fahy, 2011; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997). Research shows that experts and lay-people's judgments of the risks and benefits and acceptance of complex science and technological innovations differ significantly, particularly if they are perceived as synthetic or man-made (e.g., Blok, Jensen, & Kaltoft, 2008; Hartmann, Hübner, & Siegrist, 2018).

The irrational fear of chemicals and everything the term stands for among lay-people can be termed as "Chemophobia" (e.g., Entine, 2011; e.g., Hartings & Fahy, 2011; Royal Society of Chemistry, 2015). The Royal Society of Chemistry (2015) claimed that experts overestimate the degree of chemophobia in the public and its implications for consumer choices and behavior. Other research suggests, however, that misconceptions exist among the lay public (Bearth, Cousin, & Siegrist, 2014; Dickson-Spillmann, Siegrist, & Keller, 2011;

Nieuwenhuijsen, Grey, Golding, & Grp, 2005). For instance, consumers underestimate the riskiness of prescription drugs or eco-cleaning products, while the potential hazardousness of food additives (e.g., Aspartame) is overvalued (Bearth et al., 2014; Bearth, Miesler, & Siegrist, 2017; Dickson-Spillmann, Siegrist, Keller, & Wormuth, 2009).

The divergence in judgments between lay-people and experts is frequently explained by pointing out the different levels of knowledge and potential misconceptions that lay-people might have, (e.g., Bearth & Siegrist, 2016; Bredahl, Grunert, & Frewer, 1998; Frewer et al., 2013). The differentiation of "risk as analysis" and "risk as feeling" describes that risk judgments might be based on two distinct strategies: First, people's estimation of the risk based on all available data and second, heuristics or other simple decision strategies, such as trust in public authorities, affect or perceived naturalness (Raue, Lermer, & Streicher, 2018; Slovic, Finucane, Peters, & MacGregor, 2004). Lay-people usually lack the necessary resources (e.g., time, motivation, attention, lack of education) to apply the "risk as analysis" strategy and instead rely on "risk as feelings." For instance, lay-people might be well aware of the safeguards implemented regarding food additives, but might still express worry and reject foods with a particular food additive due to the feelings they have or due to a lack of trust in risk assessors and regulators. Particularly, (a lack of) trust in scientists and risk analysis might contribute as an intuitive factor to the public's acceptance of or skepticism towards "chemicals" (Siegrist, 2008). Also, someone's personal concern with health might have implications how much concern chemicals induce, as a common narrative is that some man-made substances (e.g., Aspartame) are carcinogenic independent of the exposure level (Bearth et al., 2014; Levy, Weinstein, Kidney, Scheld, & Guarnaccia, 2008; MacGregor, Slovic, & Malmfors, 1999; Nieuwenhuijsen et al., 2005).

The goal of the present research was to investigate consumers' knowledge of toxicology and its principles and relate this knowledge, as well as trust and health concern, to the level of reported chemophobia. By focusing on this issue, we hope to contribute to facilitating the communication between experts, such as toxicologists from research and industry, and the lay public. For this, a large-scale survey was distributed to lay-people in eight European countries.

3.2.Methods

3.2.1. Participants

For this study, subjects from Switzerland, Austria, France, Germany, Italy, Poland, Sweden and the United Kingdom were recruited with the support of a professional provider of consumer panels (respondi in Cologne, Germany). In Switzerland, three of the four national languages were considered (i.e., 70% German-speaking, 24% French-speaking, 6% Italian-speaking participants). Participants who filled out the questionnaire too fast (i.e., half the duration of the median duration of all participants per country), and likely only participated for the incentive offered by the panel provider, were excluded from the final sample (Greszki, Meyer, & Schoen, 2014). On average, this applied to n = 79 participants per country. Table 7 presents an overview of the socio-demographics per country with the final samples. As quota-sampling for age and gender was applied (gender: 50:50, age: six groups from 18 to 79 years), no significant differences between countries were expected or uncovered (gender: ($\chi^2(7)$ = 1.17, p = .992; age: $F(7, 5623)$ = 0.79, p = .597, η^2 = .00). Regarding education ($\chi^2(28)$ = 1133.135, p < .001) and the number of school-years ($F(7, 5631)$ = 71.27, p < .001, η^2 = .08) significant differences were found. These differences originate in the different socio-cultural contexts of these countries and should be considered when interpreting this study’s findings.

Table 7. Socio-demographics per country.

	CH	AT	FR	DE	IT	PL	SE	UK
Total	698	731	708	711	695	693	682	713
Gender *N* (%)								
Female	352 (50.4)	368 (50.3)	364 (51.4)	356 (50.1)	351 (50.5)	349 (50.4)	357 (52.3)	358 (50.2)
Male	346 (49.6)	363 (49.7	344 (48.6)	355 (49.9)	344 (49.5)	344 (49.6)	325 (47.7)	355 (49.8)
Age *M* (*SD*)	50.7 (16.9)	49.5 (16.8)	50.4 (16.9)	50.3 (16.8)	50.2 (16.5)	50.9 (16.8)	51.4 (16.7)	50.7 (17.0)
Years of school *M* (*SD*)	12.1 (5.0)	11.4 (5.1)	10.1 (6.6)	10.8 (6.1)	14.1 (4.7)	14.6 (3.6)	11.1 (5.0)	13.4 (4.4)
Education *N* (%)								
No school completed	1 (0.1)	1 (0.1)	34 (4.8)	5 (0.7)	-	-	-	8 (1.1)
Mandatory school	34 (4.9)	40 (5.5)	79 (11.2)	45 (6.3)	55 (7.9)	24 (3.5)	52 (7.6)	106 (14.9)
Apprenticeship	338 (48.4)	307 (42.0)	94 (13.3)	298 (41.9)	66 (9.5)	80 (11.5)	92 (13.5)	46 (6.5)
High school	233 (13.2)	201 (27.5)	196 (27.7)	150 (21.1)	299 (43.0)	288 (41.6)	274 (40.2)	289 (40.5)
University	233 (33.4)	182 (24.9)	305 (43.0)	213 (30.0)	275 (39.6)	301 (43.4)	264 (38.7)	264 (37.0)
Children in household *N* (%)								
Yes, full time	96 (13.8)	91 (12.4)	126 (17.8)	104 (14.6)	137 (19.7)	181 (26.1)	115 (17.0)	123 (17.3)
Yes, part time	31 (4.4)	35 (4.8)	38 (5.4)	29 (4.1)	42 (6.1)	34 (4.9)	55 (8.1)	45 (6.3)
No	571 (81.8)	605 (82.8)	544 (76.8)	578 (81.3)	516 (74.2)	478 (69.0)	512 (75.1)	545 (76.4)
Household tasks *N* (%)								
Main responsibility	386 (55.3)	414 (56.6)	399 (56.4)	412 (58.0)	433 (62.3)	374 (54.0)	363 (53.2)	403 (56.5)
Shared responsibility	271 (38.8)	276 (37.8)	282 (39.8)	262 (36.8)	227 (32.7)	299 (43.1)	284 (41.6)	268 (37.6)
No responsibility	41 (5.9)	41 (5.6)	27 (3.8)	37 (5.2)	35 (5.0)	20 (2.9)	35 (5.1)	42 (5.9)
Work in industry *N* (%)								
Yes	103 (14.8)	116 (15.9)	96 (13.6)	72 (10.1)	44 (6.3)	79 (11.4)	120 (82.4)	58 (8.1)
No	595 (85.2)	615 (84.1)	612 (86.4)	639 (89.9)	651 (93.7)	614 (88.6)	562 (82.4)	655 (91.9)

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom

3.2.2 Questionnaire

The study is part of a Swiss government-funded research project that aims at investigating consumers' perceptions and handling of chemical products. However, for this paper, solely knowledge, chemophobia, trust in public authorities and health concern scales, socio-demographics and control variables will be considered. The questionnaire was translated from German into French, Italian, Polish, Swedish and English and subsequently, back-translated into German by a native speaker. Irregularities were discussed and solved by the first author.

The knowledge scale aimed at measuring people's Knowledge of Toxicological Principles with focus on negative health effects. The scale was developed and validated in a previous study with German-speaking Swiss participants (Saleh, Bearth, & Siegrist, submitted). For this new study, items pertaining to regulatory actions were removed as they will likely be closely related to trust in public authorities. Moreover, previously un-scalable items were rephrased. The included knowledge scale comprised seven incorrect and five correct statements and for each, participants were asked to indicate whether they thought the statement was "true," "false" or "do not know," which was subsequently recoded to 1 for correct responses and 0 for the other two responses. Figures 4 and 5 in the results section present the 12 items.

Chemophobia (5 items) was defined as the irrational fear of chemical substances, such as the wish to live in a chemical-free world. Health Concern (5 items) measured how worried participants were about their personal health. Trust in Public Authorities (3 items) measured their amount of trust that public authorities in their country protect their health. Responses were measured on a 6-point Likert scale with 1 "do not agree at all" to 6 "strongly agree." The chemophobia and health concern scales were also previously used in the study by Saleh et al. (submitted). Principal component and reliability analyses suggested a one-factor solution for chemophobia, whereas health concern loaded on two separate factors in all eight countries. Thus, health concern was split into two scales: Health concern and Health Worry, with the latter focused more strongly on the fear of potential illness. The three trust items loaded on one factor. Table 8 presents all scales and their corresponding items with means and standard deviations.

Lastly, socio-demographics and control variables were assessed, namely gender, age, level of education and school years, whether they worked in an industry that handles chemical products.

Table 8. Chemophobia (Means, Standard Deviations; 1 do not agree at all – 6: strongly agree).

	CH N=698		**AT** N=731		**FR** N=708		**DE** N=711		**IT** N=695		**PL** N=693		**SE** N=682		**UK** N=713	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Chemophobia (α =.86)	**3.63**	**1.21**	**3.55**	**1.22**	**4.33**	**1.09**	**3.70**	**1.23**	**4.30**	**1.14**	**4.16**	**1.16**	**3.70**	**1.20**	**3.41**	**1.18**
Chemical substances scare me.	3.27	1.52	3.03	1.59	4.05	1.55	3.25	1.56	4.09	1.49	3.75	1.6	3.52	1.56	3.18	1.55
I do everything I can to avoid contact with chemical substances in my daily life.	3.94	1.51	3.68	1.54	4.38	1.39	3.81	1.52	4.55	1.32	4.28	1.46	3.43	1.49	3.69	1.55
I would like to live in a world where chemical substances don't exist.	3.61	1.64	3.51	1.69	4.42	1.50	3.60	1.65	4.18	1.56	3.86	1.70	4.01	1.64	3.59	1.60
I believe that chemical substances are the main reason why people suffer from cancer.	3.42	1.43	3.42	1.41	4.13	1.39	3.64	1.45	4.01	1.41	4.14	1.42	3.52	1.43	2.91	1.45
I believe that chemical substances are the reason for most environmental problems.	3.90	1.46	4.13	1.45	4.68	1.25	4.18	1.42	4.63	1.32	4.75	1.35	4.04	1.40	3.69	1.45
Trust in public authorities (α =.65)	**4.44**	**1.19**	**3.98**	**1.38**	**3.46**	**1.48**	**3.72**	**1.37**	**4.18**	**1.15**	**3.75**	**1.28**	**4.07**	**1.27**	**4.21**	**1.18**
I think that the legislations on chemical household products in my country are strict enough.	4.47	1.29	3.99	1.50	3.53	1.53	3.80	1.50	4.04	1.34	3.73	1.36	3.94	1.46	4.08	1.38
I trust the public authorities in my country regarding the authorization and control of chemical household products.	4.50	1.33	4.06	1.53	3.46	1.62	3.77	1.54	4.07	1.37	3.82	1.46	4.20	1.42	4.31	1.33
I trust the public authorities in my country that they do everything they can to protect the health of consumers.	4.35	1.35	3.89	1.53	3.40	1.65	3.58	1.50	4.43	1.35	3.70	1.50	4.07	1.45	4.24	1.35

	CH N=698		AT N=731		FR N=708		DE N=711		IT N=695		PL N=693		SE N=682		UK N=713	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Health concern (α =.65)	**4.51**	**1.01**	**4.41**	**1.05**	**4.61**	**1.07**	**4.48**	**1.04**	**4.67**	**0.95**	**4.72**	**1.03**	**4.45**	**1.01**	**3.92**	**1.11**
I am very concerned about my health.	4.53	1.21	4.44	1.26	4.50	1.29	4.44	1.25	4.70	1.14	4.47	1.31	4.16	1.31	3.65	1.50
I hardly ever worry about my health.	2.31	1.43	2.39	1.48	2.10	1.41	2.32	1.40	2.28	1.44	2.30	1.50	1.90	1.26	2.79	1.48
I protect myself as much as possible from getting even slightly sick.	4.30	1.37	4.17	1.43	4.42	1.38	4.32	1.35	4.60	1.18	5.01	1.20	4.09	1.44	3.89	1.45
Health worry (α =.87)	**3.34**	**1.52**	**3.30**	**1.56**	**3.98**	**1.55**	**3.74**	**1.52**	**4.33**	**1.39**	**4.66**	**1.33**	**3.67**	**1.59**	**3.71**	**1.52**
I worry a lot about getting a serious disease (e.g., cancer).	3.44	1.65	3.37	1.67	4.16	1.70	3.87	1.64	4.38	1.45	4.65	1.43	3.73	1.70	3.59	1.64
I am afraid of getting a chronic disease.	3.24	1.58	3.24	1.64	3.79	1.62	3.62	1.62	4.28	1.47	4.67	1.40	3.60	1.68	3.83	1.64

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom.

3.2.3. Data analysis

Descriptive analyses, bivariate correlations, regression analyses and Chi^2-Tests and ANOVAs (two-tailed) to compare data from the different countries were conducted in SPSS 25 (IBM Corp., 2017). The scalability of the knowledge items was assessed with an approach from the probabilistic test theory, more specifically Mokken scale analysis (Mokken & Lewis, 1982). It is based on the assumption that the knowledge items can be ordered according to their difficulty and that each person's probability to give the correct response depends on the item's difficulty and the person's ability. A Mokken scale is a collection of ability items, ordered according to difficulty, that measure an underlying latent construct (i.e., knowledge of toxicological principles). It is a more stringent test for one-dimensionality than classical test theory. Loevinger's scalability coefficient H indicates the scale's quality, where H = 0.3-0.4 is considered a still acceptable scale, H = 0.4-0.5 is an average scale and H = 0.5-1.0 is a strong scale. The individual coefficients of the items are required to be higher than $H_i = 0.3$ to include this item in the scale (Mokken & Lewis, 1982). The Mokken scale analysis was done in R, utilising the Mokken package (R Core Team, 2018; van der Ark, 2007).

3.3. Results

3.3.1. Knowledge of toxicological principles

Figures 4 and 5 present the five correct and seven incorrect statements of the knowledge of toxicological principles scale, and the frequency distribution of correct responses. For most knowledge items, responses exhibited significantly different distributions between the countries ($\chi^2(7) > 26.21$, $p < .001$). An exception was the statement regarding the chemical structure of synthetically manufactured and naturally occurring salt, $\chi^2(7) = 8.47$, $p = .293$. Overall, the easiest item pertained to the interdependence of amount and frequency of exposure for potential harmful effects of a substance (75% or more correct responses). Furthermore,

more than half of the participants responded correctly to the statements related to the fatalness of large amounts of any chemical substance and that both synthetic and natural substances can be carcinogen. The incorrect statements regarding the labelling of consumer products, the ability of the human body to deal with natural and synthetic substances, and the dose at which these substances might cause illness exhibited correct response rates between 30% and 50%. The most difficult correct statements were related to the harmfulness of having a small amount of toxic chemical substance in a consumer product and the chemical structure of synthetically produced and naturally occurring salt (less than 25% correct responses). Incorrect statements that exhibited the lowest correct response rates were related to the transferability of insights from animals to humans, causes of allergies, accumulation in the human body and the dose-response relationship between being exposed to a toxic substance and the substance actually causing harm (less than 20% correct responses).

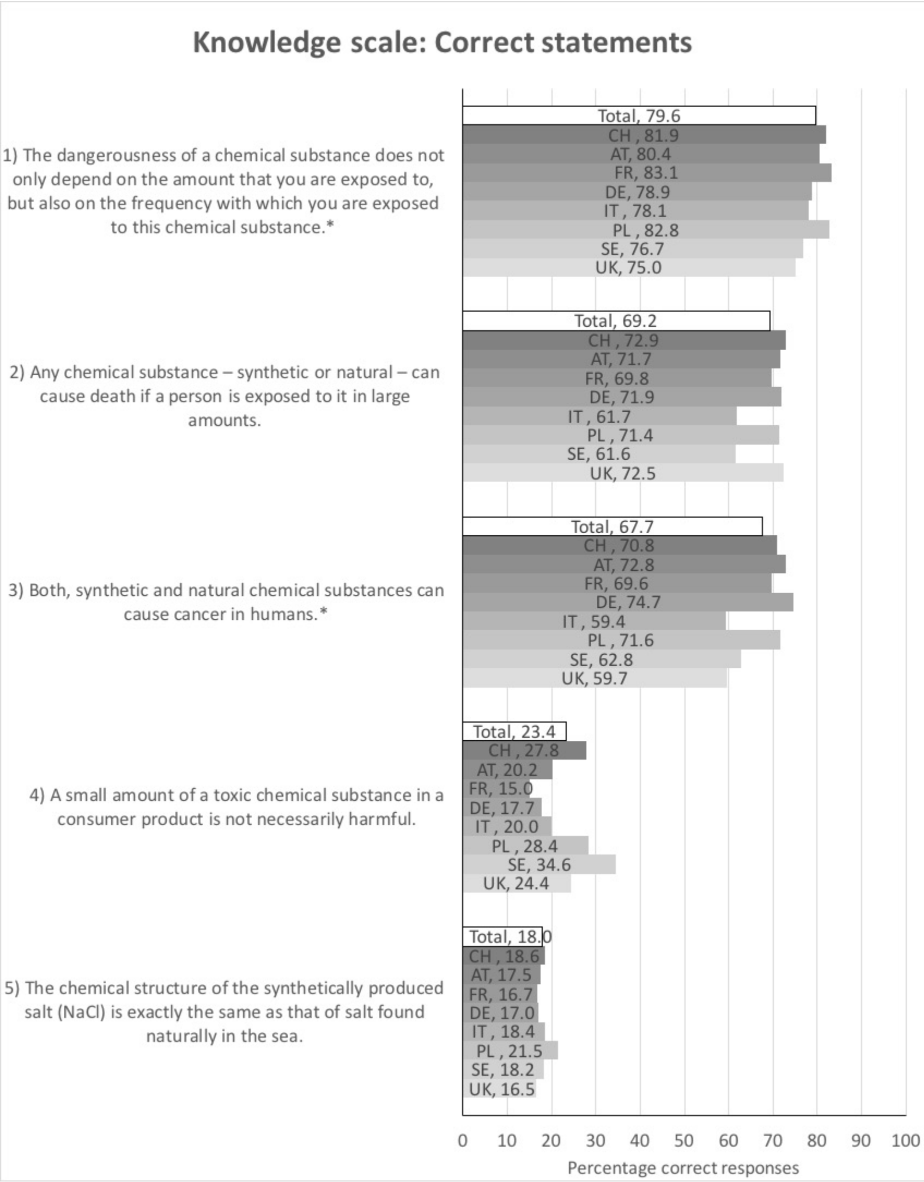

Figure 4. Correct statements of the knowledge scale (Total N=4943; CH: Switzerland (N=698); AT: Austria (N=731); FR: France (N=708); DE: Germany (N=711); IT: Italy (N=695); PL: Poland (N=693); SE: Sweden (N=682); UK: United Kingdom (N=713); *: included in the Mokken scale

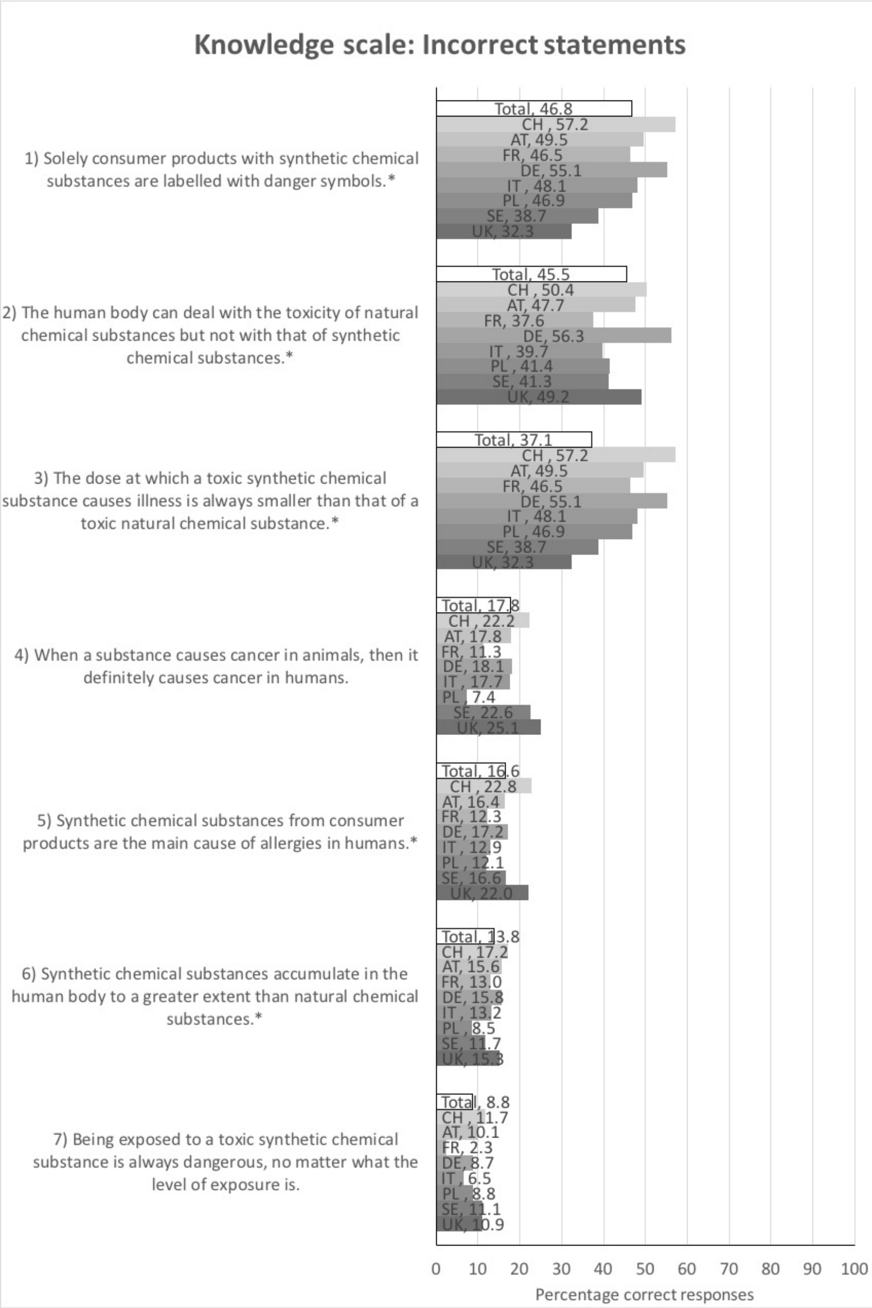

Figure 5. Incorrect statements of the knowledge scale (Total N=4943; CH: Switzerland (N=698); AT: Austria (N=731); FR: France (N=708); DE: Germany (N=711); IT: Italy (N=695); PL: Poland (N=693); SE: Sweden (N=682); UK: United Kingdom (N=713); *: included in the Mokken scale

Mokken scale analysis with the total sample showed that seven of the 12 knowledge items were scalable on one dimension with a $H_i > .30$. Table 9 presents the scalability coefficients for this scale with the seven items for the total sample and separately for the eight countries. It shows that the scale did not work equally well in all countries. Particularly, in Poland, the scalability coefficient was slightly below the acceptable value of H = .30. In Germany, the item regarding the frequency of exposure performed poorly, but the whole scale was good. Therefore, for comparability the same scale was used for all eight countries by summing up the correct responses. This knowledge index had a range of 0 to 7, with higher scores suggesting a higher knowledge of toxicological principles. The mean knowledge score for the total sample was $M = 3.07$ ($SD = 1.75$). A one-way ANOVA showed that knowledge differed significantly between the eight countries, $F(7, 5623) = 15.00$, $p < .001$, $\eta^2 = .02$. The highest knowledge score was observed for Germany ($M = 3.45$, $SD = 1.73$), Switzerland ($M = 3.42$, $SD = 1.83$) and Austria ($M = 3.21$, $SD = 1.79$). Lower knowledge scores were observed for Italy ($M = 2.97$, $SD = 1.73$), Poland ($M = 2.95$, $SD = 1.51$), France ($M = 2.91$, $SD = 1.67$), and the UK ($M = 2.87$, $SD = 1.82$). The lowest knowledge score had participants in Sweden ($M = 2.79$, $SD = 1.81$).

