Received: 4 February 2022 | Revised: 30 June 2022 | Accepted: 2 August 2022

DOI: 10.1002/fes3.417

Food and Energy Security Open Access WILEY

ORIGINAL ARTICLE

European consumer and societal stakeholders' response to crop improvements and new plant breeding techniques

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Funding information
European Union's Horizon 2020 Research and Innovation Programme, Grant/Award Number: 817690

Abstract

The global demand for providing nutritious, sustainable, and safe diets for a 10 billion population by 2050 while preserving affordability, reducing environmental impacts, and adapting to climate change will require accelerating the transition to sustainable agri-food systems. A plausible way to help tackle these challenges is by developing new plant varieties that have improved crop yield, plant nutritional quality, and sustainability (or resilience) traits. However, stakeholders, consumers, and citizens' concerns and appreciation of future-proofing crops and the acceptability of new plant breeding strategies are not well-established. These groups are actors in the agri-food systems, and their views, values, needs, and expectations are crucial in helping to co-design fair, ethical, acceptable, sustainable, and socially desirable policies on new plant breeding techniques (NPBTs) and the transition to sustainable agri-food systems. In this study, we engaged with consumer experts and societal stakeholders to consider their perceptions, expectations, and acceptability of improving crops and NPBTs for future-proofing the agri-food systems. Our analysis points to a need for governments to take a proactive role in regulating NPBTs, ensure openness and transparency in breeding

new crop varieties, and inform consumers about the effects of these breeding programmes and the risks and benefits of the new crop varieties developed. Consumer experts and societal stakeholders considered these strategies necessary to instil confidence in society about NPBTs and accelerate the transition to sustainable agri-food systems.

KEYWORDS

acceptability, biotechnology, food security, risk perception

1 | INTRODUCTION

Food production needs to increase by 70%–100% by 2050 to meet the global demands of feeding 10 billion people (Food and Agriculture Organization, 2009). It is also well established that current agri-food systems are under pressure from the compounded effects of population growth, urbanisation, migration, resource scarcity, increasing demand for animal protein, land-use change, and climate change (Fischer et al., 2005; Mitter et al., 2020; Scrieciu, 2011; Wiebe et al., 2015). Plants are the primary energy source and essential nutritional components in the agri-food systems. Breeding crops often involves using chemical inputs that can negatively impact the environment and human and animal health, resulting in lower system resilience and increased concerns about the sustainability of the production systems (Phelps et al., 2013; Pretty et al., 2018; Rasmussen et al., 2018; Siipi, 2015; Tilman, 1999). In addition, climatic changes and increasingly extreme weather conditions reduce crop resilience and farm output (Bebber et al., 2013; Chaloner et al., 2021; Nelson et al., 2009; Rosenzweig & Parry, 1994; Tobey et al., 1992). A plausible way to tackle these challenges is to future-proof those plants' characteristics. Future-proofing plants entail breeding plant varieties with improved yield, nutritional quality, and sustainability (crop resilience) traits. New plant breeding techniques (NPBTs) can serve as a path to increased nutrition security and sustainable agri-food systems as they can be used to develop plants with these improved traits faster and with better precision (McCouch et al., 2013). Opinions differ on what plant breeding techniques should be called "new." To avoid a detailed debate on the definition, in our paper, we adopt the working definition of NPBTs as those techniques developed since the knowledge of DNA structure became applied to plant breeding. This definition thus includes genetically modified organisms (GMOs).