ANOVAs were conducted to check whether education, gender or working in an industry that manufactures, imports, trades or uses chemical products influence knowledge scores. First, an ANOVA was conducted with all variables entered as fixed variables. As there were no interaction effects, the results of separate one-way ANOVAs are reported. There was a significant effect of education ($F(2, 5628) = 69.38$, $p < .001$, $\eta^2 = .02$): The highest knowledge score was observed for participants with the highest level of education (university; $M = 3.41$, $SD = 1.78$), followed by medium levels of education (high school, apprenticeship; $M = 2.93$, $SD = 1.71$) and the lowest level of education (no education or mandatory school; $M = 2.58$, $SD = 1.69$). There was a significant gender effect ($F(1, 5629) = 62.85$, $p < .001$, $\eta^2 = .01$); Men ($M = 3.26$, $SD = 1.78$) exhibited higher knowledge scores than women ($M = 2.89$, $SD = 1.71$). Also, the professional background had a significant effect on knowledge ($F(1, 5629) = 33.06$, $p < .001$, $\eta^2 = .01$), with higher levels for people who work with chemicals ($n = 688$; $M = 3.43$, *SD* = 1.87), than other people (n = 4943, M = 3.02, *SD* = 1.73). Bivariate correlation analyses revealed very small, positive correlations between knowledge of toxicological principles and age ($r = .05$, $p < .001$) and school years ($r = .15$, $p < .001$).

Table 9. Knowledge of toxicological principles (Loevinger's scalability coefficient H for scale and H_i items and reliability coefficient (rho))

	Total H = .379 5631	**CH H = .410** 698	**AT H = .411** 731	**FR H = .405** 708	**DE H = .353** 711	**IT H = .344** 695	**PL H =. 292** 693	**SE H = .429** 682	**UK H = .380** 713
Synthetic chemical substances accumulate in the human body to a greater extent than natural chemical substances.	.427	.492	.482	.427	.467	.336	.307	.399	.416
The dose at which a toxic synthetic chemical substance causes illness is always smaller than that of a toxic natural chemical substance.	.421	.483	.461	.432	.410	.364	.321	.461	.414
The human body can deal with the toxicity of natural chemical substances but not with that of synthetic chemical substances.	.402	.441	.435	.449	.386	.404	.311	.459	.409
Both, synthetic and natural chemical substances can cause cancer in humans.	.379	.372	.447	.429	.322	.289	.311	.465	.364
Solely consumer products with synthetic chemical substances are labelled with danger symbols.	.366	.398	.400	.396	.383	.376	.285	.384	.332
Synthetic chemical substances from consumer products are the main cause of allergies in humans.	.322	.348	.306	.314	.343	.298	.167	.406	.325
The dangerousness of a chemical substance does not only depend on the amount that you are exposed to, but also on the frequency with which you are exposed to this chemical substance.	.304	.294	.299	.325	.134	.280	.296	.400	.411
Reliability coefficient (rho)	**.69**	**.71**	**.70**	**.68**	**.68**	**.68**	**.57**	**.72**	**.70**

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom

3.3.2. Relationships with trust in public authorities, health concern and chemophobia

First, a one-way ANOVA was conducted to check for significant differences in chemophobia among participants from different countries. There were significant differences between the mean chemophobia among the eight countries, $F(7, 5623) = 90.50$, $p < .001$, $\eta^2 = .08$ (cf. boxplots in Figure 6). The highest levels of chemophobia were observed in France, Italy and Poland. Germany, Austria, Switzerland, Sweden and UK exhibited lower levels of chemophobia.

In separate linear regression analyses for each country, the effect of socio-demographics, health concern, trust and knowledge on chemophobia was investigated (cf. Table 10). In all countries, the knowledge of toxicological principles was significantly, negatively related to people's levels of chemophobia with the strongest associations in Sweden, Germany and Italy (B = -0.10) and the weakest association in the UK (B = -0.04). Health concern and worry was significantly, positively related to chemophobia for all countries. Thus, people that were more concerned for their health and worried more about getting ill expressed more chemophobia. Trust in public authorities was significantly associated solely in the German-speaking countries and France, but not in the other countries. The negative association suggests that more trust was significantly related to a lower level of chemophobia in the respective countries. Regarding the socio-demographics, particularly higher age was significantly associated with more chemophobia in some countries (Switzerland, Austria, Germany, Poland). In Switzerland, the women expressed significantly more chemophobia than men (B = -0.28). Regarding education, solely in Italy a significant relationship between having a higher education and expressing less chemophobia could be observed (B = -0.56).

Table 10. Linear regression analysis with chemophobia as dependent variables.

	CH		**AT**		**FR**		**DE**		**IT**		**PL**		**SE**		**UK**	
	N=698		N=731		N=708		N=711		N=695		N=693		N=682		N=713	
	$F(8, 689) = 38.15$ $p < .001$		$F(8, 722) = 37.75$ $p < .001$		$F(8, 699) = 43.13$ $p < .001$		$F(8, 702) = 46.03$ $p < .001$		$F(8, 686) = 30.09$ $p < .001$		$F(8, 684) = 22.95$ $p < .001$		$F(8, 673) = 35.04$ $p < .001$		$F(8, 704) = 28.19$ $p < .001$	
	$R^2 = .31$		$R^2 = .30$		$R^2 = .33$		$R^2 = .34$		$R^2 = .26$		$R^2 = .21$		$R^2 = .29$		$R^2 = .24$	
	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t
Constant	2.61 (1.97,3.25)	8.01***	2.21 (1.64,2.78)	7.63***	2.77 (2.33,3.22)	12.25***	1.86 (1.30,2.42)	6.52***	2.39 (1.8,2.97)	8.02***	1.97 (1.29,2.65)	5.67***	2.50 (1.87,3.13)	7.77***	1.57 (1.02,2.11)	5.65***
Sex[a]	-0.28 (-0.44,-0.13)	-3.60***	-0.24 (-0.39,-0.09)	-3.12**	0.21 (-0.34,-0.07)	-3.00**	-0.11 (-0.26,0.04)	-1.48	-0.14 (-0.29,0.01)	-1.90	-0.23 (-0.39,-0.07)	-2.86**	-0.24 (-0.40,-0.08)	-3.00**	-0.10 (-0.26,0.05)	-1.29
Age	0.01 (0.01,0.02)	4.77***	0.01 (0.01,0.02)	6.02***	0.01 (0.00,0.01)	3.10**	0.01 (0.01,0.01)	4.34***	0.01 (0.00,0.01)	2.83**	0.01 (0.00,0.01)	3.54***	0.01 (0.00,0.01)	2.05*	0.01 (0.00,0.01)	2.96**
Education medium[c]	-0.06 (-0.41,0.29)	-0.34	0.00 (-0.33,0.33)	-0.02	-0.08 (-0.28,0.11)	-0.83	0.09 (-0.20,0.39)	0.61	-0.24 (-0.52,0.05)	-1.65	0.12 (-0.32,0.56)	0.54	-0.14 (-0.44,0.16)	-0.93	0.08 (-0.14,0.30)	0.70
Education High[c]	-0.49 (-0.86,-0.12)	-2.62**	-0.45 (-0.80,-0.10)	-2.49*	-0.27 (-0.47,-0.06)	-2.57*	-0.12 (-0.44,0.20)	-0.74	-0.56 (-0.85,-0.27)	-3.79***	-0.07 (-0.52,0.37)	-0.32	-0.44 (-0.75,-0.13)	-2.78**	-0.09 (-0.32,0.14)	-0.74
Knowledge	-0.09 (-0.14,-0.05)	-4.32***	-0.09 (-0.13,-0.04)	-3.89***	-0.07 (-0.11,-0.03)	-3.29**	-0.10 (-0.14,-0.05)	-4.37***	-0.10 (-0.14,-0.05)	-4.41***	-0.05 (-0.10,0.01)	-1.77	-0.10 (-0.15,-0.06)	-4.68***	-0.04 (-0.09,0.00)	-2.02*
Trust	-0.12 (-0.18,-0.05)	-3.61***	-0.15 (-0.21,-0.10)	-5.51***	-0.10 (-0.14,-0.05)	-4.13***	-0.15 (-0.20,-0.09)	-5.18***	0.04 (-0.03,0.10)	1.06	0.04 (-0.02,0.11)	1.41	-0.04 (-0.10,0.02)	-1.43	0.01 (-0.06,0.07)	0.15
Health concern	0.26 (0.18,0.34)	6.5***	0.33 (0.26,0.40)	8.91***	0.30 (0.23,0.37)	8.19***	0.32 (0.24,0.39)	7.82***	0.23 (0.14,0.31)	5.38***	0.17 (0.09,0.25)	4.05***	0.25 (0.17,0.34)	6.09***	0.23 (0.14,0.32)	5.09***
Health worry	0.22 (0.17,0.27)	8.25***	0.17 (0.12,0.22)	6.75***	0.22 (0.17,0.26)	8.91***	0.25 (0.20,0.30)	9.40***	0.28 (0.23,0.34)	10.10***	0.27 (0.20,0.33)	8.38***	0.24 ()0.19,0.29)	9.06***	0.22 (0.16,0.29)	6.64***

Note. [a] 0: female; 0: low education; CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom; ***: $p < .001$, **: $p < .01$, *: $p < .05$.

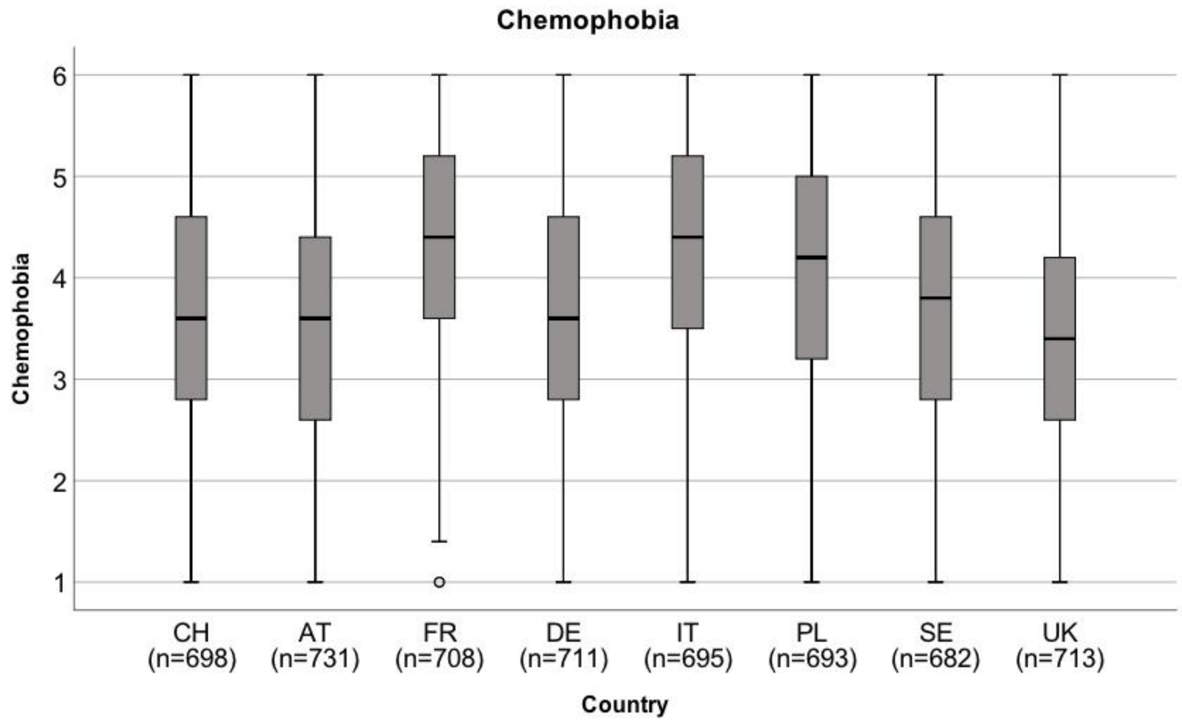

Figure 6. Boxplots of chemophobia per country (Different superscript letters denote significant differences according to Bonferroni post hoc tests: CH: Switzerland[cd], AT: Austria[d], FR: France[a], DE: Germany[c], IT: Italy[a], PL: Poland[b], SE: Sweden[c], UK: United Kingdom[c]).

3.4. Discussion

The knowledge scale used in this study did uncover a number of prevalent misconceptions and knowledge gaps among lay-people related to toxicology and its principles. The response patterns also resonates the findings of the original intuitive toxicology papers (Kraus et al., 1992; Slovic et al., 1995): Lay-people exhibit particular insecurities regarding the dose-response relationship, synthetic versus natural chemicals and the circumstances that might lead to harmful effects of a particular substance. The notion among experts is that a basic understanding of toxicology, the dose-response relationship, and the risk assessment process would enable lay-people to retrace risk-and-benefit analyses and might improve their ability to make fact-based decisions related to chemicals (Entine, 2011; Royal Society of Chemistry, 2015; Smith, 2011). Previous research also suggests that appropriately presented information about the risk assessment process is associated with lower risk perception of chemicals (Bearth, Cousin, & Siegrist, 2016; Shim et al., 2011). While it might be helpful to find ways to convey these concepts, it might be even more important to address the differences in terminology of what constitutes a "chemical" and the non-existent differentiation between "natural" and "synthetic" in science communication efforts (Royal Society of Chemistry, 2015). Science does not differentiate between chemicals of artificial and natural origin; any substance can be harmful depending on the dose or exposure (Fan et al., 2015). Lay-people on the other hand have a rather narrow definition of the term "chemical," as a man-made substance, usually dangerous or harmful to health. Previous research showed that lay-people report more negative affect towards the term "synthetic chemical substance" than towards the term "natural chemical substance," despite having received a definition of both terms beforehand (Saleh et al., submitted). This tendency among lay-people, to prefer natural substances or rather, substances perceived to be natural, is well-documented in the literature (Bearth et al., 2016; Dickson-

Spillmann et al., 2011; Ropeik, 2012; Rozin, Fischler, & Shields-Argelès, 2012; Scott & Rozin, 2017).

The present study demonstrates that knowledge of toxicological principles is important for people not to experience and express irrational fears of chemicals. Thus, efforts of informing consumers and increasing their knowledge about toxicology and its principles is a promising way to reduce chemophobia, but a focus on just the analytical aspect of risk judgments falls short (Hartings & Fahy, 2011; Slovic et al., 2004). For instance, trust has been discussed to be particularly important in the absence of knowledge or when a risk is complex and of high uncertainty. Based on the trust literature (e.g, Earle, Siegrist, & Gutscher, 2007; Siegrist & Cvetkovich, 2000; Siegrist, Cvetkovich, & Roth, 2000), trust in regulatory bodies could potentially be improved by providing believable and transparent information or by providing cues that suggest high competence or similar values as the recipient of the information. Furthermore, health concern and worry were more strongly related to chemophobia in all countries. The strong impact of health concern and worry could be explained by the association of chemical substances with cancer, chronic illnesses or other diseases that cause a large amount of dread (Lee, Lemyre, Mercier, Bouchard, & Krewski, 2005; Levy et al., 2008). Thus, participants that are particularly worried about contracting a dreadful disease, also exhibit more chemophobia, which might be caused by the perception that chemical substances are the main source of disease.

Inspecting the particularly difficult knowledge items, two concepts from risk research might play a role in lay-people's perceptions of chemicals: First, the concept of "contagion," which denotes that the attributes of a disgusting or otherwise negatively connoted object can permanently transfer to a neutral or positive object. Second, man-made chemical substances, despite offering a multitude of benefits for consumers, suffer from "technological stigma." Introduced by Gregory, Flynn, and Slovic (1995), the term denotes that for stigmatized technologies, such as use of chemicals or nuclear power, public discourse focuses much more on the potential risks than on the benefits. Previous research has for instance shown that people evaluate a human-caused oil spill more negatively than a natural oil spill; similar results were uncovered for energy systems (Siegrist & Sütterlin, 2014). Thus, lay-people's perceptions of risk of man-made chemicals are amplified, benefits are underestimated. This is largely fueled by the negative associations and imagery that the term "chemicals" raises (Bush, Moffatt, & Dunn, 2001; Loewenstein, Weber, Hsee, & Welch, 2001; Saleh et al., submitted). Related to our findings, consumers believe that the chemical structure of synthetically produced salt cannot be the same as salt found naturally in the sea, as one is man-made and "tainted" by human intervention (correct statement #5). This could also explain the frequently uncovered dose-response insensitivity, as they believe that a negative or dangerous object (i.e., chemical) causes harm, independent of the dose (correct statement #4, incorrect statements #6-7; Kraus et al., 1992; MacGregor et al., 1999). Thus, information provision might be insufficient, as lay-people reject synthetic chemicals and products containing synthetic chemicals purely for being man-made.

While the stigmatization related to the terms "chemicals" is well-documented in the literature, little effort has been undertaken to experimentally investigate how stigmatization could be reduced in communication and educational efforts. This is desirable as chemophobia might not only impede individual informed decision making, but also might hinder technological advancements via market boycotts, lobbying or other forms of public protest. It might be difficult to remove stigma by renaming and using different, non-stigmatized terms, but nonetheless it could be fruitful to investigate how the expression "everything's chemical" is understood by consumers and what effects this piece of information has on their perceptions and decision making. Furthermore, specific and personally relevant benefits could be addressed or an alternative world without man-made chemical substances could be evoked, to reduce stigmatization. More generally, chemophobia is an example of distrust in science and low scientific literacy and thus, intolerance of scientific uncertainty (Boele-Woelki, Francisco, Hahn, & Herz, 2018; Fasce & Pico, 2019). Communicating risk-benefit considerations and scientific uncertainty is complex and a more intensive educational approach might be necessary to improve people's abilities to make informed decisions. This matches the calls for including a more intensive education in the sciences (i.e., chemistry, toxicology) in school curriculums at all educational levels (Boele-Woelki et al., 2018).

Chemophobia was higher in France, Italy and Poland than in Switzerland, Austria, Germany, Sweden and the UK. It might be important to inform and educate consumers everywhere, but regional differences might need to be taken into account when communicating or educating the public on toxicological principles. For instance, in France, chemophobia might be strongly related to a lack of trust in public authorities, as the French participants reported the lowest trust and it was significantly related to their chemophobia. In Italy, trust in public authorities was not significantly related to chemophobia, but knowledge and education, as well as health concern and worry were. Lastly, in Poland, other variables than the ones included in this survey were relevant for people's chemophobia. Thus, communication and educational efforts should be adjusted accordingly.

In terms of limitations, the concept of chemophobia should be reconsidered in future research, as the current scale comprises potentially rational items. In line with the experts' definition of a chemical substance, it makes no sense to agree to "I would like to live in a world where chemical substances do not exist." However, the argument that chemical substances are the main reason why people suffer from cancer or are the reason for most environmental problems depends on the chemical that respondents think of (i.e., chemicals in cigarettes, CO_2). There is strong support in the literature that the majority of lay-people do not think of particular chemicals when confronted with the term "chemical substance," but rather more general, negative associations (Bearth et al., 2014; Bearth et al., 2017; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Saleh et al., submitted). Nonetheless, particular care should be taken in the future to methodically differentiate between people's actual irrationality regarding chemical substances and issues related to a misunderstanding or different understanding of words.

3.5. Conclusion

To sum up, informing and educating consumers about toxicological principles and the risk assessment of chemical substances might improve trust in the executing authorities and lead to lower levels of chemophobia. This paper indicates in which areas particular misconceptions are more prevalent. Nonetheless, a purely informational and educational approach might not be the solution for all of the issues, as a more intuitive layer of influential factors might also play a role. An important first step to improve the communication between toxicologists and lay-people, could be to find a common wording of the term "chemical" or at least to clarify what exactly these terms mean to someone.

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Chapter IV How chemophobia affects public acceptance of pesticide use and biotechnology in agriculture

Manuscript submitted for publication as:

Saleh, R., Bearth, A., & Siegrist, M. (submitted). How chemophobia affects public acceptance of pesticide use and biotechnology in agriculture.

Abstract

Protecting crops from infestations is critical to ensuring stable, safe food production. However, many consumers are concerned about the use of pesticides and agricultural biotechnology (agri-biotech) applications. The stigmatization of these applications' scientific labels can be associated with negative perceptions. A lack of consumer acceptance can prevent potentially beneficial applications from being utilized. This study examines consumer acceptance of pesticide use in conventional and organic agriculture and agri-biotech applications as crop-protection measures. Further, it examines whether consumer acceptance of agri-biotech applications differs based on the scientific labels describing such applications (e.g., "gene technology" or "gene editing"). Two online between-subject experiments were conducted with participants from the German-speaking part of Switzerland ($N_{\text{experiment 1}} = 643$, $N_{\text{experiment 2}} = 635$). The results revealed that consumers were most willing to accept gene transfers (even if described as "gene technology") as a protection measure, provided the gene came from a wild variety of the same species as the cultivated plant. Both chemophobia and the importance of naturalness in food influence consumer acceptance of pesticide use and agri-biotech applications. Addressing chemophobia and informing consumers about the role of technologies in pest-management and crop-protection could lead them to trust and accept related agricultural policies.

4.1.Introduction

Crop-protection measures are key to securing stable yields of safe, good-quality food (Food and Agriculture Organization of the United Nations, 2017, 2019). In recent decades, the use of pesticides to protect crops from infestations has facilitated mass food production (Cooper & Dobson, 2007). However, excessive reliance on pesticides has adverse effects on the environment (e.g., soil contamination, harm to non-target organisms; van Lexmond, Bonmatin, Goulson, & Noome, 2015) and human health (e.g., pesticide poisoning; Ntzani, Ntritsos, Evangelou, & Tzoulaki, 2013; Williamson, 2011).

Consumers' concerns regarding the risks of pesticides arose when pesticide residues were found in food and drinking water (Peterson, 2000; Williams & Hammitt, 2001). Consumers tend to consider any level of pesticide residue in food as risky (Entine, 2011a), even if it is below the maximum acceptable level (Lamichhane, Dachbrodt-Saaydeh, Kudsk, & Messean, 2016). Consumers' concerns about pesticide residues, along with the adverse effects of pesticide usage, have prompted governments to monitor residue levels and develop legislation to reduce the reliance on, and risks of, pesticide use (Eyhorn, Roner, & Specking, 2015; Lamichhane et al., 2016). Currently, there are no effective and economically feasible replacements for pesticides, although there are some measures for reducing pesticide use (Lamichhane et al., 2015). One such measure is agricultural biotechnology, whereby techniques are used to modify plants, animals, and microorganisms (Persley & World Bank., 1993). Plants can be modified to become resistant to infestations through the manipulation of their genetic material, thereby reducing the need for pesticides. Yet, consumers might prove reluctant to accept genetically modified food (Frewer et al., 2013; Lucht, 2015) due to its perceived unnaturalness (Hansen, 2006; Scott, Inbar, & Rozin, 2016; Scott, Inbar, Wirz, Brossard, & Rozin, 2018; Sjöberg, 2000). Without public acceptance of agricultural biotechnology (agri-biotech) applications, the agriculture industry may be unable to successfully implement such measures.

Investigating consumer perceptions of agri-biotech applications and pesticide use is important, as both measures are necessary to ensure crop safety. Further, identifying and comparing the influences on public acceptance of such measures could help with risk-communication efforts.

4.2. Theoretical background

4.2.1. Consumer perception of pesticide use

Consumers' concerns regarding pesticide residues have been documented (Dunlap & Beus, 1992; Entine, 2011a; Koch, Epp, Lohmann, & Bol, 2017b; Ott, Huang, & Misra, 1991; Peterson, 2000; Williams & Hammitt, 2001). Most European consumers perceive pesticide residues to be a key food-safety concern, along with food additives and antibiotic or steroid residues in meat (European Food Safety Authority, 2010, 2019). Many consumers associate pesticides in food with severe, long-term health risks (Fife-Schaw & Rowe, 1996; Miles & Frewer, 2001) and have reservations regarding synthetic pesticides, although not regarding pesticides of "natural" origin. The latter are mainly used in organic food production, which some consumers perceive as safer and healthier (Saba & Messina, 2003; Shafie & Rennie, 2012; von Alvensleben, 2001). This perception indicates that consumers' concerns regarding synthetic pesticides are influenced by a fear of chemicals (or chemophobia). Chemophobics perceive any level of synthetic chemicals as inherently dangerous (Bearth, Saleh, & Siegrist, 2019; Dickson-Spillmann, Siegrist, & Keller, 2011; Kraus, Malmfors, & Slovic, 1992; Saleh, Bearth, & Siegrist, 2019; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997). Thus, chemophobics strive to reduce their contact with synthetic chemicals and to consume only chemical-free food products (Bearth et al., 2019; Entine, 2011a, 2011b; Saleh et al., 2019; Siegrist & Bearth, 2019). Consequently, some chemophobics demand the banning of synthetic chemicals in agriculture. For example, two citizen-led initiatives in Switzerland seek to ban all synthetic pesticides and switch to organic food production by 2030 (Swiss Federal Council, 2020a, 2020b). These initiatives do not, however, demand the banning of natural pesticides potentially harmful to human health and the environment, such as copper-based pesticides (Eyhorn et al., 2015). This shows how public perceptions can misdirect policy-makers toward banning synthetic pesticides simply for being man-made, not based on their toxicity and/or risk assessment. Such bans could limit agriculture to the use of natural chemicals, which are not necessarily safer or more efficient than their synthetic counterparts (Lamichhane et al., 2015). Understanding consumer perceptions of pesticide use in conventional and organic agriculture represents the first step toward addressing opposition to pesticide use and developing agricultural policies that are acceptable to all stakeholders.

4.2.2. Consumer perception of agri-biotech applications

Agri-biotech represents a promising method for protecting plants from infestations. However, public skepticism has been noted, especially in Europe (Frewer et al., 2013; Savadori et al., 2004; Siegrist, 2003; Siegrist, Hartmann, & Sutterlin, 2016). In Switzerland, the majority of citizens voted in favor of a gene-technology moratorium in 2005 (Swiss Federal Council, 2018). This led to the commercial cultivation of genetically modified (GM) crops being prohibited until 2022. Public opinion regarding GM food might be influenced by the perceived naturalness of food (Bredahl, 1999; Connor & Siegrist, 2010; Frewer, Howard, & Shepherd, 1996; Miles, Ueland, & Frewer, 2005; Siegrist, 2008; Tenbült, de Vries, Dreezens, & Martijn, 2005), as GM foods are often viewed as unnatural and unacceptable (Lucht, 2015; Siegrist, 2008). Public perceptions of naturalness depend on the agri-biotech application in question (Lucht, 2015; Mielby & Lassen, 2009; Mielby, Sandoe, & Lassen, 2013; Miles et al., 2005; Tenbült et al., 2005). For example, public acceptance of GM foods is particularly low when crops are produced using transgenic-modification (Delwaide et al., 2015; Lucht, 2015; Shew et al., 2016), which involves the genes of different species being combined via the introduction of foreign DNA (Holme, Wendt, & Holm, 2013). This artificial combination of genes may explain why consumers perceive GM crops as unnatural (Batista & Oliveira, 2009; Bauer & Gaskell, 2002; Gaskell & Bauer, 2001; Hansen, 2006; Kronberger, Wagner, & Nagata, 2014; Lassen, Madsen, & Sandoe, 2002; Tenbült et al., 2005). The more uncomfortable consumers are with the idea of interfering with nature, the more likely they are to oppose human activities that "tamper" with natural processes (Raimi, Wolske, Hart, & Campbell-Arvai, 2019).

Agri-biotech applications that render plants resistant to infestations could represent promising alternatives to transgenic-modification. Cisgenic-modification, for example, involves the transfer of genes with desirable traits between plants of the same species. Further, gene technologies that apply new tools might not require any gene transferring. This "gene editing" process involves adding, deleting, or altering specific DNA locations within the genome of the plant to achieve the desired resistance to infestation (Huang, Weigel, Beachy, & Li, 2016; Shew, Nalley, Snell, Nayga, & Dixon, 2018). Studies have compared consumers' acceptance of cisgenic-modification and gene editing to their acceptance of transgenic-modification (e.g., Araki & Ishii, 2015; Colson & Huffman, 2011; Ishii & Araki, 2016; Muringai, Fan, & Goddard, 2020; Rousselière & Rousselière, 2017; Shew et al., 2016; Shew et al., 2018) and found that cisgenic-modification and gene editing are more acceptable than transgenic-modification, possibly due to perceptions that they are more natural (Delwaide et al., 2015; Kronberger et al., 2014; Lusk, Roosen, & Bieberstein, 2014; Shew et al., 2016). However, consumers might hesitate to accept gene editing or cisgenic-modification if stigmatized labels such as "gene modification" or "gene technology" are used (Kato-Nitta, Maeda, Inagaki, & Tachikawa, 2019; Shew et al., 2016; Shew et al., 2018). Therefore, the type of agri-biotech application and the terminology used when describing it can influence consumers' naturalness perceptions and acceptance levels.

4.2.3. Study aims

Consumers perceptions and acceptance of pesticide use (e.g., Koch, Epp, Lohmann, & Bol, 2017a; Ott et al., 1991; Saba & Messina, 2003; Stoleru, Munteanu, & Istrate, 2019; Williams & Hammitt, 2001) and agri-biotech applications in agriculture (e.g., Boccia, 2016; Boccia, Covino, & Sarnacchiaro, 2018; Colson & Huffman, 2011; Delwaide et al., 2015; Mielby et al., 2013; Shew et al., 2016; Shew et al., 2018) have mostly been examined separately. Few studies have assessed consumers' preference and acceptance regarding foods grown using agri-biotech applications in light of their potential to reduce pesticide use (Edenbrandt, 2018; Edenbrandt, Gamborg, & Thorsen, 2018; Muringai et al., 2020; Rousselière & Rousselière, 2017; Shew et al., 2016). Additionally, to the best of our knowledge, no direct comparison between consumers' perceptions and individual characteristics and their acceptance of food grown using cisgenic-modification (gene transfer), gene editing, or pesticides (natural and synthetic) has been conducted. Therefore, the first aim of this study was to compare how the types of crop-protection measures influence consumers' naturalness perceptions and acceptance levels. The second aim was to determine what influences consumers' acceptance of crop-protection measures. The final aim was to evaluate whether consumers' acceptance of agri-biotech applications changes based on the utilized scientific labels. For this, the stigmatized "gene technology" label and the newer "gene editing" label were used. The overall aim of this study is to aid with risk-communication efforts intended to address public skepticism regarding crop-protection measures.

4.3. Experiment 1

4.3.1. Methods

4.3.1.1. Experiment aim and design

Experiment 1 addressed the first and second aims of the study. It examined consumers' acceptance of pesticide use and agri-biotech applications intended to protect potato crops from infestation. Potatoes were chosen because they are a commonly harvested crop that is vital to the food supply in Switzerland. Further, different crop-protection measures can be applied to their cultivation (Swiss Academies of Arts and Science, 2018).

The online between-subject experiment involved four experimental groups. Prior to being randomly assigned to a group, the participants provided informed consent and answered control (profession, potato consumption frequency, baseline naturalness perception of potato plants) and basic socio-demographic (gender, age) questions. The participants were then shown a text describing a fungal disease (potato blight) that affects potato farming in Switzerland (cf. Appendix A).

Pictures of potato plants infected with blight were shown alongside the text to render the disease more salient. The four groups were then each introduced to one crop-protection measure for dealing with the blight. The first group ("synthetic pesticides") was presented with the spraying of synthetic fungicides used in conventional farming. The second group ("natural pesticides") was presented with the spraying of natural fungicides used in organic farming. The third and fourth groups were presented with agri-biotech as a solution for fighting potato blight. The third group ("gene transfer") was shown a text in which cisgenic-modification was described as the transfer of genes from a wild variety to the cultivated potato to render it resistant to blight. The fourth group ("gene editing") was shown a text describing the editing of specific genes to render the potato resistant to blight (cf. Appendix A).

After reading the assigned texts, the participants were asked about their general acceptance of the relevant crop-protection measure, their willingness to eat the altered potatoes, and their naturalness perception of the potatoes. The participants' beliefs regarding the importance of naturalness in food, chemophobia, and tampering with nature were also assessed.

Further, the texts were evaluated concerning their clarity and credibility. Finally, the participants indicated their education level.

4.3.1.2. Participants

Based on a prior power analysis, it was determined that a minimum sample of $N = 492$ participants was needed to detect differences in the means between groups with a small effect size of $d = 0.15$ and a power of 0.80 (Cohen, 1988). The effect size was based on the findings of similar studies on consumer perceptions of chemicals (Bearth, Cousin, & Siegrist, 2016; Saleh, Bearth, & Siegrist, 2020). More participants were sampled, as it was expected that some participants would have to be excluded for working in a chemical or biotechnology-related field or for not eating potatoes frequently. A sample of Swiss German-speaking participants was recruited via a consumer panel provided by a market research company. They were invited to take part in this experiment in January 2020 and were compensated with a small financial incentive of 0.54 CHF (0.59 USD). The content of the experiment was not revealed at the start of the questionnaire to avoid selection bias. Quota sampling was applied to ensure a balanced ratio of male to female respondents and age distributions. There was a total of $N = 910$ invited participants, from which 130 were screened out from the experiment for having a profession in the chemical or biotechnological sector, or for rarely or never consuming potatoes. A total of $N = 678$ participants completed the experiment in full. Of these, 34 respondents completed the experiment in half the median time (i.e., in less than 3 minutes, which may be an indication that participants have not filled out the questionnaire seriously), and one respondent exhibited a conspicuous response pattern, so they were excluded from the analysis.[1] The final sample comprised 643 respondents (51.5% female, $M_{age} = 46$ years, $SD_{age} = 17$, range: 18–90 years

[1] There was no substantial difference in the results when data was analyzed with and without these 35 respondents. However, to ensure that the results presented are not affected at all by random or invalid responses, those 35 respondents were dropped from the analysis.

old). The respondents' self-reported education levels ranged from mandatory school, basic apprenticeship, prevocational school, or apprenticeship (*n* = 322, 50.1%) to high school or technical and vocational training (*n* = 177, 27.5%) and university (*n* = 144, 22.4%). There were no significant differences between the four groups in terms of education levels (χ^2 (6, N = 643) = 7.35, *p* = .29) or gender distribution (χ^2 (3, *N* = 643) = 3.63, *p* = .31). Age distribution was also not significantly different between the four groups (*F* (3, 639) = 2.38, *p* = .07). Table 11 presents the socio-demographics for the four groups.

4.3.1.3.Materials

Each group indicated how acceptable the relevant crop-protection measure is on a scale ranging from 0 (not acceptable at all) to 100 (completely acceptable). The participants also indicated their willingness to eat potatoes grown using the relevant crop-protection measure on a scale ranging from 0 (not willing to eat at all) to 100 (very willing to eat). This rating scale was used because it captures the variance in participants' responses and their true evaluations of the investigated crop-protection measures, which would not be possible using dichotomous rating scales. The acceptance scale was constructed based on the mean general acceptance of the crop-protection measure and the participants' willingness to eat potatoes grown using that measure. The scale exhibited a high Cronbach's alpha of α = 0.92.

The participants' naturalness perceptions were measured twice. First, they were presented with a picture of a potato plant. They indicated how natural they perceived the plant to be on a scale ranging from 0 (not natural at all) to 100 (completely natural). Their answers to this question were considered their "baseline naturalness perceptions." The participants also indicated how natural they perceived the potato plant to be using the same scale after they had read the provided texts. These answers were termed their "naturalness perceptions post-texts." Any change in naturalness perception was calculated by subtracting the naturalness perceptions post-text values from the baseline values.

Chemophobia was assessed using an adapted version of the naturalness scale (Bearth et al., 2019; Saleh et al., 2019). The participants indicated how strongly they agreed with each of seven items on a six-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree). After conducting a principal component analysis (PCA) (Dunteman, 1989), the scale was constructed by taking the mean of all the items for which a higher score indicated a higher fear of chemicals. Based on Kaiser's criterion and the scree plot, a one-factor solution was uncovered for the multi-item scale (cf. item-total correlations in Table 12) (Cattell, 1966). Based on the reliability analysis, the seven-item chemophobia scale had a high Cronbach's alpha of $\alpha = 0.85$.

Table 12. Experiment 1: Item-total correlations (Item-total r) and Cronbach's alpha (α) for chemophobia, importance of naturalness in food, and tampering with nature scales.

Chemophobia scale (alpha = .85)	**Item-total correlation**
I would like all chemical substances to be risk-free.	0.25
In a world without chemical substances, there would be no environmental disasters.	0.57
I do everything I can to avoid contact with chemical substances in my daily life.	0.62
The chemical industry is responsible for more people suffering from cancer.	0.65
I would like to live in a world where chemical substances don't exist.	0.68
I am scared of chemical substances that I cannot pronounce.	0.71
Chemical substances scare me.	0.73
Importance of naturalness in food scale (alpha = .82)	**Item-total correlation**
It is important to me that the food I eat on a typical day:	
Contains natural ingredients	0.57
Contains no additives	0.73
Contains no artificial ingredients	0.74
Tampering with nature scale (alpha = .83)	**Item-total correlation**
People who push for technological fixes to environment problems are underestimating the risks.	0.55
Human beings have no right to meddle with the natural environment.	0.70
Altering nature will be our downfall as a species.	0.70
I would prefer to live in a world where humans leave nature alone.	0.71

N=643

The importance of naturalness in food was assessed using the naturalness subscale by Steptoe et al. (1995), which consists of three items focused on the natural content of food. This subscale is the shortest, most valid, and most commonly used scale compared to similar existing scales (Michel & Siegrist, 2019). Participants indicated how important it is to them that the food they eat has no additives or artificial ingredients. Responses ranged from 1 (not important at all) to 4 (very important). A one-factor solution was uncovered based on the PCA (cf. item-total correlations in Table 2), and the scale was built by taking the mean of the three items. A higher score indicates a higher importance of naturalness in food. This scale exhibited a high Cronbach's alpha of $\alpha = 0.82$.

Participants' aversion to tampering with nature was measured using a scale that was developed by Raimi et al. (2019). Participants indicated their agreement with five statements on a seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Before taking the mean of all the items, one reverse-coded item ("*People who say we shouldn't tamper with nature are just being naïve*") was excluded from the scale for having low item-total correlation ($r = 0.17$). The low item-total correlation ($r < 0.3$) showed that the item did not fit well into the scale, possibly because of cultural differences in the connotations of the item. The final scale consisted of four items (cf. item-total correlations in Table 12), with higher scores indicating greater discomfort with tampering with nature. The scale exhibited a high Cronbach's alpha of $\alpha = 0.83$.

The credibility of each text was assessed according to five categories: whether the text was believable, accurate, trustworthy, unbiased, and reflected the whole story. Each experimental group rated their respective text using five bipolar adjectives on a scale ranging from 1 (e.g., text is unbelievable) to 5 (e.g., text is believable). For every text, a scale for overall credibility was calculated by taking the mean of the five categories' scores; a higher score indicated higher credibility. The overall credibility of the texts had a high Cronbach's alpha of $\alpha = 0.78$. Participants also rated the clarity of the texts using a slider scale ranging from 0 (not understandable at all) to 100 (completely understandable).

4.3.1.4. Data analysis

Data was analyzed and visualized using SPSS version 25.0 (IBM Corp., 2017). One-way analyses of variances (ANOVA) with Tukey's post-hoc tests were conducted to compare the individual differences between the four groups on the following dependent variables: acceptance of crop-protection measures, naturalness perceptions of potatoes at baseline and at post-texts. Effect sizes n_p^2 were reported for the results of the one-way ANOVAs. Paired sample t-tests were used to evaluate the significance of the change in naturalness perceptions within each experimental group. Pearson's correlations were used to examine the relationships between the following variables: acceptance, naturalness perception post-texts, chemophobia, importance of naturalness in food, and tampering with nature. Multiple linear regression analyses were conducted to examine which factors (age, gender, education, chemophobia, importance of naturalness of food) influenced the participants' acceptance of crop-protection measures.

4.3.2. Results

4.3.2.1. Acceptance of crop protection measures

There were significant differences between the groups' acceptance of the assigned crop-protection measures (F (3, 639) = 14.07, p < .001, η_p^2 = .06). The "gene transfer" group (M = 68.90, SD = 27.92) had significantly higher acceptance than the "synthetic pesticides" (M = 50.83, SD = 27.47), "natural pesticides" (M = 55.62, SD = 26.26) and "gene editing" (M = 52.39, SD = 26.95) groups (cf. Table 13). There were no significant differences between the "synthetic pesticides", "natural pesticides", and "gene editing" groups.

Table 13. Experiment 1: Means (M), standard deviations (SD), and one-way analyses of variances in the effects of the four groups on four dependent variables.

	Group					
	Synthetic pesticides n=168	**Natural pesticides n=168**	**Gene transfer n=149**	**Gene editing n=158**	**F (3, 639)**	**η_p^2**
Baseline naturalness perception	75.17 (20.90)[a]	74.42 (22.94)[a]	74.13 (23.68)[a,b]	67.44 (24.29)[b]	3.92**	0.02
Naturalness perception post-text	41.45 (26.07)[a]	46.19 (27.29)[a]	54.83 (30.13)[b]	39.49 (26.40)[a]	9.49***	0.04
Change in naturalness perception	33.72 (29.09)[a]	28.23 (33.86)[a,b]	19.31 (32.85)[b]	27.94 (32.57)[a,b]	5.37**	0.03
Acceptance of crop protection measures	50.83 (27.47)[a]	55.62 (26.26)[a]	68.90 (27.92)[b]	52.39 (26.95)[a]	14.07***	0.06

Means in a row sharing the same subscripts are not significantly different from each other.

*** p<.001, F value (degrees of freedom),
η_p^2: partial eta square.

4.3.2.2.Naturalness perceptions at baseline and post-texts

There were significant differences between the groups regarding their perceptions of naturalness post-text (F (3,639) = 9.49, p < .001, η_p^2 = .04). The "gene transfer" group (M = 54.83, SD = 30.13) had significantly higher naturalness perceptions post-text than did the "synthetic pesticides" (M = 41.45, SD = 26.07), "natural pesticides" (M = 46.19, SD = 27.29), and "gene editing" (M = 39.49, SD = 26.40) groups (cf. Table 13). There was were no significant differences between the "synthetic pesticides", "natural pesticides", and "gene editing" groups.

Participants' perceptions of the naturalness perception of the potatoes post-texts significantly decreased from the baseline naturalness perception for the "synthetic pesticides"

(t (167) = 15.02, $p < .001$), "natural pesticides" (t (167) = 10.81, $p < .001$), "gene transfer" (t (148) = 7.18, $p < .001$) and "gene editing" (t (157) = 10.78, $p < .001$) groups (cf. means in Table 13).

The changes in naturalness perceptions varied significantly among the groups (F (3, 639) = 5.37, $p < .01$, $\eta_p^2 = .03$). The "gene transfer" group (M = 19.31, SD = 32.85) exhibited a significantly lower change in naturalness perception of the potatoes than the "synthetic pesticides" group (M = 33.72, SD = 29.09), but not compared to the "natural pesticides" (M = 28.23, SD = 33.86) and the "gene editing" (M = 27.94, SD = 32.57) groups. There were no significant differences in the change of naturalness perceptions between the "natural pesticides", "synthetic pesticides" and "gene editing" groups.