Ongoing efforts have explored the role of NPBTs in future-proofing the agri-food sector. Several recent publications discuss the role NPBTs play in improving crop traits (Baekelandt et al., 2022), extreme scenarios of future agri-food systems (Cornelissen et al., 2021), and agri-food system stakeholder's responses to crop improvement strategies (Stetkiewicz et al., 2022b). There is also some information on consumers' responses to GMOs (Aleksejeva, 2014; Delwaide et al., 2015; European Commission Directorate General for Health and Food Safety, 2020; European Food Safety Authority, 2019; Scientific Foresight Unit, 2021; Luck et al., 2015; Nielsen & Anderson, 2001; Popek & Halagarda, 2017; Scholderer, 2005). However, societal stakeholders and consumers' specific concerns and appreciation of strategies for future-proofing crops and the acceptability of NPBTs are not well established (Beghin & Gustafson, 2021; Shew et al., 2018). Their views can substantially influence the societal debate regarding future-proofing crops using NPBTs. The current paper aims to give consumers and societal stakeholders insights and recommendations on future-proofing crops and NPBTs. To do so, we analyse consumer experts and societal stakeholders (i) views vis-à-vis the main challenges for Europe's agri-food sector, (ii) views and responses to crop improvements and (iii) acceptability of using new plant breeding techniques for future-proofing Europe's food and agriculture sector to inform the policy and decision-making on future-proofing Europe's crops. Whilst Europe is the focus, our findings have relevance for other geographical areas.

Section 2 of this article describes the methods used to elicit consumer experts and societal stakeholders and the analysis framework. In Section 3, we present the knowledge generated through our workshops. In Section 4, we discuss our results by comparing consumer experts' and societal stakeholders' views on crop improvement strategies and the acceptability of NPBTs for crop improvements. In the conclusion section, we highlight consumer experts and societal stakeholders' main concerns and their needs and recommendations.

2 | METHODS

We conducted three virtual workshops, two with consumer experts and one with societal stakeholders from

Europe, as a part of the CropBooster-P project (Baekelandt et al., 2022). The CropBooster-P project aims to develop a roadmap for introducing new crop varieties in current agricultural practice by aligning the development of these crops with the needs, concerns, wishes, and expectations of society. Detailed semi-structured online focus group protocols were developed for all workshops based on prior experience (Menary et al., 2021). The participants, design, materials used, and procedure followed in each workshop are described in the subsequent sections, and the protocols for each workshop are appended in the Annexe. A purposive sample of consumer experts and societal stakeholders was used to elicit knowledge about NPBTs for crop improvements. We engaged with these groups as it allowed the creation of a broad overview of currently deemed important issues on crop improvements.

We approached potential participants via email based on a standardised template. We informed participants about the programme, GDPR protection laws, and asked for their signed consent as the workshops were video recorded to capture the entire online interaction. Once participants joined the Microsoft Teams meeting, we started the workshop focus groups with a round of introductions and explained the ground rules. We also brought the few who arrived late up to speed at the earliest given opportunity. Once we finished our discussion and interactions, we debriefed the participants and thanked them. All the online workshop focus groups ranged from two to three participants, and the discussions lasted between 1 h and 15 min and 2 h and 15 min.

2.1 | Workshop I: "Consumer expert's response on crop improvement strategies"

2.1.1 | Participants and focus group design

The first workshop with consumer experts was organised in June 2020. It consisted of three small-scale focus groups and discussed "Consumer expert's response on crop improvement strategies." We choose to ask experts focusing on consumer science within sustainable farming, food production, diets, and health about their opinions on consumers' responses to improving crops using new plant breeding techniques to elicit a broad overview of consumer views. We reached out to 120 experts, received 13 confirmations, and after last-minute cancellation, eight experts participated from across Europe.

Participants represented five EU countries, Belgium ($n = 2$), France ($n = 1$), Italy ($n = 2$), Sweden ($n = 1$), the United Kingdom ($n = 1$), and the Republic of Ireland ($n = 1$). Of these eight participants, six identified as female and two identified as male and represented academic institutes ($n = 6$), non-governmental ($n = 1$), and private sector ($n = 1$) organisations.

2.1.2 | Materials

In this workshop, we sought to elicit consumer experts' views on the potential economic, social, and environmental impact of the CropBooster-P options for improving crop yield, sustainability, and nutritional quality traits.

The CropBooster-P options presented (Figure 1) during these workshops were crop improvement options identified via a critical review drawing on state-of-the-art from the plant science community (Baekelandt et al., 2022). In collaboration with CropBooster-P's plant science community, we classified the options under CropBooster-P's three overarching "goals": increasing yield (Hilty et al., 2021), nutritional quality (Scharff et al., 2021), and sustainability (Gojon et al., 2022). The categorisation of these options primarily corresponds to the intended goal despite having interconnected effects.

Experts were introduced to the 15 CropBooster-P "options" on double-sided cards to facilitate discussion and present participants' options. These cards showed the broader aim of the option with a scientific example of its effects on at least one crop. In addition to the 15 option cards, a blank card—"Option Card #16"—was created to foster discussion about potential crop improvement strategies that could be added to the list of CropBooster-P options. See Annexe for the CropBooster-P option cards used in the workshop.

The primary questions we asked were

Q1 "What are the biggest challenges for the European agri-food sector over the next 30 years?"

Q2 "Which CropBooster-P option is most important?"

Q3 "Which CropBooster-P option is least important?"

Q4 "What are the potential social, environmental, or economic impacts of the CropBooster-P options?"

Q5 "How do these options meet the challenges facing the European agri-food sector?"

Microsoft Teams was combined with the website *Mural* (www.mural.co) to facilitate working with different option cards, which provides a platform for multi-person, interactive whiteboarding. The option cards were incorporated into a *Mural* whiteboard, and multiple copies were created and used with different card orders to avoid ordering bias.

2.1.3 | Procedure

After the initial formalities associated with starting the workshop, we first asked the participants Q1. They were then allowed to discuss and tell us their views about the

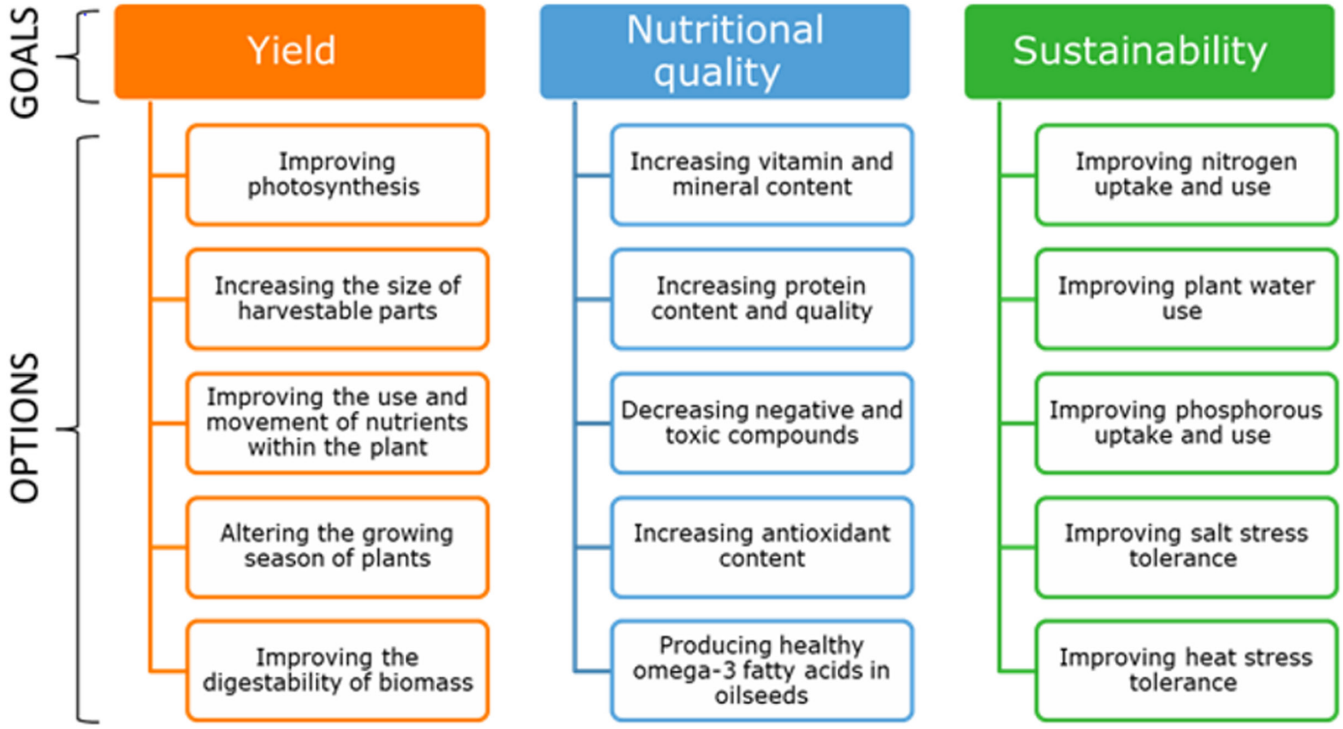


FIGURE 1 CropBooster-P goals and options used in the workshops

most significant challenges for Europe's agri-food systems. Then, we showed the experts a set of CropBooster-P options related to a CropBooster-P goal and asked them to prioritise and appraise them based on Q2–Q5. Once they discussed and appraised these options, they were invited to discuss crop improvement strategies they felt were important via Option Card #16 in *Mural*.