Despite randomization, there were significant differences in the participants' baseline perceptions of the naturalness of the potato plant, as shown by F (3, 639) = 3.92, $p < .01$, $\eta_p^2 = .02$ (cf. Table 13). This was likely a random effect, especially since there were no significant differences between the groups in terms of socio-demographic variables (cf. Table 11). Due to these differences in baseline perceptions, the change scores in naturalness perception were used as the main point of focus in this category.

4.3.2.3.Chemophobia, importance of naturalness in food, tampering with nature

There were no significant differences in chemophobia (F (3, 639) = 1.78, $p = .15$, $\eta_p^2 = .01$), the importance of naturalness in food (F (3, 639) = 0.70, $p = .55$, $\eta_p^2 = .00$), and tampering with nature (F (3, 639) = .66, $p = .57$, $\eta_p^2 = .00$) between the groups. All three (M = 3.53, SD = 1.07; M = 3.26, SD = 0.68; M = 4.54, SD = 1.32, respectively) were high across the whole sample (cf. appendix B for the means and standard deviations of the items of the scales).

4.3.2.4. Regression analysis of acceptance of crop protection measures

Table 14 shows Pearson's correlations between the participants' acceptance of crop protection measures, chemophobia, importance of naturalness in food, and tampering with nature. Most variables were found to be significantly correlated. Chemophobia exhibited significant negative correlations with the respondents' acceptance of all the crop protection measures. Importance of naturalness in food had significant negative correlations with participants' acceptance of "synthetic pesticides", "gene transfer" and "gene editing" measures. The negative correlation between the importance of naturalness in food with the acceptance of natural pesticides was not significant. Tampering with nature had significant positive correlation with chemophobia in all four groups. To avoid multicollinearity in the independent variables, chemophobia was chosen over tampering with nature as a predictor in all regression analyses.

Table 14. Experiment 1: Pearson's correlations with confidence intervals between acceptance, chemophobia, importance of naturalness in food, and intolerance to tampering with nature by group.

	Group											
	Synthetic pesticides (n=168)			**Natural pesticides (n=168)**			**Gene transfer (n=149)**			**Gene editing (n=158)**		
Variables	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
1. Acceptance	-			-			-			-		
2. Chemophobia	-.41** [-0.53, -0.27]			-.38** [-0.50, -0.24]			-.27** [-0.41, -0.11]			-.26** [-0.40, -0.11]		
3. Importance of naturalness in food	-.41** [-0.53, -0.27]	.46** [0.33, 0.57]		-.10 [-0.25, 0.05]	.41** [0.27, 0.53]		-.27** [-0.41, -0.11]	.34** [0.19, 0.47]		-.35** [-0.48, -0.20]	.34** [0.19, 0.47]	
4. Intolerance to tampering with nature	-.35** [-0.48, -0.21]	.58** [0.47, 0.67]	.41** [0.27, 0.53]	-.40** [-0.52, -0.26]	.63** [0.53, 0.71]	.32** [0.18, 0.45]	-.30** [-0.44, -0.15]	.53** [0.40, 0.64]	.35** [0.20, 0.48]	-.28** [-0.42, -0.13]	.53** [0.41, 0.63]	.30** [0.15, 0.43]

** p<.01

Table 15 presents the results of the multiple linear regression analyses for participants' acceptance of crop-protection measures based on conditions. The four models were found to be statistically significant for the "synthetic pesticides" (F (5,162) = 11.83, p <.001), "natural pesticides" (F (5,162) = 6.44, p < .001), "gene transfer" (F (5,143) = 3.64, p < .01) and "gene editing" (F (5,152) = 6.51, p < .001) measures. The model explained 25 percent of the variance in the acceptance of "synthetic pesticides" and 14 percent for the variance in the acceptance of "natural pesticides". For the acceptance of "gene transfer" and "gene editing", the models explained eight and 15 percent of the variances, respectively. Chemophobia displayed a statistically significant negative relationship with the acceptance of each crop-protection measure. The importance of naturalness in food also displayed statistically significant negative relationships with the acceptance of "synthetic pesticides", "gene transfer" and "gene editing" crop-protection measures, but not with the acceptance of "natural pesticides". The socio-demographic variables (age and gender) only had significant positive relationships with the acceptance of "synthetic pesticides". The respondents' education levels had no significant influence on their acceptance of any crop-protection measure. The non-standardized regression coefficients and confidence intervals are shown in Table 15[2].

[2] The "overall credibility" of the texts was accounted for in the regression models. A minor change in the results was observed in one group ("gene transfer" group). That is, chemophobia had a marginal significant effect on the acceptance (α = .08). However, the "overall credibility" of the texts is linked to the respondent's perceptions, since information that is in line with peoples' perceptions tend to be viewed as more credible than information that is not (Edwards & Smith, 1996). Therefore, the "overall credibility" of the texts is linked to the manipulation performed in experiment 1 and should not be controlled for (Allen, 2017). Because of the above-mentioned reasons, the "overall credibility" was not added in the regression models.

Table 15. Experiment 1: Regression analyses on respondents' acceptance of crop protection measures by group.

	Acceptance of crop protection measures											
	Synthetic pesticides (n=168)			**Natural pesticides (n=168)**			**Gene transfer (n=149)**			**Gene editing (n=158)**		
Predictors	*B (se)*	*95% CI*	*β*	*B (se)*	*95% CI*	*β*	*B (se)*	*95% CI*	*β*	*B (se)*		*β*
Constant	115.21 (11.32)	[92.86, 137.55]		83.41 (11.89)	[59.94, 106.89]		107.40 (13.42)	[80.87, 133.93]		115.93 (13.59)	[89.07, 142.78]	
Age	**0.24 (0.12)**	**[0.01, 0.47]**	**0.15***	-0.07 (0.12)	[-0.30, 0.17]	-0.04	0.05 (0.14)	[-0.22, 0.31]	0.03	0.08 (0.13)	[-0.17, 0.33]	0.05
Gender	**7.87 (3.91)**	**[0.15, 15.58]**	**0.14***	-5.63 (3.77)	[-13.07, 1.81]	-0.11	-1.38 (4.50)	[-10.27, 7.51]	-0.03	-7.58 (4.12)	[-15.73, 0.56]	-0.14
Education	-0.00 (1.23)	[-2.42, 2.42]	0.00	0.75 (1.22)	[-1.66, 3.15]	0.05	1.12 (1.47)	[-1.79, 4.03]	0.06	-1.94 (1.32)	[-4.55, 0.67]	-0.12
Chemophobia	**-8.46 (2.06)**	**[-12.53, -4.38]**	**-0.32*****	**-9.04 (1.96)**	**[-12.92, -5.17]**	**-0.39*****	**-4.90 (2.29)**	**[-9.42, -0.37]**	**-0.19***	**-5.17 (2.13)**	**[-9.37, -0.67]**	**-0.27****
Importance of naturalness in food	**-14.74 (3.37)**	**[-21.40, -8.08]**	**-0.35*****	2.08 (2.86)	[-3.58, 7.73]	0.06	**-8.54 (3.56)**	**[-15.56, -1.51]**	**-0.21***	**-11.08 (3.39)**	**[-17.78, -4.37]**	**-0.20***
R^2 adjusted	0.25			0.14			0.08			0.15		
F (df1, df2)	11.83*** (5, 162)			6.44*** (5, 162)			3.64** (5, 143)			6.51*** (5, 152)		

B is the non-standardized regression coefficient. For B, the 95% confidence interval is shown. β is the standardized regression coefficient. df: degrees of freedom.
Significance: *p<0.05; **p<0.01; and ***p<0.001.
Education encompass 7 different levels, from 1 (mandatory school) to 7 (university degree).

4.3.2.5. Overall credibility and clarity of the texts

The overall credibility of the texts differed significantly between the groups (F (3,639) = 4.48, p < .001, η_p^2 = .02). The mean overall credibility was significantly higher in the "gene transfer" group (M = 3.59, SD = 0.75) than for the "synthetic pesticides" group (M = 3.32, SD = 0.85) and the "natural pesticides" (M = 3.31, SD = 0.83), but not so for the "gene editing" group (M = 3.46, SD = 0.59). The texts' credibility did not significantly differ between the "synthetic pesticides", "natural pesticides", and "gene editing" groups. There were no significant differences in the clarity of the texts between the groups (F (3,639) = 2.33, p = .07, η_p^2 = .01). The clarity of all four texts was very high (M = 79.27, SD = 19.79, Range: 0-100).

4.3.3. Discussion

The participants perceived gene transfers as more natural and acceptable than pesticide use and gene editing. Similar to previous findings (Kronberger et al., 2014; Siegrist, 2008; Siegrist et al., 2016; Tenbült et al., 2005), their acceptance of each measure was largely influenced by their naturalness perceptions.

Chemophobia and the importance of naturalness heavily influenced the participants' acceptance of pesticides and agri-biotech applications. Chemophobics hesitated to accept pesticides, likely due to concerns about the danger of pesticide residues in food (Bearth et al., 2019; Entine, 2011a; Peterson, 2000; Saleh et al., 2019; Williams & Hammitt, 2001). The participants also hesitated to accept agri-biotech applications, which suggests that chemophobics judge such applications and pesticides similarly. Likewise, participants who valued naturalness were likely to oppose synthetic pesticides and agri-biotech applications. Interestingly, the participants did not accept copper-based pesticides, despite their natural origins. In fact, all the groups reported low levels of perceived naturalness, suggesting that none of the measures satisfied the participants' desire for natural foods. The decrease in perceived naturalness for gene transfers was not as significant as for the other methods. Rather, gene transfers from a wild variety to a cultivated variety of the same species positively influenced the participants' naturalness perceptions and acceptance levels (Delwaide et al., 2015; Kronberger et al., 2014).

4.4. Experiment 2

The labels used for crop-protection measures might also affect consumers' naturalness perceptions and acceptance levels, as scientific labels can trigger negative associations (Siegrist, 2008; Zahry & Besley, 2019). For instance, in Experiment 1, the participants might have been more accepting of gene transfers because the provided description did not explicitly refer to gene technology. They might have recollected traditional plant breeding, which is more accepted than gene technology (Tanaka, 2013). Similarly, they may have associated gene editing with stigmatized gene technology and so been hesitant to accept it. Thus, clarifying whether consumers' acceptance of agri-biotech applications changes when scientific labels are added to the descriptions of such applications is necessary.

4.4.1. Methods

4.4.1.1. Experiment aim and design

Experiment 2 investigated how an application's label influences participants' perceptions. Two scientific labels, gene technology and gene editing, might carry stigmas and so negatively affect naturalness perceptions and the acceptance of agri-biotech applications.

The online experiment followed a procedure similar to that in Experiment 1, albeit without the pesticide-related conditions. It followed a two (gene transfer, gene editing) by three (control, gene technology, gene editing) design. The participants were provided with a description of a gene transfer from a wild potato to a cultivated potato, or a description of gene editing on a potato. Different scientific labels were applied to the gene-transfer and gene-editing processes. The first and second groups were controls. They were provided with descriptions of gene transfer and gene editing as crop-protection measures without the addition of scientific labels. The third and fourth groups were provided with descriptions of gene transfer and gene editing labeled "gene technology." The descriptions provided to the fifth and sixth groups were labeled "gene editing" (cf. Appendix C). It is important to note that for the fifth group, gene transfer was labelled as "gene editing" although in reality this application would not be called gene editing. However, this group was needed to find out how strongly perceptions are influenced by the label of a technology and how strongly by the description of the technology.

The participants were randomized into one of the six groups after providing informed consent and answering control and basic socio-demographic questions. After reading the texts, the participants indicated their general acceptance of the relevant agri-biotech application, their willingness to eat the described potato, and their naturalness perception of the potato. The credibility and clarity of the texts were assessed. Finally, the participants indicated their education level.

4.4.1.2. Participants

A prior power analysis determined that a minimum sample of $N = 576$ participants was needed to detect differences in the means between groups with a small effect size of $d = 0.15$ and a power of 0.80 (Cohen, 1988). To avoid having participants that are aware of the content of the experiment, which would bias the results of experiment 2, the market research company that we relied on to recruit participants in experiment 1 was not used again. Instead, the participants were recruited from the online panel of the Consumer Behavior Group at the Swiss Federal Institute of Technology in Zurich. Participants were invited to take part in the study via e-mail in March 2020. To avoid selection bias, the study's aim and topic were not revealed in the invitation.

A total of N = 648 participants completed the experiment. Fifty-five respondents were screened out for working in the chemical or biotechnological sector or for rarely or never consuming potatoes. An additional 13 respondents completed the experiment too quickly (i.e., in less than 2 minutes, which is half the median time) and were thus excluded from the analysis.[3] The final sample was comprised of 635 respondents (36.2% female, M_{age} = 65 years, SD_{age} = 12, range: 22–90 years). The respondents' self-reported education levels ranged from mandatory school; basic apprenticeship, prevocational school, or apprenticeship (n = 172, 27.1%); high school or technical and vocational training (n = 226, 35.6%); to university (n = 237, 37.3%). There were no significant differences between the six groups in terms of education levels (χ^2 (10, N = 635) = 12.87, p = .23) and gender distribution (χ^2 (5, N = 635) = 8.07, p = .15). Age distribution was also not significantly different between the six groups F (5, 629) = 1.54, p = .18 (cf. Table 16).

[3] There was no substantial difference in the results when data was analyzed with and without these 13 respondents. However, to ensure that the results presented are not affected at all by random or invalid responses, those 13 respondents were dropped from the analysis.

Table 16. Experiment 2: Socio-demographics total and by groups.

		Groups						
			"Control" groups		"Gene technology" groups		"Gene editing" groups	
		Total N = 635	**Group 1 N=102**	**Group 2 N=103**	**Group 3 N=107**	**Group 4 N=107**	**Group 5 N=109**	**Group 6 N=107**
Age	*M*[a] (*SD*)[b]	64.57 (12.43)	63.59 (11.88)	62.84 (12.36)	66.73 (12.39)	65.45 (13.01)	65.28 (11.69)	63.42 (13.00)
Gender	Female	230 (36.2%)	45 (44.1%)	44 (42.7%)	32 (29.9%)	33 (30.8%)	37 (33.9%)	39 (36.4%)
	Male	405 (63.8%)	57 (55.9%)	59 (57.3%)	75 (70.1%)	74 (69.2%)	72 (66.1%)	68 (63.6%)
Education	Low	172 (27.1%)	24 (23.5%)	29 (28.2%)	27 (25.2%)	22 (20.6)	32 (29.4%)	38 (35.5%)
	Middle	226 (35.6%)	38 (37.3%)	29 (28.2%)	38 (35.5%)	42 (39.3%)	38 (34.9%)	41 (38.3%)
	High	237 (37.3%)	40 (39.2%)	45 (35.8%)	42 (39.3%)	43 (40.2%)	39 (35.8%)	28 (26.2%)

[a] Mean [b] Standard deviation

4.4.1.3.Materials

The participants' general acceptance of the agri-biotech applications, willingness to eat the potatoes, and their perception of the potatoes' naturalness at baseline and post-text were assessed using the same scales as in Experiment 1. The acceptance scale was built by taking the mean over participants' general acceptance of the applications and their willingness to eat the potatoes grown with the agri-biotech applications. The scale exhibited a high Cronbach's alpha of $\alpha = .86$. The credibility and clarity of the texts were assessed in the same manner as in Experiment 1.

4.4.1.4.Data analysis

Univariate ANOVAs with simple main effects analyses were conducted to compare the differences between the groups and agri-biotech applications on the following dependent variables: acceptance of agri-biotech applications and naturalness perceptions of the potatoes post-text. Effect sizes n_p^2 were reported for the ANOVAs results. A one-way ANOVA was used to compare the baseline naturalness perceptions and the text credibility and clarity between the six groups.

4.4.2. Results

A significant main effect of the "agri-biotech applications" was found on the acceptance of the applications (F (1, 629) = 13.20, p < .001, η_p^2 = .02) and the post-texts naturalness perception of the applications (F (1, 629) = 9.97, p < .01, η_p^2 = .02). The "gene transfer" application (M = 54.78, SD = 30.47) was perceived as significantly more natural than the "gene editing" application (M = 47.37, SD = 28.63). Likewise, the acceptance of "gene transfer" (M = 64.79, SD = 29.62) was significantly higher than that of "gene editing" (M = 56.10, SD = 30.66). No significant main effect was found for "groups" on the acceptance of the applications (F (2, 629) = 0.60, p = .55, η_p^2 = .00), nor the post-text naturalness perception of the applications (F (2, 629) = 0.34, p = .71, η_p^2 = .00). The results also revealed no significant interaction effect of "agri-biotech applications" and "groups" on the acceptance (F (2, 629) = 0.51, p = .60, η_p^2 = .00), nor on post-texts naturalness perception of the applications (F (2, 629) = 0.51, p = .60, η_p^2 = .00) (cf. Table 17).

The simple effects analysis revealed that the "agri-biotech applications" effect was significant for the "gene technology" groups (F (1, 629) = 6.51, p < .05, η_p^2 = .01) but not for the "control" (F (1, 629) = 3.19, p = .08, η_p^2 = .01) and "gene editing" groups (F (1, 629) = 1.28, p = .26, η_p^2 = .00) in terms of naturalness perception post-text. Regarding acceptance, the "agri-biotech applications" effect was significant for the "control" (F (1, 629) = 4.00, p < .05, η_p^2 = .01) and "gene technology" groups (F (1, 629) = 8.15, p < .01, η_p^2 = .01) but not for the "gene editing" group (F (1, 629) = 2.07, p = .1, η_p^2 = .00).

Table 17. Experiment 2: Mean values of naturalness perceptions post-text and acceptance of “agri-biotech applications” by “groups”.

		Groups								
	Dependent variables	**Control group**			**Gene technology**			**Gene editing**		
	Naturalness perception post-texts	M	SE	N	M	SE	N	M	SE	N
Agri-biotech applications	Gene transfer	55.71	2.93	102	54.93	2.86	107	53.78	2.84	109
	Gene editing	48.32	2.92	103	44.59	2.86	107	49.22	2.86	107
	F (1,629)	3.19			6.51			1.28		
	α	0.08			0.01			0.26		
	Acceptance									
Agri-biotech applications	Gene transfer	66.08	2.99	102	66.74	2.92	107	61.67	2.89	109
	Gene editing	57.65	2.98	103	54.95	2.92	107	55.76	2.92	107
	F (1,629)	4.00			8.15			2.07		
	α	0.05			0.00			0.15		

Note: The mean values in the same column with different superscript letters are significantly different. Higher values indicate higher perceptions of naturalness post-text and higher acceptance of agri-biotech applications as crop-protection measures.

Regarding the control questions, the baseline naturalness perception was high (*M* = 63.84, *SD* = 27.64) across the whole sample and did not differ significantly between the six groups (F $(5, 629) = 0.12$ $p = .99$, $\eta_p^2 = .00$). Likewise, there were no significant differences in text credibility (F $(5,629) = 1.28$, $p = .27$, $\eta_p^2 = .01$) and clarity (F $(5,629) = 0.58$, $p = .72$, $\eta_p^2 = .01$), which were high across the whole sample (*M* = 3.73, *SD* = 0.81, Range:1-5 and *M* = 88.55, *SD* = 18.75, Range:0-100, respectively).

4.4.3. Discussion

The respondents differentiated between the gene transfer application and gene editing in terms of naturalness and acceptance. Transferring genes between varieties of the same species was perceived to be more natural and acceptable than the gene editing of species, even when both measures were described as gene technologies. This indicates that the process of modification (transfer or editing) might be more relevant for public acceptance than the scientific label (Lucht, 2015; Rozin, 2005; van Hove & Gillund, 2017). When the measures were described as gene editing, naturalness perceptions and acceptance of these measures did not differ. This finding suggests that the label "gene editing" has negative connotations among consumers.

4.5. General discussion

Previous research indicates that biotechnology applications have poor consumer acceptance (Frewer et al., 2013; Lucht, 2015). This study suggests that acceptance of agri-biotech applications might be context-specific, depending more on the technology's process than its label (Gomez, 2015; Rozin, 2005, 2006). Gene transfers between varieties of the same species are best accepted when the process is described, despite being labeled gene technology. Consumers might perceive the process to be natural because it can occur in nature (Gaskell et al., 2011; Holme et al., 2013; Lucht, 2015; Mielby et al., 2013) and does not involve any gene modifications (Telem et al., 2013). This allows the natural identity and existence of the transferred genes to be perceived as preserved (Mielby et al., 2013). By contrast, gene editing can prove difficult for consumers to associate with naturalness. It might be worthwhile to evaluate whether a clarification of what the genes would look like post-editing would influence consumers' naturalness perceptions and acceptance.

The participants were more accepting of gene transfers than pesticides. This finding is promising for modern agriculture, as gene transfers can be used to reduce pesticide use. However, pesticides and agri-biotech applications still face opposition from chemophobics, who might not accept pesticides simply for being chemicals (Saleh et al., 2019), which they feel should never be used in agriculture (Buzby & Skees, 1994; Dunlap & Beus, 1992; Lamichhane et al., 2016). In terms of agri-biotech applications, chemophobics might judge gene technology similarly to other food hazards, despite their lack of experience with gene technology (Bredahl, 1999; Siegrist, 2003). This study's finding that chemophobics who oppose pesticides might also fear and oppose agri-biotech applications is plausible. However, further investigation is required, as it is unclear whether chemophobics perceive genes as chemical substances or as harmful entities that can contaminate crops (von Alvensleben, 2001). Identifying consumers' misconceptions regarding genetics could help explain the relationship between chemophobia and acceptance of agri-biotech applications.

Ensuring consumers' acceptance of pesticides and agri-biotech applications could help develop agricultural policies and more effective approaches to protecting crops (Lamichhane et al., 2015). Policy-makers might need to act as risk communicators and address consumers' skepticism regarding pesticides and agri-biotech. First, they could describe and emphasize the role that pesticides play in pest-management. For instance, consumers might be unaware of integrated pest-management approaches that rely on pesticides only as a last resort (Barzman et al., 2015; Lamichhane et al., 2016). However, this message might not reduce consumers' concerns about pesticide residues, especially if they exhibit chemophobia. Tackling chemophobia might help reduce the stigma associated with pesticides and promote informed decision making. Through providing consumers with information on dose-response relationships and exposure levels, chemophobia could be mitigated (Bearth et al., 2016; Bearth et al., 2019; Saleh et al., 2019, 2020; Shim et al., 2011; Siegrist & Bearth, 2019), which could help people better assess the risks of pesticide residues. Second, fostering consumers' trust in policy-makers could influence their acceptance of agricultural practices (Siegrist, 2000, 2008). Policy-makers should continuously and transparently highlight the potential of scientific innovations to reduce pesticide reliance, which should help combat public skepticism and increase acceptance of relevant policies. Presenting other measures (i.e., cisgenic-modification) as possible means of minimizing or replacing pesticide use might alleviate consumers' concerns and ensure their acceptance (Edenbrandt, 2018; Gheysen & Custers, 2017; Lucht, 2015; Rousselière & Rousselière, 2017). Finally, the findings of this study imply that labelling cisgenetically modified food as GM food might not be helpful (Delwaide et al., 2015; Kronberger et al., 2014; Schouten et al., 2006), although providing a short description of the cisgenic-modification process as a gene transfer between the same species could prove useful. More research is required to determine the feasibility of this approach.