2.2 | Workshop II: "Consumer expert's response on New Plant Breeding Techniques"

2.2.1 | Participants and design

The second workshop, "Consumer expert's response on New Plant Breeding Techniques," was organised in August 2020. This workshop had three focus groups with seven participants from the first workshop, one replacement for a participant who could not attend and one additional participant that could attend the second consumer expert workshop but not the first. In this workshop, we asked them about their opinions on consumers' responses to new plant breeding techniques to elicit a broad overview of consumer views. These eight participants represented five EU countries, Belgium ($n = 2$), France ($n = 1$), Italy ($n = 3$), Sweden ($n = 1$), and the United Kingdom ($n = 1$). Of these eight participants, six identified as women, two identified as men, mostly from academic organisations ($n = 6$), private sector ($n = 1$), and non-governmental organisations ($n = 1$). We conducted this workshop in English to facilitate interaction between experts from different countries.

2.2.2 | Materials

In the second workshop focus group, we sought to analyse consumer experts' views on NPBTs, their acceptability and preference change in prioritising CropBooster-P options given the available NPBTs for selecting and creating new plant varieties. The primary questions we asked were

Q6 "What are your views regarding NPBTs available for crop improvement?"

Q7 "What are your expectations regarding applying NPBTs for crop improvement?"

Q9 "How do you prioritise the CropBooster-P options given the NPBTs currently used to create new varieties?"

Q9 "Which improvement strategies are the most important for future-proofing Europe's agri-food sector given the available NPBTs?"

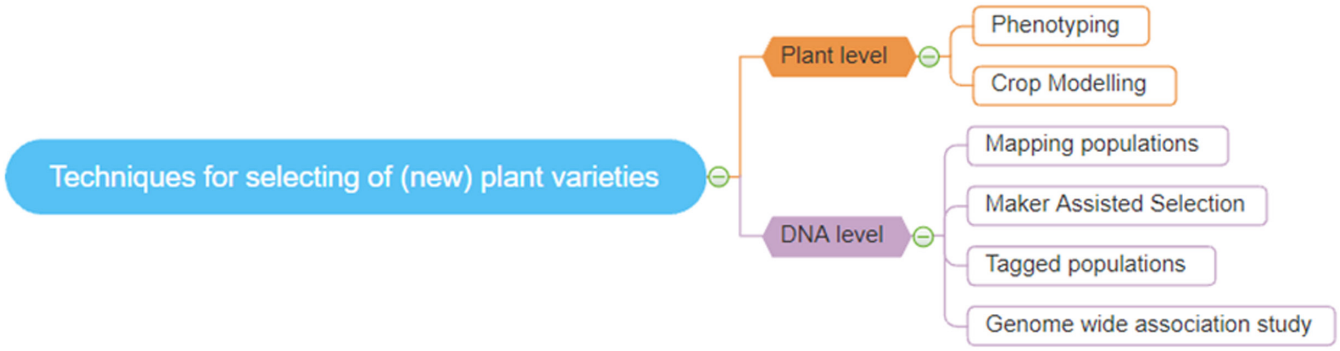
Q10 "Which crop improvement strategies are the riskiest for future-proofing Europe's agri-food sector given the NPBTs currently used?"