In terms of limitations, the baseline naturalness perception differed across the groups. The "gene editing" group exhibited the lowest naturalness perception, which might have led to lower post-text naturalness perceptions and lower acceptance of gene editing. Further investigation of the naturalness perceptions and acceptance of gene editing when compared to pesticides could indicate consumers' positions regarding the use of gene editing for crop-protection. Another limitation was that the study did not connect the implications for consumers' acceptance of food grown using the different crop-protection measures to real-life decisions and behaviors. This was because consumer acceptance was self-reported and might have been overestimated. Further, the findings do not allow for generalizations regarding consumers' acceptance of gene transfers for obtaining other desirable traits in crops. For instance, medical applications of biotechnology are perceived more positively than non-medical applications (Bonfadelli et al., 1998; Frewer & Shepherd, 1995). This means it cannot be assumed that consumers who accept gene transfer as a crop-protection measure would also accept it for making crops more nutritious or flavorful. Examining these intricacies might help policy-makers understand the extent to which gene transferring could be implemented in agriculture. The limiting of gene transfers to plants of the same species may also have influenced consumers' positive reactions. Future studies should investigate consumers' reactions to inter-plant-species gene transfers. A better understanding of consumer perceptions concerning gene transferring could be achieved by systematically manipulating the perceived distance between where genes come from and where they are implemented. Lastly, while the participants in Experiment 1 were representative of the Swiss-German population (62% of the Swiss population are German-speaking; Swiss Federal Statistical Office, [2018]), Experiment 2 involved a convenience sample in which females were under-represented and the mean age was higher than that of the general population (Swiss Federal Statistical Office, 2019). Therefore, future studies should examine consumers' perceptions of agri-biotech labels using representative samples.

4.6. Conclusion

This study elucidates consumer perceptions of chemical and genetic crop-protection measures. Both types (chemical and genetic) are measures that consumers tend to be most skeptical about when compared with other crop-protection measures (e.g., physical, mechanical), which presents a challenge for policy-makers. The future of pest-management practices depends on how natural crop-protection measures are perceived by consumers. A process that preserves the natural existence of food crops and diminishes (or eliminates) the presence of synthetic entities is likely to be accepted by consumers. Therefore, cisgenic-modification, when presented as gene transfers between the same plant species, might be a promising measure that consumers are likely to accept. Policy-makers should consider consumers' naturalness perceptions and chemophobia when communicating about pest-management practices. Consumers' trust in such practices could increase if chemophobia is addressed and consumers are informed about crop-protection processes and their role in pest-management.

Appendices

<u>Appendix A:</u>

<u>Experiment 1</u>

<u>The potato blight issue presented with pictures to all participants:</u>

Potatoes are one of the most harvested crops in Switzerland. One of the biggest challenges with growing potatoes is dealing with potato blight. Potato blight is a fungal disease that attacks the leaves of the potatoes and can spread rapidly in potatoes and destroy them, leading to large losses in potato crops and endangering the security of food supplies.

(Pictures of potato plants infected with the fungal disease were provided alongside the texts to make the disease more salient to the participants).

<u>The solutions to the potato blight issue presented to the four groups of participants</u>

The "synthetic pesticide" group: To protect the potatoes from potato blight in conventional farming, fungicides are sprayed on the potatoes until harvesting time. The fungicides are sprayed on the leaves of the potatoes, while the potatoes are under the soil, therefore there is no direct contact between the fungicides and the potatoes.

The "natural pesticides" group: To protect the potatoes from potato blight in organic farming, copper is sprayed on the potatoes until harvesting time. Copper is sprayed on the leaves of the potatoes, while the potatoes are under the soil, therefore there is no direct contact between the copper and the potatoes.

The "gene transfer" group: To protect potatoes from potato blight, genes of a wild potato that is resistant to potato blight are transferred into the cultivated potato. This gene transfer makes the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

The "gene editing" group: To protect potatoes from potato blight, certain locations in the genome of the potato are edited. This leads to the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

Appendix B

Experiment 1:

Means (*M*) and standard deviations (*SD*) of the items of the chemophobia, importance of naturalness in food, and tampering with nature scales

Chemophobia scale (*M* = 3.53, *SD* = 1.07)	**M (SD)**
I would like all chemical substances to be risk-free.	4.99 (1.21)
In a world without chemical substances, there would be no environmental disasters.	2.63 (1.44)
I do everything I can to avoid contact with chemical substances in my daily life.	3.44 (1.43)
The chemical industry is responsible for more people suffering from cancer.	3.56 (1.50)
I would like to live in a world where chemical substances don't exist.	3.60 (1.63)
I am scared of chemical substances that I cannot pronounce.	3.12 (1.61)
Chemical substances scare me.	3.40 (1.52)

Importance of naturalness in food scale (*M* = 3.26, *SD* = 0.68)	**M (SD)**
It is important to me that the food I eat on a typical day:	
Contains natural ingredients	3.47 (0.73)
Contains no additives	3.11 (0.79)
Contains no artificial ingredients	3.20 (0.85)

Tampering with nature scale (*M* = 4.54, *SD* = 1.32)	**M (SD)**
People who push for technological fixes to environment problems are underestima the risks.	4.33 (1.57)
Human beings have no right to meddle with the natural environment.	4.57 (1.67)
Altering nature will be our downfall as a species.	4.20 (1.73)
I would prefer to live in a world where humans leave nature alone.	5.04 (1.51)

N=643

Respondents indicated how strongly they agree with the items relating to "chemophobia" on a six-point Likert scale (1 = strongly disagree, 6 = strongly agree).

Items of the importance of naturalness in food were filled out using a four-point Likert scale (1 = not important at all, 2=a little important, 3=moderately important, 4= very important).

They also indicated how much they agree with the items of the scale "tampering with nature" using a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree)

Appendix C:

Experiment 2

The same potato blight issue presented in Experiment 1 shown in Appendix A was presented to all the participants of Experiment 2.

The solutions to the potato blight issue presented to the six groups of participants

The two "control" groups: These groups were given descriptions of gene transfer and gene editing as crop-protection measures without the addition of scientific labels.

Group 1: To protect potatoes from potato blight, genes of a wild potato that is resistant to potato blight are transferred into the cultivated potato. This gene transfer makes the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

Group 2: To protect potatoes from potato blight, certain locations in the genome of the potato are edited. This leads to the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

The two "gene technology" groups: The third and fourth groups were given descriptions of gene transfer and gene editing labeled as "gene technology."

Group 3: To protect potatoes from potato blight, genes of a wild potato that is resistant to potato blight are transferred into the cultivated potato with gene technology. This gene transfer makes the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

Group 4: To protect potatoes from potato blight, certain locations in the genome of the potato are edited with gene technology. This leads to the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

The two "gene editing" groups: The fifth and sixth groups were given descriptions of gene transfer and gene editing labeled as "gene editing".

Group 5: To protect potatoes from potato blight, genes of a wild potato that is resistant to potato blight are transferred into the cultivated potato with gene editing. This gene transfer makes the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

Group 6: To protect potatoes from potato blight, certain locations in the genome of the potato are edited with gene editing. This leads to the desired changes in the genome of the cultivated potato enabling it to protect itself against potato blight.

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Chapter V Addressing chemophobia: informational vs. affect-based strategies

Manuscript published as:

Saleh, R., Bearth, A., & Siegrist, M. (2020). Addressing Chemophobia: Informational versus Affect-based Approaches. *Food and Chemical Toxicology, 140*.

doi:10.1016/j.fct.2020.111390

Abstract

This study investigated the effect of two communication strategies (informational and affect-based) in reducing chemophobia, the irrational fear of chemicals. In an online experiment, participants (N = 448) were randomly assigned to one of three groups ("control", "knowledge", or "affect" group). The following dependent variables were assessed: chemophobia, knowledge of basic toxicological principles, affect towards chemicals, benefit perception of the use of chemicals, and preference for natural substitutes in consumer products. The results showed that only the informational approach, which conveys knowledge of basic toxicological principles, significantly decreased chemophobia and the preference for natural substitutes in consumer products. The affect-based approach significantly increased positive affect towards chemicals and the benefit perception of their use, but did not decrease chemophobia. This suggested that the provision of relevant information about basic toxicological principles is a more effective strategy than merely addressing laypeople's affect towards chemicals to reduce chemophobia. Relevant knowledge could be taught in schools or disseminated by toxicologists and scientists who are trusted by the public.

5.1. Introduction

Chemophobia is the irrational fear of chemicals (Entine, 2011; Gribble, 2013; Michaelis, 1996). People exhibiting chemophobia tend to be overly concerned with the risks of chemicals and believe that chemicals are harmful at any concentration and exposure level (Kraus, Malmfors, & Slovic, 1992; Mertz, Slovic, & Purchase, 1998; Saleh, Bearth, & Siegrist, 2019; Slovic et al., 1995). In fact, for lay-people, the term "chemicals" likely refers to synthetic chemicals, since chemophobia is more strongly associated with the fear of exposure to synthetic chemicals than natural ones (Entine, 2011; Gribble, 2013; Rozin, 2005; Rozin et al., 2004; Saleh et al., 2019; Siegrist & Bearth, 2019). People expressing chemophobia tend to prefer chemicals of natural origin over synthetic chemicals in products. This is because the former is perceived as safe and healthy while the latter is perceived as inherently dangerous (Entine, 2011; Rozin, Fischler, & Shields-Argeles, 2012; Rozin et al., 2004). Thus, the risk of a chemical is judged based on its origin (man-made or found in nature), despite the fact that this is not an indicator of its toxicity (Bearth, Saleh, & Siegrist, 2019; Saleh et al., 2019).

People's risk perceptions can influence their decision-making and their behaviors (Slovic, 1987; Slovic, Peters, Finucane, & Macgregor, 2005; Williams & Noyes, 2007). Hence, chemophobia may prevent people from making informed decisions regarding chemicals and consumer products. For instance, people with high levels of chemophobia may reject certain chemicals and products (e.g., pharmaceutical drugs, vaccines) that are beneficial, simply for being man-made and thus, perceived as unsafe (Entine, 2011; Lynch & Berry, 2007).

Previous research suggests that a better understanding of basic toxicological principles is associated with lower levels of chemophobia (Bearth et al., 2019; Saleh et al., 2019). However, this association does not infer a causal relationship between knowledge and chemophobia. An experimental examination of this relationship can help determine how to address chemophobia. Moreover, risk literature stresses the role of affect for consumers' risk perceptions and decision-making since people may lack the knowledge to make an informed decision (Alhakami & Slovic, 1994; Finucane, Alhakami, Slovic, & Johnson, 2000; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997).

Therefore, the present study examines the effect of two different communication strategies, informational and affect-based (i.e., based on emotions), on people with chemophobia and their perceptions of synthetic and natural chemicals. Overall, the findings of this study could provide potentially effective risk communication strategies that could address laypeople's misconceptions of toxicological principles and, consequently, chemophobia.

5.2. Theoretical background

5.2.1. Chemophobia: origin and consequences

Laypeople tend to possess a distorted image of the risks of (synthetic) chemicals while being unaware of their benefits. The term "chemical" itself is stigmatized and often associated with cancer, toxicity, and death (Ropeik, 2015; Rozin et al., 2004; Saleh et al., 2019). Consumer goods companies avoid this stigma by replacing E numbers or synthetic-sounding ingredients with more appealing names such as "aroma" for foods or "fragrances" for perfumes (Asioli et al., 2017; Gribble, 2013). "Chemical-free" or "green" labels are also used on different consumer goods (e.g., food, cleaning products), which may contribute to peoples' fears of chemicals and the erroneous belief that a chemical-free life is possible (Entine, 2011; Francl, 2013).

Furthermore, people tend to believe that anything produced by human intervention cannot be equal to what originates in nature (Principe, 2013; Rozin, 2005). What is perceived as natural holds positive connotations in many contexts (e.g., health, medicine, food production (Meier, Dillard, Osorio, & Lappas, 2019; Rozin, 2005; Rozin et al., 2012; Rozin et al., 2004). Rozin and colleagues have argued that ideational and instrumental beliefs drive preferences for natural chemicals (Rozin, 2005; Rozin et al., 2012; Rozin et al., 2004). Ideational beliefs account for the perception of chemicals of natural origin as morally superior to synthetic chemicals. Instrumental beliefs, however, focus on specific attributes of chemicals, such as chemicals of natural origin being safer and healthier than synthetic chemicals (Rozin, 2005; Rozin et al., 2004). Anecdotal evidence suggests that people who are afraid of chemicals prefer natural ingredients over synthetic ones in consumer products (Entine, 2011). In fact, the preference for chemicals of natural origin in different consumer products (e.g., food, medicine, household cleaning products, personal care products) is well-documented in research but has never explicitly been linked to chemophobia (Apaolaza, Hartmann, Lopez, Barrutia, & Echebarria, 2014; Bearth, Cousin, & Siegrist, 2014; Chermahini, Majid, & Sarmidi, 2011; Dickson-Spillmann, Siegrist, & Keller, 2011; Lynch & Berry, 2007; Meier et al., 2019; Rozin et al., 2004). However, chemicals of natural origin in consumer products do not necessarily make these products less risky or healthier. The assumption that any product labelled "natural" is safer and better for health than regular products is inaccurate and may have consequences. For example, people exhibiting chemophobia are more likely to take herbal medicine than over-the-counter and prescription drugs because herbal medicine is perceived to be natural and safer than synthetic medicine (Lynch & Berry, 2007). Moreover, they may view a hazardous consumer product, such as essential oils or eco-labelled drain cleaner, as natural and safe and unknowingly endanger their own health, as well as the health of others (Bearth, Miesler, & Siegrist, 2017; Gribble, 2013). In addition, people may support bans on certain chemicals (e.g., synthetic agriculture chemicals, vaccines, food additives) that may be irreplaceable or even replaced with natural alternatives that are not necessarily safer, more effective or efficient (Gribble, 2013; Winter & Katz, 2011; Entine, 2011; McKee & Bohannon, 2016). Lastly, risk management authorities might waste national funds responding to such unwarranted scares (Monro, 2001; Ropeik, 2012). Therefore, reducing chemophobia is important to prevent unnecessary overreactions to synthetic chemicals and ensure informed decision-making

5.2.2. Chemophobia: the role of knowledge vs. affect heuristic

Several misconceptions regarding chemicals and basic toxicological principles have been identified in the literature (Bearth et al., 2019; Chalupa & Nesmerak, 2014; Entine, 2011; Francl, 2013; Kauffman, 1989; Kraus et al., 1992; Saleh et al., 2019). People who are afraid of chemicals might infer definite adverse health effects from minor doses and exposure to them (Bearth et al., 2019; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Saleh et al., 2019; Slovic et al., 1997). In addition, higher levels of chemophobia are associated with the misconception that synthetic and natural entities are chemically different (Bearth et al., 2019; Saleh et al., 2019). Lastly, natural chemicals are not necessarily recognized as "chemicals" since people associate the word with synthetic ingredients.

Previous research showed that chemophobia is related to low levels of knowledge about toxicological principles. A basic understanding of chemicals and basic toxicological principles may reduce chemophobia and support informed decision-making (Bearth, Cousin, & Siegrist, 2016; Bearth et al., 2019; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Saleh et al., 2019; Shim et al., 2011; Siegrist & Bearth, 2019). However, due to the lack of knowledge and resource restraints (e.g., lack of time, motivation or attention), laypeople do not always rely on the analytical evaluations of risks (Slovic, Finucane, Peters, & MacGregor, 2002, 2004). In fact, in the absence of knowledge, people may rely on heuristics, which are mental shortcuts to make quick decisions. The "affect heuristic" might be one heuristic people employ when judging chemicals. According to the affect heuristic, chemicals may evoke images and associations tagged with negative or positive feelings. People rely on these feelings (i.e., their affect) to judge their acceptance, risk and benefit perception of a particular issue (Alhakami & Slovic, 1994; Finucane et al., 2000; Slovic et al., 2005). A negative affect towards an issue could lead to a higher risk perception and a lower benefit perception of that issue and vice versa (Finucane et al., 2000; King & Slovic, 2014; Slovic et al., 2004). The use of affect is faster and can be more efficient than undergoing analytical evaluations (Finucane et al., 2000; Gigerenzer & Gaissmaier, 2011). Nonetheless, decisions made by relying on affect might be biased and not in the person's best interest (Ropeik, 2011; Siegrist & Sutterlin, 2014; Slovic et al., 2002, 2004). For instance, previous research suggests that a significant proportion of people have neutral or even negative associations with chemicals and thus, negative affect (Saleh et al., 2019). This negative affect might drive people's negative perceptions of chemicals and chemophobia (Entine, 2011; Saleh et al., 2019). Therefore, de-stigmatizing chemicals might be necessary to reduce negative affect and unwarranted risk perceptions of chemicals.

5.2.3. Study aims and design

Thus far, risk communication efforts to de-stigmatize synthetic chemicals, clarify misconceptions, and reduce concerns related to chemicals have rarely been evaluated systematically (Bearth et al., 2016; Chalupa & Nesmerak, 2018; Royal Society of Chemistry, 2015). Therefore, the goal of the present research was to investigate strategies that successfully reduce chemophobia and increase knowledge of toxicological principles. More specifically, the primary objective was to test the effect of two communication strategies on chemophobia. The first strategy was based on the information provision of basic toxicological principles, such as the dose-response relationship. The second strategy was an affect-based approach focusing on de-stigmatizing chemicals and conveying their benefits to individuals and society. Based on previous literature (Bearth et al., 2016; Bearth et al., 2019; Dickson-Spillmann et al., 2011; Saleh et al., 2019; Shim et al., 2011), it was hypothesized that information provision would reduce chemophobia. However, the affect heuristic also states that, in the absence of knowledge, people might rely more heavily on their affect when judging a risk. Thus, it was hypothesized that the affect-based approach would also reduce chemophobia. Therefore, the main focus of this study was to investigate which strategy would be more effective for reducing chemophobia. The secondary objective was to investigate the impact of the two communication strategies on people's preferences for natural substitutes in consumer products.

5.3.Methods

5.3.1. Experimental design

The study has a between-subjects design with two experimental groups and a control group. Prior to being randomly assigned to one of the three groups, participants gave their informed consent and answered basic socio-demographic questions. Then, each group of participants was presented with a different video. The first experimental group ("affect" group) was shown a video about the widespread uses of chemicals in different consumer products and services (e.g., in food, water, clothes, electronics, cars, medicine) to portray the beneficial aspect of chemicals and its role in everyday life. For example, the video shows the presence of synthetic fibers in medical wear for protection, safety and hygiene. This video was developed and published in 2011 by the United Nations Educational Scientific Cultural Organization (UNESCO, 2011). The second experimental group ("knowledge" group) watched a video explaining basic toxicological principles (e.g., dose-response relationship, natural and synthetic chemicals toxicity, etc.) to provide basic information on chemicals and toxicological principles. The video's content was based on the findings of two previous studies on people's misconceptions and knowledge gaps about toxicological principles (Bearth et al., 2019; Saleh et al., 2019). In order to ensure comparable conditions in the control group, another video was developed on a topic unrelated to the study: black holes. The "control" group video was timely due to the recent release of the first picture of a black hole. The "knowledge" group's experimental video and the "control" group's video were made by the authors for the purpose of this study. The contents of the two videos were discussed with experts to ensure correctness and accuracy. All three videos were of the same length (2 minutes 40 seconds) (cf. all three videos in Appendix A). The sources of the videos were revealed at the end of the experiment.

After presenting the videos, participants were asked whether they had any technical difficulties when playing the videos (visual or auditory). Specific questions regarding the visual content of the videos were asked to ensure that people paid attention and did not fast-forward or skip sections. Participants were then asked to evaluate the quality of the videos, whether they had ever seen the videos or similar videos before, and whether they learned new information. Subsequently, several dependent variables (chemophobia, knowledge of basic toxicological principles, affect towards chemicals, benefit perception of the use of chemicals, and preference for natural substitutes in consumer products) were assessed. At the end of the survey, participants answered additional socio-demographic and control questions (e.g., level of education, profession). Lastly, all participants were provided with an optional written text that cleared up any uncertainties raised by the questionnaire.

5.3.2. Participants

A sample of Swiss German-speaking participants from the online panel of the Consumer Behavior Group at the Swiss Federal Institute of Technology in Zurich (ETH Zurich) was recruited. The registered panel members had previously agreed to participate in the groups' studies on a regular basis. Participants were invited to take part in this online study via e-mail in July 2019. A reminder e-mail was sent one week after the initial invitation. To avoid selection bias, the study aim and topic were not revealed in the invitation.

Based on a prior power analysis, a sample of at least $N = 432$ participants is needed to detect a small effect size of $d = 0.15$ with a power of 0.80 (Cohen, 1988). The effect size was based on the findings of a similar prior study with videos informing consumers about the risk assessment of food additives (Bearth et al., 2016). More participants were sampled, as it was expected that some participants would have to be excluded due to technical difficulties while watching the videos or for not passing the manipulation check. A total of $N = 470$ of the $N =$ 973 invited participants fully completed the online experiment without experiencing technical difficulties playing the videos, which corresponds to a response rate of 48.3%. From this sample, 22 participants were dropped from the analysis, of which 8 did not pass the manipulation check, and 14 had a profession in a chemical-related field. The final sample was composed of 448 participants (59.8% males, M_{age} = 61.76 years, SD_{age} = 13.44, range: 19–89 years). The respondents' self-reported education levels ranged from mandatory school, basic apprenticeship, prevocational school, or apprenticeship (n = 132, 29.5%), to high school or technical and vocational training (n = 140, 31.3%), and university (n = 186, 39.3%). There were no significant differences between the three groups in terms of education levels (χ^2 (4, N = 448) = 2.41, p = .66), and gender distribution (χ^2 (2, N = 448) = 0.17, p = .92). Age distribution was also not significantly different between the three groups F (2, 445) = 1.67, p = .19. Table 18 presents the socio-demographics of the three groups.

Table 18. Socio-demographics total and by groups.

			Groups		
		Total (*N*=448)	**Control** (*n*=151)	**Knowledge** (*n*=155)	**Affect** (*n*=142)
Age	*M*[a] (*SD*)[b]	61.76 (13.44)	60.16 (14.14)	62.28 (12.92)	62.87 (13.16)
Gender	Female	180 (40.2%)	60 (39.7%)	61 (39.4%)	59 (41.5%)
	Male	268 (59.8%)	91 (60.3%)	94 (60.6%)	83 (58.5%)
Education	Low	132 (29.5%)	50 (33.1%)	40 (25.8%)	42 (29.6%)
	Middle	140 (31.3%)	42 (27.8%)	52 (33.5%)	46 (32.4%)
	High	176 (39.3%)	59 (39.1%)	63 (40.6%)	54 (38.0%)

[a] Mean [b] Standard deviation

5.3.3 Materials

5.3.3.1. Evaluations for the overall quality of the videos

Participants evaluated the quality of the videos regarding five aspects (if the video was understandable, convincing, believable, useful, and interesting) on a Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree). For each video, a scale for overall quality was calculated by taking the mean of the five quality aspects for each participant. Based on a reliability analysis (i.e., measures how strongly the items included in the scale are correlated), this overall quality scale had an excellent internal consistency with Cronbach's alpha $\alpha = 0.92$. Values of Cronbach's alpha between 0.6 - 0.7 indicate acceptable levels of reliability. Values of 0.8 and 0.9 indicate good and excellent levels of reliability respectively (Streiner, 2003).

5.3.3.2. Dependent variables

Chemophobia was assessed with an adapted version of a previously used measure, on a Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree) (Bearth et al., 2019; Saleh et al., 2019). The items are shown in Table 19. The scale for chemophobia was built by taking the mean of all items after conducting principal component analysis and reliability analysis. According to Kaisers' criterion and the scree plot, one-factor solutions were uncovered for the multi-item scale (cf. item-total correlations in Table 19)(Cattell, 1966). The item-total correlations show the association between each item of the scale with the total scale scores without that particular item (i.e., how well the item fits into the scale) (Streiner, 2003). These correlations revealed that one item (*it is possible to purify the body with detox treatment*) has a low correlation with the total scale ($r < 0.3$). This low correlation suggests that this item is not measuring the same construct as the other items, and should be excluded from the scale. Hence, the chemophobia scale consisted of seven items with a good Cronbach's alpha $\alpha = 0.83$ indicating that this scale is reliable.

Table 19. Chemophobia and preference for natural substitutes in consumer products: Item-total correlations (Item-total r) and scales' Cronbach's alpha (α).

Items	Item-total r
Chemophobia scale[a] (α = .83)	
I do everything I can to avoid in my daily life contact with chemical substances	.65
I would like to live in a world where chemical substances don't exist	.65
Chemical substances scare me	.64
I am scared of chemical substances I cannot pronounce	.57
In a world without chemical substances, there would be no environmental disasters	.52
The chemical industry is responsible for more people suffering from cancer	.51
I would like all chemical substances to be risk-free	.41
Preference for natural substitutes in consumer products scale[b] (α = .90)	
Everyday care products (e.g., deodorant, shampoo)	.80
Regular cleaning products (e.g., window cleaner, dish washer)	.79
"Specialized" cleaning products (e.g., descalers)	.74
Convenience food (e.g., frozen Lasagne)	.71
Beverages (e.g., flavors in soft drinks)	.69
Medicine (e.g., nasal spray, painkiller)	.66

N = 448

The knowledge scale comprised seven items based on the validated knowledge of basic toxicological principles scale (Bearth et al., 2019; Saleh et al., 2019). The scale comprises two correct statements (items 6 and 7) and five incorrect statements (items 1–5) about toxicological principles (cf. Figure 7). Participants could respond to each item with "right," "wrong" or "do not know." All correct responses were recoded as 1 and all incorrect and "do not know" responses as 0. Correct responses were summed for each participant to produce a knowledge score. Thus, a high score indicates high knowledge, while a low score indicates little knowledge.

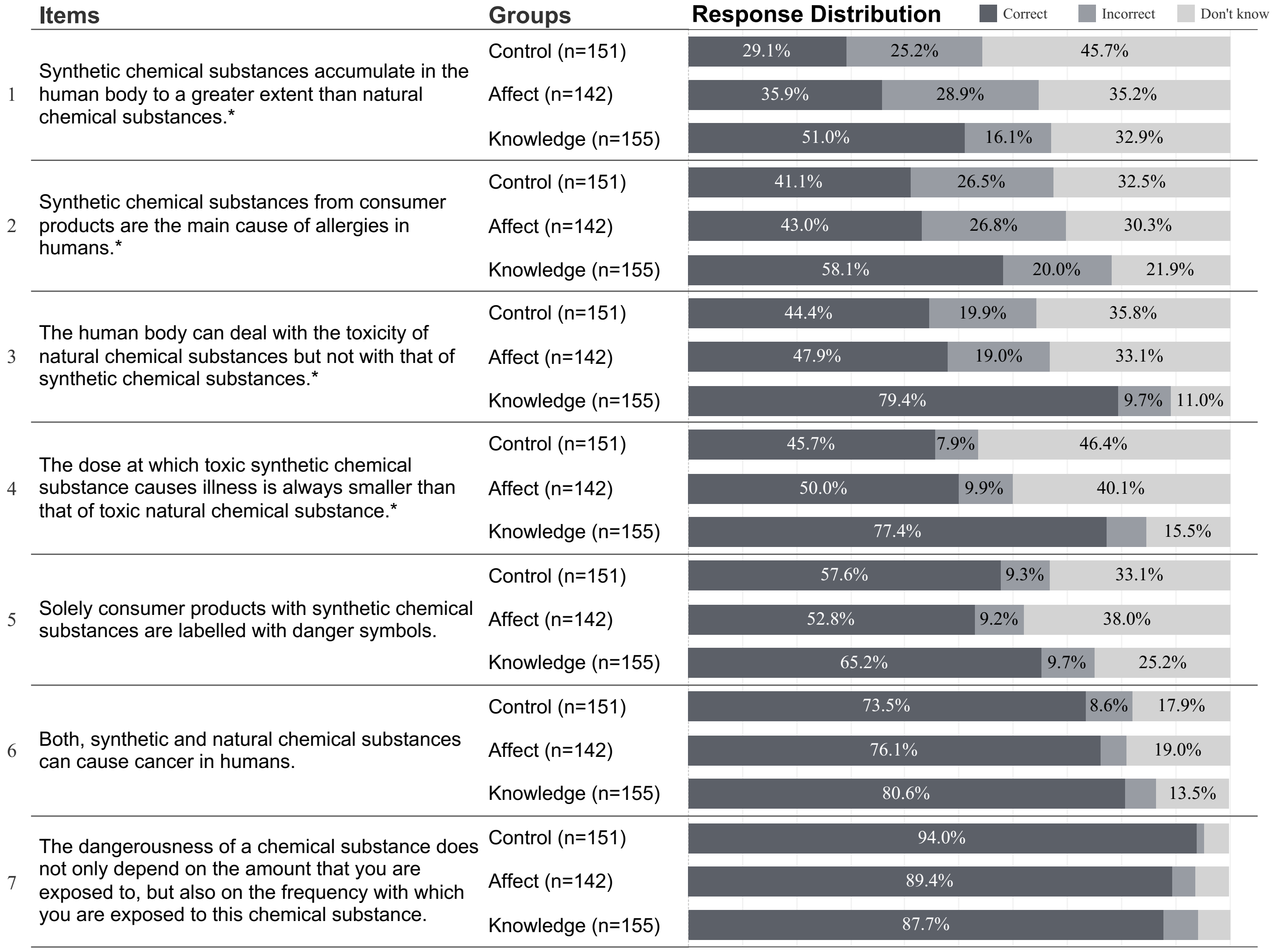

Figure 7. Response distribution of the items regarding the knowledge of basic toxicological principles scale for the three groups.

(*) denotes items with response distributions significantly different between the three groups.

Affect towards chemicals was measured by asking participants the following question: “What type of feelings are evoked in you when you think of the term ‘chemical substances’?” Participants could indicate their evoked affect towards chemicals on a slider ranging from 0 (extremely negative) to 100 (extremely positive).

Benefit perception was measured with the following question: “How beneficial do you think the use of chemical substances is in consumer products?” Participants’ responses were recorded on a slider ranging from 0 (not beneficial at all) to 100 (extremely beneficial).

To assess the preference for natural substitutes in consumer products, participants were asked the following question: “How important is it for you that there are natural alternatives for the chemical substances used in the following products?” Five consumer products from different products domains (food, beverages, medicine, household cleaning products, and personal care products) were listed. Participants indicated the importance of having natural chemicals in each of the five products on a Likert scale ranging from 1 (not important at all) to 6 (extremely important). Similar to the chemophobia scale, the scale for the preference for natural substitutes in consumer products was built by taking the mean of the items for the construct. For this scale, a one factor solution was found (cf. item-total correlations in Table 19). The scale also exhibited an excellent Cronbach’s alpha of $\alpha = 0.90$ based on reliability analysis.

5.3.4. Data analysis

Data was analyzed using SPSS version 25.0 (IBM Corp., 2017). One-way analyses of variances (ANOVA) with Tukey’s post-hoc tests that allows to evaluate whether and which groups differ on the variables of interest (Iversen & Norpoth, 1987), were conducted to compare the differences between the three groups on the following dependent variables: chemophobia, knowledge of basic toxicological principles, affect towards chemicals, benefit perception of the use of chemicals, and preference for natural substitutes in consumer products. Effect sizes n_p^2 were reported for results of one-way ANOVAs to assess the strength of the differences in the dependent variables due to the videos (Cortina & Nouri, 2000). Additional analyses to evaluate the relationship between knowledge provision and the communication strategies (informational and affect-based) were conducted using Chi-square tests (Ugoni & Walker, 1995). Figures featured in this study were prepared using Tableau Desktop (Tableau Software Inc., 2003) and SPSS (IBM Corp., 2017).

5.4. Results

5.4.1. Evaluations for the overall quality of the videos

The overall quality of the videos (i.e., if the video was understandable, convincing, believable, useful, and interesting) was significantly different between the groups, F (2,445) = 31.48, p < .001. The post-hoc tests indicated that the mean overall quality of the videos were significantly higher for the "knowledge" group (M = 4.92, SD = 1.08) than the "control" group (M = 4.36, SD = 1.09). The video quality for the "affect" group was lower than the others (M = 3.85, SD = 1.30). In addition, 45.1% of the "control" group and 36.2% of the "knowledge" group reported having learned new information from the videos, compared to 18.7% from the "affect" group, χ^2 (2, N = 448) = 62.19, p < .001.

5.4.2. Effect of different videos on the dependent variables

5.4.2.1. Chemophobia

Participants' self-reported chemophobia differed significantly between the groups, F (2,445) = 13.32, p < .001 (cf. Table 20). The post-hoc tests indicated that the "knowledge" group had significantly lower chemophobia levels (M = 2.57, SD = 0.97) than both the "affect" (M = 3.06, SD = 0.98) and the "control" (M = 3.07, SD = 0.94) groups (cf. Figure 8). There was no significant difference between the "affect" and "control" groups.

Table 20. Means (M), standard deviations (SD), and one-way analyses of variances for the effect of the three groups on five dependent variables.

	Groups				
	Control (*n*=151)	**Knowledge** (*n*=155)	**Affect** (*n*=142)		
Dependent Variables	M (SD)	M (SD)	M (SD)	F (2, 445)	η_p^2
Chemophobia	3.07 (0.94) $_a$	2.57 (0.97) $_b$	3.06 (0.98) $_a$	13.32**	0.06
Knowledge of basic toxicological principles	3.85 (1.91) $_a$	4.99 (1.62) $_b$	3.88 (1.90) $_a$	19.61**	0.08
Affect towards chemicals (0 = negative, 100 = positive)	48.56 (13.08) $_a$	44.03 (13.26) $_a$	54.34 (20.37) $_b$	15.86**	0.07
Benefit perception of the use of chemicals	40.67 (23.47) $_a$	51.45 (22.72) $_b$	49.31 (26.88) $_b$	8.32**	0.04
Preference for natural substitutes	4.62 (1.05) $_a$	3.97 (1.34) $_b$	4.49 (1.26) $_a$	12.04**	0.05

Means in a row that have the same subscript letter (i.e., a or b) are not significantly different from each other (reading example: The means of the "control" and "affect" groups have the subscript a, while the mean of the "knowledge" group has the subscript b. This suggests that the mean of the "knowledge" group differed significantly from the means of the "control" and "affect" groups). ** $p < .001$, F value (degrees of freedom), η_p^2: partial eta square.

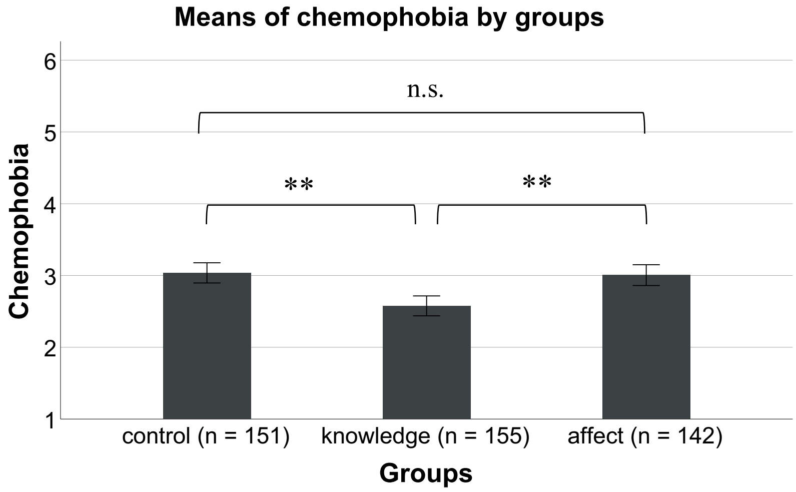

Figure 8. Chemophobia with 95% confidence intervals by groups

*** indicates significance at p < .001*

n.s. indicates significance at p > .05 (not significant

5.4.2.2. Knowledge of basic toxicological principles

Overall, participants' understanding of basic toxicological principles differed significantly between the groups, F (2,445) = 19.61, p < .001 (cf. Table 20). The post-hoc tests indicated that the understanding of basic toxicological principles of the "knowledge" group (M = 4.99, SD = 1.62) was significantly higher than the "control" (M = 3.85, SD = 1.91) and "affect" (M = 3.88, SD = 1.90) groups (cf. Figure 9). There was no significant difference between the "control" and "affect" groups.

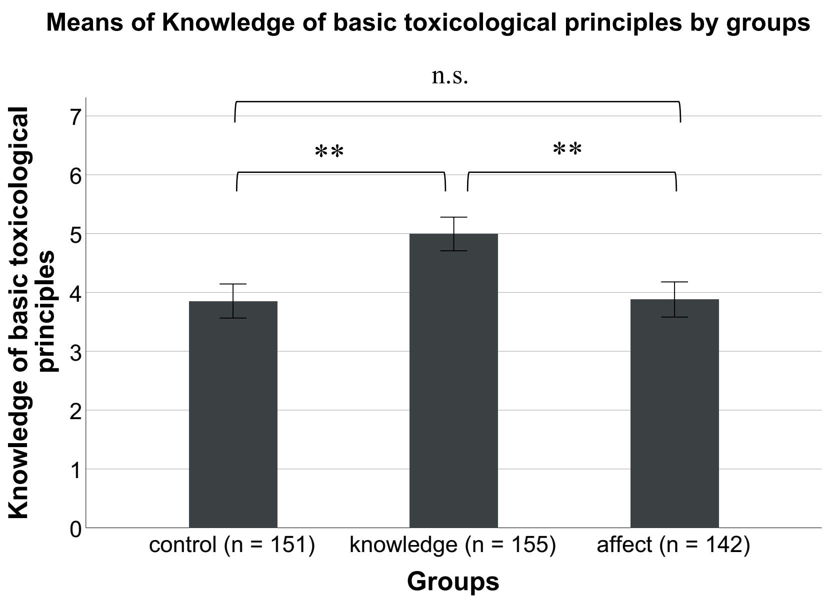

Figure 9. Knowledge of basic toxicological principles with 95% confidence intervals by groups.

** indicates significance at $p < .001$

n.s. indicates significance at p > .05 (not significant)

Additionally, Figure 7 shows the response distribution of the seven knowledge items, separated by groups. The response distributions related to the accumulation of chemicals in the human body (χ^2 (4, N = 448) = 28.47, $p < .001$), allergic reactions (χ^2 (4, N = 448) = 10.75, $p < .05$), toxicity (χ^2 (4, N = 448) = 47.17, $p < .001$), and doses (χ^2 (4, N = 448) = 40.47, $p < .001$) were dependent on which video the participants watched. For these items, participants responded less frequently with “do not know” responses in the “knowledge” group (10–30%) than the “affect” (30–46%) and “control” (30–45%) groups. Overall, the “knowledge” group had more correct responses (50–80%) than the “affect” (35–50%) and “control” (29–45%) groups. However, there was no association between which video the participants watched and the responses related to the regulation of chemicals (χ^2 (4, N = 448) = 5.94, p = .20), carcinogenic effects (χ^2 (4, N = 448) = 3.71, p = .45), and exposure assessments (χ^2 (4, N = 448) = 5.79, p = .22).

5.4.2.3. Affect Towards Chemicals

Participants' affect towards chemicals differed significantly between the groups, F (2,445) = 15.86, p < .001 (cf. Table 20). The post-hoc tests indicated that the reported affect towards chemicals of the "affect" group (M = 54.34, SD = 20.37) was significantly higher than the "control" (M = 48.56, SD = 13.08) and "knowledge" (M = 44.03, SD = 13.26) groups (cf. Figure 10). There was no significant difference between the "control" and "knowledge" groups.

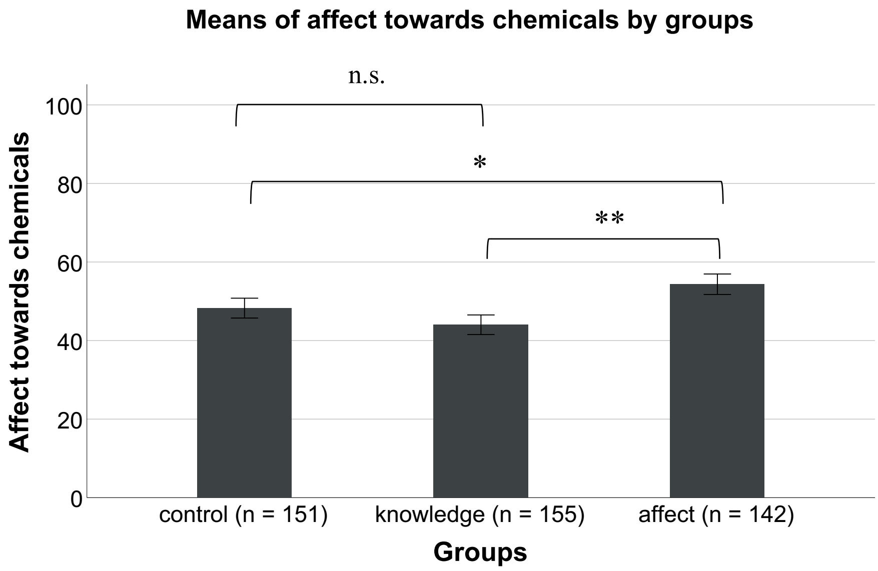

Figure 10. Affect (*0 = negative; 100 = positive*) towards chemicals with 95% confidence intervals by groups.

** indicates significance at p < .01*

*** indicates significance at p < .001*

n.s. indicates significance at p > .05 (not significant)

5.4.2.4. Benefit perceptions of the use of chemicals in consumer products

Both experimental videos had significant effects on participants' perceptions of the benefits of chemicals in consumer products, F (2,445) = 8.32, p < .001 (cf. Table 20). The post-hoc tests indicated that the "affect" (M = 49.31, SD = 26.88) and "knowledge" (M = 51.45, *SD* = 22.72) groups perceived higher benefits of the use of chemicals than the "control" group (*M* = 40.67, *SD* = 23.47) (cf. Figure 11). There was no significant difference between the "affect" and "knowledge" groups.

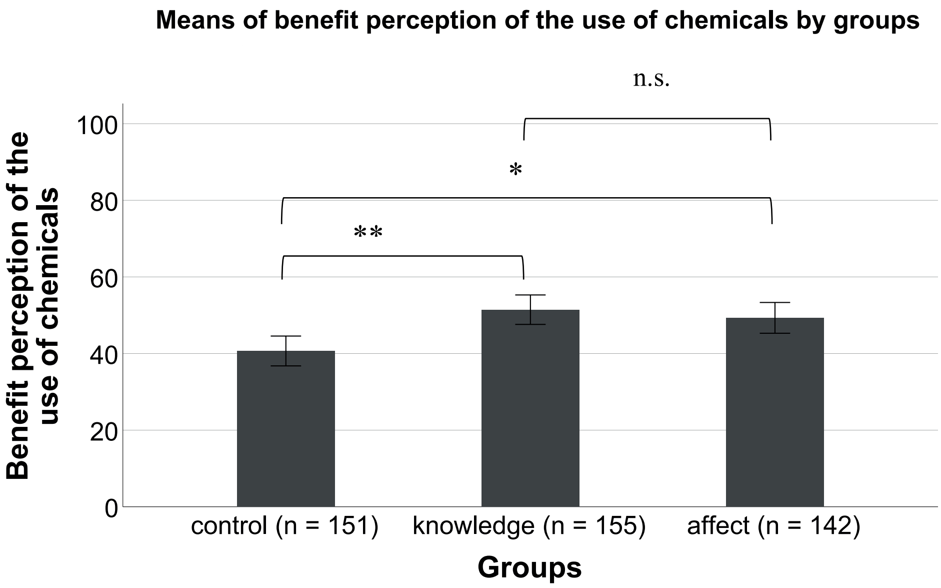

Figure 11. Benefit perception of the use of chemicals with 95% confidence intervals by groups.

** indicates significance at p < .01*

*** indicates significance at p < .001*

n.s. indicates significance at p > .05 (not significant)

5.4.2.5. Preference for natural substitutes in consumer products

There were significant group differences in the preference for natural substitutes in consumer products, $F\ (2,445) = 12.04$, $p < .001$ (cf. Table 20). The post-hoc tests indicated that the mean preference was lower for the "knowledge" group (*M* = 3.97, *SD* = 1.34) than the "control" (*M* = 4.62, *SD* = 1.05) and "affect" (*M* = 4.49, *SD* = 1.26) groups (cf. Figure 12). There was no significant difference between the "control" and "affect" groups.