These NPBTs were extracted from the critical review drawing on state-of-the-art (Baekelandt et al., 2022). We categorised these NPBTs with help from the CropBooster-P's plant scientist community into two main themes (i)

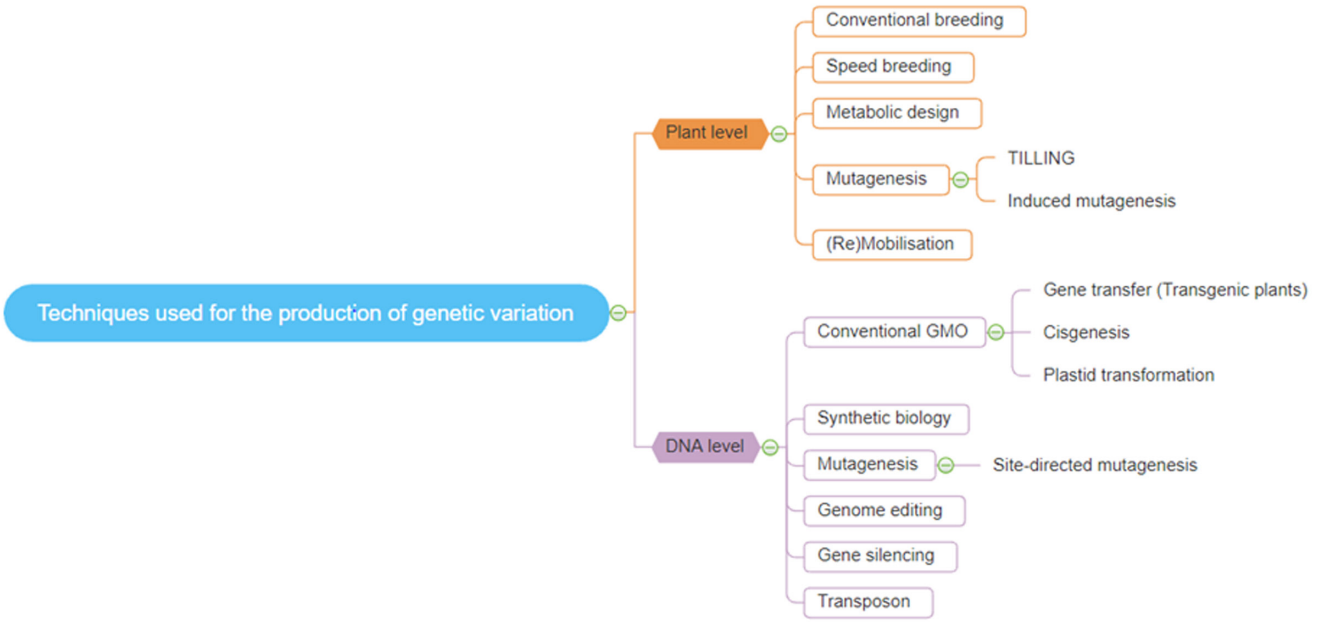
techniques for selecting plants and (ii) techniques for creating a new plant, as shown in Figure 2. Microsoft Teams combined with *MindMaster*™ (www.mindmaster.io) was used to facilitate the workshop, online activities, and discussions. *MindMaster*™, a multi-person, interactive, participatory-mapping platform, was used to present the identified NPBTs, which helped participants traverse through the NPBTs to select and create a new plant variety at the plant and DNA levels. A brief description of each NPBTs was provided to the consumer experts during the workshop. After this, the various NPBTs available for crop improvements under each CropBooster-P option were presented (yield, nutrition, and sustainability) to explore whether the prioritisation of the crop improvement strategies would change. See the protocol for the second workshop in Annexe for detailed information regarding the techniques used to improve yield nutritional and sustainability traits.

2.2.3 | Procedure

After completing the initial formalities of starting the workshop, NPBTs available for selecting and creating new plant varieties with short descriptions were presented via MindMaster™. Participants could traverse the branches and ask questions. We then asked Q6 and Q7 and allowed the experts to discuss and explain their views on NPBTs, their potential impacts, and their perception of acceptability. Following these discussions, NPBTs for each CropBooster-P option was presented. We asked them Q8–Q10 to see whether participants would change how



(a) Techniques for selecting a plant variety



(b) Techniques for creating a new plant variety

FIGURE 2 Techniques for selecting (a) and creating (b) new plants

they prioritised the CropBooster-P options compared to the first workshop.