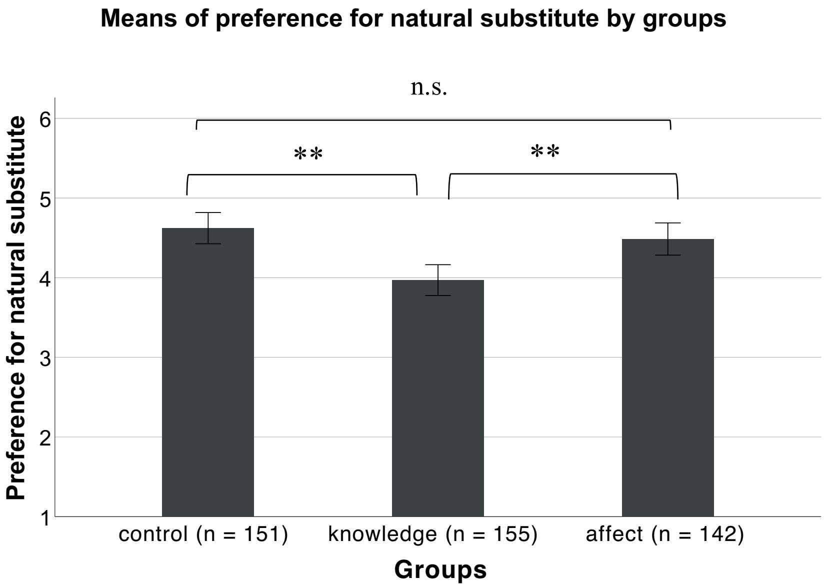

Figure 12. Preference for natural substitutes in consumer products with 95% confidence intervals by groups

** indicates significance at $p < .001$

n.s. indicates significance at p > .05 (not significant)

5.5. Discussion

Different communication strategies to reduce chemophobia were examined. On the one hand, the informational approach increased peoples' knowledge of basic toxicological principles, decreased chemophobia, increased benefit perception of the use of chemicals, and lowered preference for natural substitutes in consumer products. However, the affect-based approach only increased positive affect and benefit perception of the use of chemicals.

The informational approach successfully reduced chemophobia, which confirms the established association of lower risk perception and fear of chemicals with a better understanding of toxicological principles (Bearth et al., 2016; Bearth et al., 2019; Bredahl, Grunert, & Frewer, 1998; Entine, 2011; Royal Society of Chemistry, 2015; Saleh et al., 2019; Siegrist & Bearth, 2019). Literature shows that knowledge about a technology does not necessarily lead to a lower risk perception or greater acceptance of that technology (Connor & Siegrist, 2010; Jobin, Visschers, van Vliet, Arvai, & Siegrist, 2019; Renn, 2006; Wallquist, Visschers, & Siegrist, 2010). However, this seems to not be the case with chemicals. First and foremost, the information provided in the present study specifically addresses existing misconceptions and concerns regarding chemicals that have been identified and related to chemophobia in previous mixed-method studies (Bearth et al., 2019; Saleh et al., 2019). It did not convey general knowledge about chemicals (e.g., types of hazardous chemicals, chemical reactions) that laypeople might already be familiar with or might be irrelevant to their perceptions. It also did not include benefit-related information; although, it did improve people's benefit perception of the use of chemicals. The rating of the informational video as interesting and useful also supports the theory that the information provided was relevant for the participants to evaluate the risks and benefits of chemicals. Therefore, the informational approach conveyed relevant knowledge in a simple and accessible way (i.e., in the form of a video).

The affect-based approach increased the salience of the benefits of the use of chemicals, leading to a more positive affect and a higher benefit perception of the use of chemicals. However, it did not reduce chemophobia. According to the quality evaluations for the videos, the affect approach video was not as useful or interesting as the informational approach video. Therefore, the benefits of chemicals highlighted in this approach could have been irrelevant to laypeople with high levels of chemophobia. People's perceptions of the benefits of a technology, as well as chemicals, might differ depending on their applications (Siegrist, 2003; Siegrist, Stampfli, Kastenholz, & Keller, 2008). Similarly, the use of synthetic chemicals in different products and technologies (e.g., medicine, food, water, electronics) might not all be perceived as equally beneficial and, thus, could explain the preference for natural chemicals by people exhibiting chemophobia. For instance, chemical-containing products that are ingested by people (e.g., food, water, medicine) might be more strongly affected by chemophobia than other consumer products (e.g., cell phones, cars), It might be more important to clarify in which domains (e.g., medical, technological, food) the use of synthetic chemicals is considered beneficial or risky to people, to better address the stigma associated with particular domains.

To reduce chemophobia, establishing an understanding of basic toxicological principles might be a more sustainable approach than a purely affect-based one. In fact, there already are communication efforts using different media channels (e.g., podcasts, videos, websites) to disseminate knowledge about chemicals and basic toxicological principles among the public. However, to our knowledge, their success has not been evaluated systematically (Hartings & Fahy, 2011; Royal Society of Chemistry, 2015). These communication efforts focus on transferring an understanding of the dose-response relationship, the composition of natural entities that can in fact be presented as chemicals (e.g., food perceived to be natural, such as a banana), and explaining that the origin of a chemical (i.e., natural origin or man-made) is not an indicator of its toxicity. These messages aim at addressing peoples' misconceptions and instrumental beliefs (i.e., natural chemicals are safer and healthier than synthetic chemicals) that might be guiding preference for natural chemicals and leading people to reject or avoid potentially irreplaceable synthetic chemical-containing products or innovations (e.g., vaccines). The findings of this study show that communication efforts focusing on the knowledge of basic toxicological principles can be effective in suppressing these instrumental beliefs. This, in turn, can limit chemophobia and the preference for natural substitutes in products. Moreover, Meier et al. (2019) also recently revealed that informational messages targeting laypeople's overestimations of the safety of natural chemicals could mitigate preference for chemicals of natural origin in medications. This could have implications for peoples' adherence to prescribed conventional medications.

Communicating basic toxicological principles to the public may be a challenging and difficult task for risk communicators not familiar with the subject. Toxicologists, however, are suitable for the role of risk communicators (Chalupa & Nesmerak, 2019; Hartings & Fahy, 2011; Monro, 2001; Wallace, 2011). For this, understanding how to foster and maintain public trust in scientists is necessary as high trust in the source of information and the messages relayed can ensure effective public outreach and knowledge dissemination (Breakwell, 2000; Siegrist, Cvetkovich, & Roth, 2000). Another challenge arises when people unconvinced by the information provided, due to ideational beliefs, focus on the inherent and moral superiority of natural entities (Li & Chapman, 2012; Meier & Lappas, 2016; Rozin et al., 2004; Scott, Inbar, & Rozin, 2016). There might be a need to investigate what influences ideational beliefs to know how these beliefs can be addressed to ensure a consistent decrease in chemophobia and increase in informed decision-making. Such challenges could be resolved by including toxicology as part of school curriculums.

In terms of limitations, the implications of long-term information retention and impact on perceptions of chemicals and chemophobia cannot be derived due to the design of the present study. Furthermore, preferences for natural substitutes in consumer products were self-reported by participants and it is unclear whether these preferences will be transferred into real life consumer decisions. Future research should focus on the evaluations of the long-term effects of knowledge provision on chemophobia and preference for natural substitutes in consumer products in a real-life setting. It might also be of interest to evaluate whether other related knowledge would have an impact on peoples' chemophobia and preferences for natural products (e.g., knowledge of the distinction between hazard and risk, knowledge of chemicals' risk assessment process). Previous research suggests that knowledge about the risk assessment process impacts people's risk perception of food additives (Bearth et al., 2014). In addition, chemophobia was not measured before exposing the participants to the videos, which does not allow for a comparison of the change in chemophobia levels within groups. Thus, future research should consider focusing on the change in chemophobia within individuals. Finally, another limitation is that younger people were under-represented in the sample. Using representative samples of Swiss, as well as other populations, to investigate the impact of the informational and affect-based strategies can help determine which approaches yield better results for different cultures and generations.

5.6. Conclusion

The present experimental study provides a better understanding of chemophobia and related factors, and offers insight into potentially effective communication approaches to mitigate chemophobia. Communicating information on basic toxicological principles in a simplified and accessible way might be a promising method to inform the public. Moreover, the negative stigma associated with chemicals might be difficult to address using only affective messages focusing on the benefits of chemicals for individuals and society. However, basic toxicological principles can be fundamentally taught in schools or disseminated by toxicologists and scientists who are trusted by the public to reduce chemophobia

Appendices

Appendix A

This appendix contains information about the content of the videos used in the present study titled "Addressing Chemophobia: Informational versus affect-based approaches". Links redirecting to the videos are also provided in this document.

1. **"Knowledge" group**

Text of the informational video regarding the basic toxicological principles viewed by the "knowledge" group:

Chemical substances are everywhere, in living creatures, in the environment and in consumer products like food, medicine, cosmetics and cleaning products. It is therefore impossible to lead a life free of chemicals.
In fact, if we look at what a strawberry or egg is composed of, we get a long list of chemical substances, which we probably cannot pronounce or understand. But we can see that this strawberry and egg contain natural chemical substances. Hence, natural products contain also chemical substances.
Further, it doesn't matter whether the chemical substances are natural or synthetic, for natural chemicals and their synthetic counterparts have the same chemical identity. Let's take vitamin C as an example, which we find naturally in oranges but we can also buy in the form of tablets that are produced in laboratories. The chemical structure of vitamin C in the orange and the tablet are exactly the same. The vitamin C of the orange and of the tablet will have the same function and effects on the human body.
But natural chemical substances are often seen to be safe and healthy, while synthetic chemical substances are often seen as dangerous. But natural chemical substances are not inevitably safe and synthetic chemical substances are not inevitably harmful. Whether a chemical substance is natural or synthetic cannot tell us how dangerous it is.
In fact, every chemical substance, whether it synthetic or natural, can be toxic, when exposed to a certain dose. It is the dose that makes the chemical substance poisonous.
Let's take the example of sodium thiopental. Sodium thiopental is a synthetic chemical substance that was used in lethal injections in prisons the past. But what does an apple have in

common with sodium thiopental? The apple seeds contain amygdalin, which has approximately the same toxicity as sodium thiopental.

Both, apple seeds and sodium thiopental can be toxic, if a person is exposed to a quantity of 1000mg/kg of his bodyweight. But of course, there are such few seeds in an apple that they are not toxic at the amount present in an apple.

Link to view video: https://www.youtube.com/watch?v=ySBokHfTeQA&feature=youtu.be

2. "Control" group

Text of the control video regarding black holes viewed by the "control" group:

Black holes are objects that exist throughout the universe and possibly in all galaxies. Black holes are extremely dense, which is why their gravitation attracts everything that comes close by. Not even light can escape its grasp.

The most common black holes form when a massive star is wiped out in a big explosion and their dense core is left behind. If this core is heavier than a certain mass, the gravitational force exceeds all other forces, so that the core collapses and a new black hole is created.

Such objects can grow by swallowing material in their vicinity, such as gas, stars and even other black holes, or when two galaxies merge together. The most massive, so-called supermassive black holes, are probably in the centre of almost every galaxy, including our own.

Black holes do not emit any radiation themselves, or at least not nearly enough that it could be captured by a telescope. Therefore, the behavior and emission of material around it is observed instead, from radio to visible light up to X-rays. Since the shadow of the supermassive black hole is extremely small, it could not be observed directly until recently.

This is the picture that astronomers have taken recently of a black hole. What can be seen on this picture is indeed the shadow of a supermassive black hole in the galaxy M87.

The glowing gas surrounds the black hole, which appears as a dark circle in the middle. The gravitational pull of the black hole superheats the gas making it radiate. The colours in the picture were added by the astronomers, because the detected radiations where not visible for the naked eye. The yellow shades represent the most intensive radiations, while red depicts the less intensive radiations and black represents few or no radiations.

Why did the astronomers take a picture of a black hole in a galaxy far away, instead of one in our own galaxy?

One of the main reasons is, that the black hole in our galaxy is much smaller than the one in galaxy M87. Therefore, the material rotates much faster around the black hole in our galaxy, which would have blurred the image.

Link to view video:
https://www.youtube.com/watch?v=g7P-Ipw8w5w&feature=youtu.be

3. "Affect" group

Link to the affect-based appeal video regarding the benefits of the use of chemicals viewed by the "affect" group:
https://www.youtube.com/watch?v=iqUpNf5dAjQ&feature=youtu.be

This video was taken from the original video published by UNESCO in 2011 celebrating chemistry. The source of this video was revealed to the respondents of the "affect" group at the end of the experiment.

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Chapter VI General Discussion

6.1.Introduction

This thesis aimed to comprehend the phenomenon of chemophobia as well as its determinants, consequences, and implications for risk communication. All the studies (Chapters II – V) included in the thesis, therefore, addressed that overarching aim. In Table 21, the main findings of the included studies by chapters are summarized and presented alongside their specific aims.

The results of each study are thoroughly discussed in the relevant chapter of the thesis. Therefore, this general discussion chapter focuses on discussing the findings of the studies in terms of their overall theoretical and practical implications. In section 6.2, the theoretical implications of the findings of the studies of Chapters II-V with regard to the definition of chemophobia are presented. In section 6.3, the findings of the study presented in Chapter IV are addressed in light of its practical implications for agricultural practices in relation to communication and policy-making. The results of the final study presented in Chapter V in terms of their implications for risk communication and education are discussed in section 6.4. The general limitations of the studies altogether and suggestions for future research based on the overall findings of the thesis are presented in section 6.5. Lastly, the section 6.6 is the conclusion of the thesis.

Table 21. Overview of the general aims and main findings of the included studies by chapters

Chapter	General aim	Main findings
II	Identifying the public's knowledge and perceptions of chemicals, chemophobia, and its determinants	• The term "chemicals" is heavily stigmatized, evoking negative associations and affect among laypeople • Laypeople tend to judge the risks of chemicals based on their origin (whether synthetic or natural). Synthetic chemicals' risks are overestimated, while the risks of chemicals of natural origin are underestimated. • Knowledge of basic toxicological principles is generally low among laypeople, and is negatively related to chemophobia • Affect evoked by chemicals, risk-benefit perceptions, trust in chemicals' regulators are factors negatively related to chemophobia • Health concerns are positively related to chemophobia
III	Determining the levels of knowledge of basic toxicological principles and of chemophobia in eight European countries	• Knowledge of basic toxicological principles is low in all the investigated countries • Knowledge of basic toxicological principles is negatively related to chemophobia in most investigated countries, except for Poland • Trust is generally an important factor that is negatively related to chemophobia, although it is not relevant in all countries • Health concern and health worry are positively related to chemophobia in all investigated countries
IV	Examining the influence of chemophobia on the public's acceptance of agricultural practices	• Chemophobia is negatively related to publics' acceptance of both pesticides use and biotechnology applications as crop protection measures in the agriculture sector • The "naturalness" of food is negatively related to laypeople's acceptance of synthetic pesticide use and agricultural biotechnology applications, but it is not relevant for the acceptance of natural pesticides • Transferring genes between same-variety plants is a more accepted measure to protect crops from infestations than the use of synthetic and natural pesticides and gene editing • The process behind a given biotechnology application is more relevant for public's acceptance than its label
V	Investigating communication approaches for addressing chemophobia	• The provision of information increases knowledge and reduces both chemophobia and preferences for natural products • An affect-based communication approach focusing on the benefits of chemicals increases positive affect toward chemicals, but has no impact on chemophobia

6.2. Redefining chemophobia

Taken together, the findings of the studies presented in Chapters II-V allow for a better understanding of chemophobia and also suggest the need for a more specific definition of the phenomenon. A more precise, evidence-based definition of chemophobia is, therefore, proposed in this section.

6.2.1. Chemophobia is not a clinical phobia!

Phobias represent the most common and easily diagnosable mental disorders (Beck, 2005; Krueger, 1999; Marks, 1969). A specific phobia is a type of anxiety disorder characterized by an unreasonable and excessive fear of a specific object or situation (Stein, 2004; Stravynski, Basoglu, Marks, Sengun, & Marks, 1995). For example, arachnophobia is the irrational fear of spiders. Based on the definition of a specific phobia, chemophobia would be described as the irrational fear of chemicals. However, there are important differences between chemophobia and specific phobias. To illustrate the differences between chemophobia and a clinical specific phobia, chemophobia will be compared to arachnophobia. As Table 22 indicates, chemophobia shares some of the emotional, behavioral, and cognitive characteristics of arachnophobia (Stein, 2004). For instance, chemophobia resembles arachnophobia with regard to the irrationality and excessiveness of the fear experienced by an individual when exposed to the relevant stimuli. In addition, the beliefs (e.g., all chemicals are dangerous) associated with chemophobia can be considered just as irrational as the beliefs held by an arachnophobic (e.g., all spiders are dangerous). Thus, avoidance behavior regarding the feared stimuli is likely to be a characteristic of chemophobia, as it is of any other specific phobia (Marks, 1969; Stein, 2004). However, chemophobia is not a phobia in the true sense of the lexical label, especially since it differs from specific phobias in four important ways. First, a chemophobic is not likely to know or acknowledge that he or she has a phobia of chemicals, whereas an arachnophobic recognizes his or her phobia of spiders. Chemophobics perceive their dislike and avoidance of chemicals to be justifiable, and they are unlikely to perceive it either as a fear or as irrational. Second, chemophobics do not experience any physical symptoms (e.g., panic attacks, chest pain, disorientation, etc.) or psychological suffering (i.e., excessive strain or stress) when confronted with chemicals, whereas arachnophobics are likely to suffer from stress and panic attacks when exposed to spiders. Instead, a chemophobic's reaction to chemicals is likely to involve calling for or supporting the banning of certain chemicals from consumer products. Third, the findings of the experimental study on strategies to address chemophobia (Chapter V) revealed that the provision of knowledge can mitigate chemophobia. A real phobia, according to its clinical meaning, is unlikely to be treated by knowledge (Wolitzky-Taylor, Horowitz, Powers, & Telch, 2008). For instance, informing an arachnophobic that spiders will not sting him or her, or that certain spiders are not poisonous, will not alleviate his or her arachnophobia. Rather, real phobias are treated with repeated exposure to the relevant stimuli or with cognitive behavior therapy, medications, etc. (Gros & Antony, 2006; Wolitzky-Taylor et al., 2008). Fourth, it appears unlikely that chemophobia is caused by genetics. In fact, different situational (labels, media) and psychological (distrust in regulators, health concerns) factors are considered to represent the origins of chemophobia (cf. section 1.3 of Chapter I). Additionally, there exist certain non-clinical phobias (e.g., homophobia, which is the irrational fear of homosexual individuals) that are not necessarily "fears," but are instead a set of religious, cultural, or social stances and beliefs that are labelled as "fears" (Renzetti, 2008). Chemophobia resembles the latter type of phobia in terms of its non-clinical aspect. Thus, chemophobia is not necessarily a clinical disease or a mental disorder. Rather, it is an irrational fear or excessive dislike characterized by a set of prejudices against chemicals. Ropeik (2015) coined the term "chemonoia" to refer to this irrational and persistent fear or dislike of chemicals. However, "chemonoia" is actually a more problematic term than "chemophobia." It implies a medical condition (i.e., paranoia) related to abnormalities in the mind that hinder the individual from distinguishing between what is real and what is not (Freeman et al., 2008; Winokur, 1977). Therefore, the term "chemonoia" does not seem appropriate for describing the public's irrational fears of chemicals. Overall, differentiating chemophobia from clinical phobias and paranoias is important, as this differentiation will allow to better understand chemophobics' beliefs and reactions and to determine the best approaches to address chemophobia. To resolve and clarify the misunderstandings concerning what chemophobia stands for, a more precise definition is required. In section 6.2.2, a redefinition of chemophobia is suggested.

Table 22. Comparison of chemophobia to arachnophobia in terms of the characteristics, symptoms, causes, and treatments of specific clinical phobias

Specific clinical phobias	Arachnophobia	Chemophobia
Emotional Characteristics		
Irrational and excessive fear	✓	✓
Behavioral Characteristics		
Avoidance of the feared stimuli	✓	✓
Uncontrolled fear reactions (i.e., if the stimuli cannot be avoided, it causes the exposed phobic person to panic, scream, cry, and run away)	✓	✗
Cognitive Characteristics		
Selective attention paid to the stimuli	✓	✓
The phobic person is aware of his/her phobia	✓	✗
Irrational beliefs (e.g., all spiders are dangerous)	✓	✓
Symptoms		
Psychological distress, panic attacks, sweating, chest pain, confusion, and disorientation, etc.	✓	✗
Causes		
Traumatic experience	✓	✓
Learned from someone else	✓	✓
Genetics	✓	✗
Treatments		
Treatment via cognitive behavior therapy, mindfulness, medication, lifestyle changes, and gradual exposure to the feared stimuli	✓	✗

6.2.2. Chemophobia is the irrational fear of entities perceived to be synthetic

One of the most important findings of the present thesis concerns the misconceptions identified in Chapters II and III regarding people's knowledge of basic toxicological principles and their affective reactions to chemicals. Natural chemicals were perceived to be safer and healthier than synthetic chemicals, which is line with the findings of Rozin et al. (2004) regarding the public's preferences for natural entities. Dose–response insensitivity was particularly articulated with regard to synthetic chemicals, which demonstrated some people's tendency to overestimate the dangerousness of synthetic chemicals and to underestimate the risks of chemicals of natural origin. Moreover, some people appeared to differentiate between synthetic and natural chemicals in terms of their chemical identity. In fact, it was determined that chemicals of natural origin might not be perceived as chemicals at all. These findings suggested that the term "chemicals" appeared to be synonymous with "synthetic chemicals." This was confirmed by the reported associations evoked by the term "chemicals." Laypeople tended to report negative associations with chemicals (e.g., dangerousness, poison, unnatural), with the reported affect also being negative. If there were associations related to "natural chemicals," it is possible that the reported affect would have been more positive, as the affect reported in relation to "natural chemicals" is positive (Saleh, Bearth, & Siegrist, 2019). The higher the negative affect evoked by the associations, and the more misconceptions there are regarding chemicals, the higher the chemophobia levels are likely to be (Bearth, Saleh, & Siegrist, 2019; Saleh et al., 2019). Thus, chemophobia might be the irrational fear of synthetic chemicals, especially since chemophobics tend to avoid exposure to synthetic chemicals (i.e., the feared stimuli) and prefer products containing natural chemicals. To date, the term "chemophobia" has been used to express different meanings, including "the anxiety and concerns about chemistry" (Eddy, 2000; Michaelis, 1996; Morais, 2015), "the persistent fear of chemicals and chemistry" (Chalupa & Nesmerak, 2018, 2019), and "the irrational or excessive fear of chemicals" (Francl, 2013; Gribble, 2013; Saleh et al., 2019; Silbergeld, 1991; Tarasova & Makarova, 2020). The latter is the most commonly used definition of chemophobia. However, it implies that chemophobia is the irrational fear of everything, as chemicals are found in everything. Such a definition could prove misleading, and it might be considered inaccurate because chemophobics are not likely to fear everything they are exposed to. That is, chemophobics do not necessarily fear exposure to entities they perceive to be natural or products that contain chemicals of natural origins. Therefore, defining chemophobia as "the irrational fear of entities perceived as synthetic" is suggested. This fear is mainly characterized by a set of misconceptions regarding synthetic and natural chemicals' risks. However, to achieve a more accurate definition of chemophobia, future studies should investigate the meaning of, or what is perceived as, "synthetic." Such an investigation would facilitate an understanding of whether chemophobia is related to the fear of entities that are artificially produced and are not naturally occurring nor derived from nature (e.g., Teflon), or of entities that are man-made versions of chemicals of natural origin (e.g., the synthetic version of the vitamin C, which can be found naturally in oranges).