2.3 | Workshop III: "Societal stakeholders" response on future-proofing plants'

2.3.1 | Participants and design

For the third workshop, "Societal stakeholder response to future-proofing plants," we formed three local versions of the (in total, six focus groups) workshops in Italy, Romania, and the Netherlands. We engaged with 30 societal stakeholders (18 females and 12 males) between mid-November 2020 and late January 2021, which included (inter/non-) governmental organisations ($n = 7$), plant breeders ($n = 6$), agri-food researchers ($n = 14$), reporters ($n = 1$), farmer/politician ($n = 1$), and businesses ($n = 1$). However, due to difficulty scheduling and last-minute cancellations, not all groups or regions were equally represented. Particularly the turnout for the Romanian focus groups was large, resulting in some topics not being discussed at the same level of depth as in the other focus groups.

2.3.2 | Materials

In this workshop, we sought to elicit societal stakeholders' views on strategies for crop improvement and the acceptability of NPBTs for improving crops. The primary questions we asked were

Q11 "What are the biggest challenges for Europe's food and agriculture sector?"

Q12 "What critical crop improvement strategies should we consider for future-proofing Europe's crops?"

Q13 "What are your views regarding new plant breeding techniques for crop improvement?"

Microsoft Teams combined with *Mural* was used to brainstorm essential crop improvement strategies and *MindMaster*™ to present NPBTs (see Annexe). We gave a refined version of the NPBTs in this workshop (Figure 3) mainly because selecting a new plant variety does not modify a plant's genetic makeup. Some genetic variation techniques presented in the second workshop were re-categorised into higher breeding techniques with plant scientists to reduce ambiguity. For instance, metabolic design, synthetic biology, and (re)mobilisation are molecular-assisted breeding techniques, while gene transformations and site-directed mutagenesis, transposon, and gene silencing are techniques associated with gene editing.

2.3.3 | Procedure

Once we completed the introductory session, we asked Q11 to ease participants into our focus group discussion. Following this discussion, participants were invited to join us on the *Mural* whiteboard and tell us about crop improvement strategies that they considered critical based on Q12. After they gave us their reasoning on crop improvement strategies, we asked them Q12–13 to elicit their views on the acceptability of NPBTs for crop improvement.

2.4 | Analysis approach

A GDPR-compliant company transcribed video recordings. Transcripts were checked for errors and anonymised by removing identifying information. We adopted a *Framework Analysis* approach (Ritchie et al., 2014; Srivastava & Thomson, 2009) and tasked a researcher with developing codes and drawing out unique themes for each workshop focus group. Other researchers then reviewed the meaning and conclusions drawn from these unique themes. The transcripts were fully coded and analysed using *NVivo* qualitative data analysis software.

3 | RESULTS

3.1 | Key themes from the first consumer response workshop on crop improvements

Analysis of the first workshop revealed discussions about three key themes. Specifically, these are related to the (i) main challenges, (ii) appraisal of the CropBooster-P options, and (iii) essential strategies needed for future-proofing Europe's food and agriculture sector.

Participants describe **climate change** and the implications that an **increasing population** imposes on food and nutritional security as what they perceive as the most significant challenges for the European agri-food sector in the near future.

> "I work in emergencies, and I see how much droughts and other disasters have an impact on agriculture production."
>
> First Consumer Expert Workshop Focus Group #1

> "The biggest issue is producing enough food sustainably for an increasing population."
>
> First Consumer Expert Workshop Focus Group #2