6.3. Chemophobia: Implications for agricultural practices

Chapter IV revealed that chemophobia can lead to the public rejecting the use of both pesticides and agricultural biotechnology applications as crop protection measures. In other words, chemophobics tend to evaluate agricultural biotechnology applications in a similar way to how they evaluate the use of pesticides. It is believed that chemophobics strive to eliminate their exposure to synthetic entities, especially in their food, by preferring natural alternatives or what is perceived as natural (Entine, 2011; Gribble, 2013). Thus, chemophobia might be related to people's naturalness perceptions. In fact, the naturalness of food represents a highly important positive attribute in relation to the public's acceptance of food-related technologies and practices (Frewer et al., 2011; Frewer et al., 2013; Siegrist, 2008; Siegrist, & Hartmann, 2020). Experts in the agriculture sector have argued that agriculture is actually detached from natural conditions because there is no food production system that is entirely "natural" (Müller, 2017). Generally, food production systems rely on human-modified environments and human-made techniques to ensure the growth of crops. For example, water and nutrients are supplied to crops by means of irrigation and fertilization, while the temperature and humidity are controlled using greenhouses and plastic tunnels (Müller, 2017). However, laypeople do not necessarily perceive either agriculture or food production systems in the same way that experts do. The naturalness of food is judged differently by laypeople based on the type of intervention or transformation undergone during the food production process (Rozin, 2005, 2006). In fact, a physical or mechanical intervention tends to have a lower impact on the perceived naturalness of the produced food than a chemical or biological transformation (Evans, de Challemaison, & Cox, 2010; Rozin, 2005). It is likely, for example, that the hand picking of weeds (physical intervention) would be perceived as more natural than the use of either pesticides (chemical intervention) or biotechnology applications (biological or genetic intervention) to protect crops from weeds. Therefore, the use of both pesticides and agricultural biotechnology applications (as chemical and genetic interventions) largely decreases people's naturalness perceptions and acceptance of food produced using such agricultural practices, especially in the case of chemophobics. Furthermore, the content of the food produced using such agricultural practices appears to be relevant to chemophobics' acceptance of that food. For instance, chemophobics would reject food grown using pesticides, regardless of the origin of the specific pesticide, due to the belief that pesticide residues should not be present in the food (Buzby & Skees, 1994; Dunlap & Beus, 1992). They are, however, likely to accept genetically modified food produced using gene transfer techniques involving the same plant species. The description of the process of transferring genes between the same species of plants might in fact influence their perception of naturalness and acceptance of the food produced with this technique. Their acceptance of this agriculture practice could be due to the perception that the transferred genes are not man-made as they exist naturally in the plants and, therefore, the plants' natural identity and existence are preserved (Kronberger, Wagner, & Nagata, 2014; Mielby, Sandoe, & Lassen, 2013; Rousselière, 2017; Saleh, Bearth, & Siegrist, *submitted*).

Overall, chemophobia has important implications for the public's acceptance of agricultural practices. Chemophobics' preference for naturalness in terms of food can lead to their rejection of certain agricultural practices, which might hinder the use of needed chemicals as well as the implementation of innovative technologies in agriculture. Generally, without the public's acceptance of pesticides and biotechnology applications, only a limited number of publicly accepted measures for protecting crops are left, which could prove insufficient to sustain mass food production (Lamichhane et al., 2015). Therefore, fostering the public's trust in agricultural policies that allow for the use of a combination of well-studied crop protection measures in order to ensure secure and good-quality food production might serve to ensure the public's acceptance of agricultural practices (Siegrist, 2008; Siegrist & Cvetkovich, 2000). More importantly, chemophobia needs to be addressed to ensure informed decision-making. By mitigating chemophobia, the public's preference for naturalness can be reduced (Saleh, Bearth, & Siegrist, 2020), which can positively influence people's acceptance of the use of pesticides and agricultural biotechnology applications.

6.4.Chemophobia: Implications for risk communication

Interestingly, in Chapter V, an informational communication approach that conveyed knowledge of basic toxicological principles was proven more effective in terms of reducing chemophobia than a reliance on an affect-based approach. However, two important questions are raised. First, how does the informational communication approach differ from the widely criticized knowledge deficit model of communication? (See section 1.3.2.2 of Chapter I for an overview of the knowledge deficit model.) Second, who should seek to communicate with the public regarding toxicology and through which channels? The first question is intended to be answered in section 6.4.1, while section 6.4.2 serve to address the second question.

6.4.1. Knowledge influences chemophobia, but…

Three important distinctions need to be made between the knowledge deficit model and the suggested informational approach to conveying knowledge regarding basic toxicological principles in an effort to reduce chemophobia. First, the knowledge deficit model assumes that the public does not understand science. It assumes that when provided with scientific information chosen by experts on what they think laypeople should know, the public will inevitably and enthusiastically support science (Sturgis & Allum, 2004). However, the means of knowledge provision suggested to address chemophobia was not selected solely based on experts' opinions or beliefs regarding what information people need to make a factual decision. Instead, the provision of knowledge concerning basic toxicological principles was based on laypeople's mental models (i.e., laypeople's beliefs and opinions) regarding chemicals, which were determined both with qualitative and quantitative research as well as in various countries (Saleh et al., 2019). In Chapter II, laypeople's mental models regarding chemicals were identified and then relied upon to build a knowledge of basic toxicological principles scale alongside experts' opinions (Morgan, Fischhoff, & Bostrom, 2002). Therefore, laypeople's beliefs are not disregarded, dismissed, or marginalized in the informational communication approach. Rather, the approach takes into account and addresses their beliefs. The knowledge provided through the informational approach is thus relevant to laypeople's personal evaluations of the risks of chemicals. Second, the knowledge deficit model postulates that the scientific information conveyed will definitely and positively change the public's opinions regarding science (Hansen, Holm, Frewer, Robinson, & Sandoe, 2003; Sturgis & Allum, 2004).

Yet, the purpose of providing information regarding basic toxicological principles is not to increase support for any particular types of chemicals or to promote chemicals as benign and good entities that have led to better living standards. Instead, it is intended to foster a realistic understanding of basic toxicological principles in order to help people make informed decisions regarding chemicals. Moreover, the provision of knowledge concerning basic toxicological principles is not assumed to have a definite impact on chemophobia. In the case of those who hold strong ideational beliefs (i.e., the belief that nature and natural entities are morally superior to human interventions; Rozin et al., 2004), there is a chance that their fear of chemicals will persist despite them being provided with relevant information. Knowledge alone might not suffice, and other communication strategies might be needed to address the fears of such individuals. However, addressing ideational beliefs can prove difficult (Li & Chapman, 2012; Rozin et al., 2004). Further research should be conducted on the relationship between ideational beliefs and chemophobia, as well as on which psychological factors play a role in shaping these beliefs. Finally, unlike the knowledge deficit model, the provision of knowledge is not assumed to definitely lead to the acceptance of that knowledge by the public, or to it being considered accurate and reliable. Providing scientific information regarding basic toxicological principles to laypeople is a difficult task, especially if the information provided challenges laypeople's misconceptions and beliefs. The possibility exist that some people might be unwilling to consider such information due to trust issues (Siegrist & Cvetkovich, 2000; Siegrist, Gutscher, & Earle, 2005). For information to be considered accurate and reliable, it must be trusted. If people are to trust the information provided, it is essential that trust in the sources of the information (e.g., in toxicologists, regulators, etc.) is fostered. When a higher level of trust in regulators and experts is established, more weight is assigned to their opinions and work, which means that the public becomes less concerned and less fearful (Ropeik, 2011; Siegrist & Cvetkovich, 2000). Therefore, ensuring the public's trust in those who will serve as risk communicators is considered an important factor in relation to the public's acceptance of the messages being disseminated.

6.4.2. Communicating information on toxicology

With regard to the dissemination of knowledge of basic toxicological principles to the public, different communicators and communication channels can be considered. How should communication regarding the risks of chemicals be performed? Which stakeholders in the chemical sector could serve as risk communicators? Which platforms can be relied upon to effectively reach the public and reduce chemophobia? These questions are addressed in the subsequent sections.

6.4.2.1. Toxicology in risk communication

The fundamental goal of risk communication is to enable concerned people to make risk-related judgements on their own. It does not aim to persuade them as to whether the risks involved are tolerable or intolerable (Morgan et al., 2002; Renn, 2006). Likewise, risk communicators seeking to address chemophobia should focus on providing laypeople with information relevant to judging chemicals, such as information regarding the similarities between natural and synthetic chemicals in terms of basic toxicological principles (Bearth et al., 2019; Saleh et al., 2019). For this, risk communicators need to collaborate with toxicologists to accurately convey knowledge regarding basic toxicological principles and to highlight the value of toxicology when it comes to ensuring the safety of products. Hartings and Fahy (2011) have argued that toxicologists themselves might need to become risk communicators concerning chemical issues, as they best understand the complexity and importance of the science involved. Therefore, toxicologists might need to invest time in communicating with the public regarding information and findings with regard to natural and synthetic chemicals. To date, only a few attempts have been made by toxicologists to engage in risk communication in order to address the public's misconceptions regarding chemicals. For instance, Sense About Science is a communication organization that published a report (for example "Making sense of chemical stories") addressing the most prominent misconceptions concerning chemicals based on a collaboration with toxicologists and chemists (Sense About Science., 2006). However, it is plausible that the report only reached interested individuals, as it was only presented once following its production in 2006 and was not regularly or continuously promoted to ensure public engagement. The success of such efforts in terms of reaching and influencing the public and people's risk judgements regarding chemicals has not yet been empirically investigated. An examination of the impact of such efforts on chemophobia would serve to clarify whether they should be continuously adopted and intensified in an effort to address chemophobia.

Moreover, as discussed in section 6.4.1, the level of trust in the sources of information is important when addressing chemophobia, as it is a key factor in people's judgements and behaviors (Siegrist, 2019; Siegrist & Cvetkovich, 2000). Scientists who work in academic or governmental institutions (e.g., regulatory agencies) tend to be more highly trusted and perceived to be better qualified to convey risk information than scientists who work in industry (European Commission, 2010). It could prove worthwhile to investigate whether the informational approach examined in Chapter V, which involved the use of a video, would have different impacts if the video was indicated to come from different sources (e.g., from scientists working in the chemical industry, for consumer goods companies, in non-governmental organizations, etc.; Love, Mackert, & Silk, 2013). Such an investigation could help to determine who should act as risk communicators when it comes to addressing the public's skepticism regarding the safety of chemicals in products and so to tackling chemophobia. Additionally, the effects of the informational approach should also be investigated in different countries. It remains unclear whether such an approach would be as successful elsewhere as it was in relation to a Swiss sample. As differences in the predictors of chemophobia were found between eight European countries, it is possible that the informational approach might have different effects on certain chemophobics.

6.4.2.2. Toxicology in the regulations of the use of chemicals

Regulators appear to be important stakeholders in the chemical sector who can influence the public's perceptions and reactions in relation to chemicals (Bearth et al., 2019; Saleh et al., 2019). Thus, ensuring that regulators are actively engaged in public discourses and communication efforts regarding chemicals might be an important means of addressing chemophobia. In fact, the European Chemicals Agency (ECHA) strives to communicate with the public via online platforms (i.e., websites) regarding the risks and benefits of the chemicals used in everyday products (e.g., cleaning products, cosmetics, clothes and textiles, etc.; (European Chemicals Agency, 2018). Its website also explains the European Union oversight of the use of chemicals in such products. However, little attention is paid to providing people with information about doses and exposure levels. Such regulatory bodies might need to continuously communicate with the public regarding basic toxicological principles alongside the information provided on the different consumer products featured on their websites. Moreover, one important benefit of such websites is that they might be trusted to the same extent as the bodies responsible for managing of the websites (i.e., toxicologists and regulators). In fact, the public's trust in regulators has been found to be negatively associated with chemophobia (Saleh et al., 2019). That is, the higher the level of trust in regulatory bodies, the lower the level of chemophobia. Therefore, websites that are managed by trusted stakeholders and conveying relevant information regarding the chemicals in consumer products might be an effective communication approach to reach interested consumers concerned with the safety of chemicals.

Furthermore, an important yet often neglected aspect of the regulation of chemicals concerns the lack of regulation of the labels related to the use of compounds of natural origin in consumer products, particularly in food. Laypeople might not be aware that labels concerning the naturalness of products (e.g., “all-natural” or “100% natural” labels) are not necessarily well-defined (Berry, Burton, & Howlett, 2017), as there is no consensus between the stakeholders involved in food production regarding the meaning of “naturalness” in the context of food (Negowetti, 2013; Sandin, 2017). For example, packaged food products such as microwavable dinners can be labelled as “natural” due to the mere addition of a natural ingredient to the products (Sanchez-Siles et al., 2019). These naturalness-related labels can mislead some people who are concerned about the naturalness of food so that they perceive the relevant products to be natural and healthy even when these products still contain other non-natural entities (Berry et al., 2017; Rozin, 2005). Thus, the lack of regulation of naturalness labels could reinforce the natural-is-better heuristic and influence chemophobia. However, the present thesis did not assess laypeople’s beliefs and knowledge concerning the regulation of consumer products and its influence on chemophobia. Future studies should examine this relationship to determine what regulatory labeling strategies could be adopted to reduce chemophobia.

6.4.2.3. Toxicology in the media

There are many different media channels or platforms that might influence, via their content and means of coverage, people’s risk judgements concerning issues on a societal or individual level (Coleman, 1993; Paek, & Hove, 2017; Tyler & Cook, 1984). For instance, the news media are known to be one of the main source of scientific information for the public, thereby influencing risk judgements on a societal level (Coleman, 1993). In fact, increased coverage by the news media of a given issue can heighten the public's risk perceptions of that issue. Most importantly, the stories reported by the news media often convey chemical-related issues in a fear-arousing and arguably out-of-context way, which can cause distress and promote worry among the general public (Paek, & Hove, 2016). Severe health or environmental consequences are exaggerated, while important information on doses and exposure levels is omitted from such stories (Ropeik, 2015). This means of coverage simplifies a rather complex situation in which all relevant information (e.g., doses and exposure levels) is needed to make a fact-based judgement. It can also contribute to chemophobics' perception that chemicals can be easily divided into two categories: safe or dangerous. In fact, stories reported by the news media are thought to have contributed to unnecessary and exaggerated chemical-related scares involving food products, such as the aspartame scare (Lofstedt, 2008). Ideally, journalists and news anchors should include information about doses and exposure levels when discussing chemical issues if they are to provide the public with a complete picture of the issue (Monro, 2001). In this way, the public would be informed about the whole story, which should allow them to make fact-based decisions rather than being prompted to express fears due to incomplete or out-of-context information.

Moreover, communication channels have changed drastically over the years, and the news media are no longer the only source of information for the public. The internet and social media (e.g., Twitter, Facebook, etc.) have become important platforms that people use to gather information regarding chemicals found in consumer products, which can play a role in their misconceptions regarding chemicals (McCarthy, Brennan, De Boer, & Ritson, 2008; Paek, & Hove, 2017). In general, toxicologists might need to adapt to participate and engage on such platforms as well as to create science- and research-based content that can be presented to the public in an appealing and comprehensive way (Hartings & Fahy, 2011). They could use these new platforms to reach people concerned about certain chemicals and to address misconceptions regarding natural and synthetic chemicals. For example, an infographic that breaks down the chemical ingredients of an all-natural fruit (e.g., a banana), which was published on the internet by a chemist, could later be used as a communication tool for addressing people's misconceptions regarding natural and synthetic chemicals. The infographic could help laypeople to realize that everything is chemical, even natural products. However, it might prove challenging to prompt people to voluntarily search for information on chemicals. Some people concerned with the risks of certain chemicals found in consumer products might select information that corroborates their concerns and beliefs, and thus, disregard factual information about the relevant chemicals (Edwards & Smith, 1996; Taber, Cann, & Kucsova, 2009). Understanding how people search for information, as well as what drives their information selection and processing, might be useful in terms of determining the most effective communication medium with regard to reachability and trustworthiness.

6.4.2.4.Toxicology in schools

At a fundamental level, basic toxicological principles can be taught in schools (Monro, 2001; Saleh et al., 2020). In fact, including toxicology within the school curriculum might help fostering an understanding of the value of toxicology in relation to ensuring the safety of products. It might also excite people about the science itself and about related technologies, as chemistry appears to be less valued and recognized than other branches of science (Chalupa & Nesmerak, 2020). For instance, it is apparently difficult for the public to think of a well-known scientist from the field of chemistry, although in the cases of biology and physics, Darwin, Newton, and Einstein spring to the mind instantaneously (Hartings & Fahy, 2011). It appears important to enhance the image of chemistry and to excite the public regarding the potential of the science of chemistry and toxicology (Schummer, Bensaude-Vincent, & Van Tiggelen, 2007). Teaching basic toxicological principles in schools could, therefore, ensure that the values of chemistry and toxicology are understood in relation to the innovative production of safe consumer products. It could also help to promote informed decision making regarding chemicals and so serve to limit chemophobia (Chalupa & Nesmerak, 2020). The teaching could be conducted in an engaging and relevant way by taking examples from everyday life and tying the science to society (Morais, 2015).

6.5.General limitations and suggestions for future research

It is important to acknowledge that this thesis did have a number of limitations. First, in terms of the included studies, the actual behavior of people in the real world cannot be determined, since the laypeople's perceptions, preferences, and acceptance were all self-reported. It might prove worthwhile to evaluate people's real preferences and choices following observational and longitudinal study designs both before and after laypeople's exposure to communication materials addressing chemophobia. Additionally, the large-scale testing of the effectiveness of the utilized communication materials might be required, as convenience samples were used in the experimental studies, which did not allow for the generalization of the findings. Future studies could also explore whether people's associations with the term "chemicals" change after they are provided with information, in order to evaluate what pieces of information are retained and, thus, influence the public's perception of chemicals.

Second, the informational approach proved successful in terms of reducing chemophobia among a convenience sample in Switzerland. However, the effects of such an approach should not be overgeneralized, especially not to other countries. For instance, knowledge of basic toxicological principles did not prove relevant to chemophobia in Poland (Bearth et al., 2019). Additionally, certain variables, such as trust, have been found to have different influences on chemophobia, depending on the country. For instance, in France, the participants reported the lowest level of trust that was significantly related to their chemophobia. In Italy, trust in public authorities was not significantly related to chemophobia, although knowledge and education were (Bearth et al., 2019). Thus, the informational approach cannot be considered successful in all countries, especially not without being adjusted in terms of its content and communicators according to regional differences. Therefore, an examination of the effects of the informational approach on chemophobia in different countries might be required before it is widely adopted.

Finally, in Chapter IV, the relationship between chemophobia and the public's acceptance of pesticides and biotechnology applications in the field of agriculture was investigated. However, it is possible that chemophobia's influence on the public's acceptance of chemicals and technologies in the food domain might be more pronounced than, for example, in the cleaning products or cosmetics domains. It remains unclear whether and, if so, how chemophobia is relevant to the public's acceptance of non-food or non-ingested chemical products (e.g., cosmetics) and services (e.g., vaccines). Therefore, future studies should examine the relationship between chemophobia and the exposure route of the chemical products (e.g., skin contact with regard to cosmetics, injection with regard to vaccines, ingestion with regard to food and medicine, etc.). Such an examination will allow for a better understanding of the means and scope of chemophobia's influence on the public's perceptions and acceptance of different chemical products and services.

6.6. Conclusion

The main aim of the present thesis was to provide a better understanding of the phenomenon of chemophobia. To achieve that aim, in Chapters II and III, the prevalence and determinants of chemophobia were determined. In Chapter IV, the consequences of chemophobia were examined, particularly within the agriculture domain. Taken together, the findings of the studies in Chapters II - IV revealed the need to address chemophobia, which led to two possible risk communication approaches also being investigated in Chapter V.

Up until now, it was unclear whether chemophobia represents a clinical phobia or a social construct. The findings of the present thesis revealed that chemophobia is not a psychological disease that could be treated with exposure to the feared stimuli (i.e., synthetic chemicals) or medications or cognitive behavior therapy. Instead, chemophobia is a phenomenon characterized by misconceptions centered on natural chemicals being perceived as healthier and safer than synthetic chemicals. It is particularly prevalent in Europe, and could be hindering people from making informed decisions regarding chemicals and innovations (e.g., in the agriculture domain). The ultimate goal of risk communication in this regard is to enable laypeople to make informed choices and judgements regarding chemicals. Therefore, chemophobia must be addressed if people are to make informed decisions regarding chemicals. Limiting chemophobia should also serve to reduce people's preference for natural alternatives, which might not necessarily be safer or healthier than conventional or synthetic products. The present thesis provided important insights of what exacerbates and limits chemophobia so that the phenomenon can be addressed in practice. Chemophobia can be mitigated through the provision of knowledge regarding basic toxicological principles. More importantly, attempts to address chemophobia should involve a continuous communication effort that is performed collectively and in parallel by various stakeholders (e.g., scientists, regulators, etc.) using different communication channels (e.g., news and social media) to ensure both knowledge provision and public outreach.

However, the effectiveness and trustworthiness of such communication efforts in relation to the long-term behaviors and decision-making practices of laypeople regarding the risks posed by chemicals must not be overstated. This issue requires investigation through observational and longitudinal studies into which communication channels and stakeholders are most trusted and, therefore, most capable of influencing the public's perceptions of chemicals.

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Acknowledgements

I would first like to thank prof. Michael Siegrist for giving me the opportunity to be part of the Consumer Behavior group. Thank you for letting me grow as a researcher under your guidance and for all your invaluable feedback that resulted in interesting studies. I also thank Angela Bearth for pushing me to discover my potential and supporting me when I had doubts. You helped me more than you know, both personally and professionally. I am also grateful for prof. Martin Wilks for taking the time to be part of my doctoral defense examination.

A special thanks to the PhD students (especially Marilou, Gea, Tamara, Kim, Jeanine, Fabienne, Viktoria, Cynthia, Cornelia and Angela) whom I got to know and work alongside. To my closest friends (Aya and Ali), thank you for being there for me through hard times.

I want to deeply thank my Swiss family (Mara, Rolf, Issa and his family). I will never forget how you took care of me when I first came to Switzerland! To my family in law (Gabriel, Samar, Aline, Christine and Jeddo), thank you for your support even from far. To my brothers (Rami and Ali), thank you for your advices throughout my life. To my sisters (Karoline, Nadine, Raymonda, Rosine and Hoda) you are the symbol of kindness, dedication, perseverance and strength. You are the women who truly inspire me. To my nieces and nephews, I love you all, always dream big. To my parents (Mohammed and Iltaf), I owe you all of my successes. This is all because of you and for you. To my partner Chadi, who accompanied me from the beginning of this journey, you carried me through dark days and applauded every milestone I achieved. Thank you immensely and cheers to the next chapters in our journey together.

Alhamdulillah a thousand times for it all and for all of you.