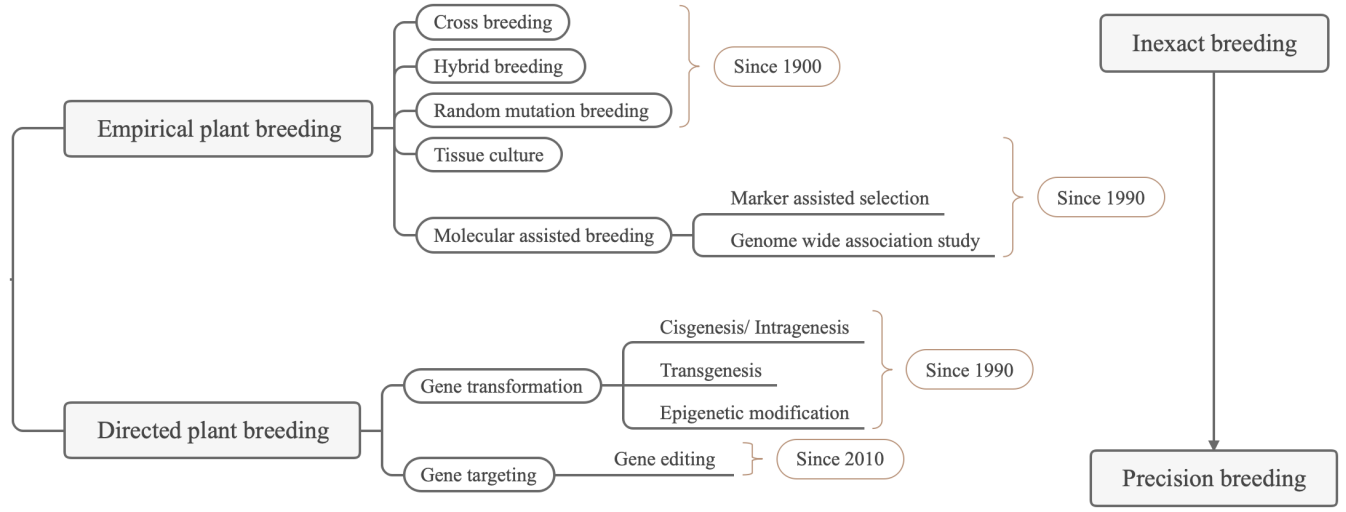


FIGURE 3 MindMaster for traversing new plant breeding techniques for creating a new plant

They also highlighted that current **regulation** around new plant breeding technologies was inadequate. They emphasised that (bio)technology regulation was outdated, requiring amendments and updates to existing legal frameworks to foster innovation and transform the agri-food systems.

> "The current legal framework in regulating GMO and others are still quite outdated in a way. So, if they want to make a change in the food system and the agricultural system, I think they should consider revising the legal framework first...."
>
> First Consumer Expert Workshop Focus Group #3

Another common observation was the perceived dangers of NPBTs for crop improvement and their implications for **consumer acceptability**. They proposed that improving communication on the impacts of these NPBTs and providing options for consumers to participate could contribute positively to consumer risk perceptions.

> "...you think a range of breeding technologies... you think yes, that sounds good. And when you dig deeper, it is a genetic modification, and there is going to be much resistance from a consumer perspective to GM crops."
>
> First Consumer Expert Workshop Focus Group #2

We also invited participants to prioritise and discuss the risks and benefits of the CropBooster-P options. Most participants expressed their **uncertainty** in prioritising options. For instance, they were uncertain about the scope and impact of these CropBooster-P options and wanted to know whether these strategies accounted for geographical scope and societal needs. In addition, they also mentioned that there is a **knowledge gap or the lack of knowledge transfer between the professional communities** (farmers, plant-breeders, businesses, policy-makers, and civil society organisations that represent consumers) that needs to be bridged to critically think about the risks and benefits of these CropBooster-P options.

> "I think it all depends a lot on which type of crops that these interventions are possible for and if it is a problem for these crops, we do not know a lot about it."
>
> First Consumer Expert Workshop Focus Group #2

> "... what you should be doing going out is telling the world these are the challenges you face, we face.
>
> First Consumer Expert Workshop Focus Group #3

They also mentioned CropBooster-P options such as "*Increasing the size of harvestable parts*", "*Increasing protein content and quality"* and "*Decreasing negative and toxic compounds"* as problematic, having **potential trade-offs** on the life cycle, nutritional profile, taste, and quality.

> "I am not excited about increasing the size of harvestable parts, and the reason is if

increasing the size has negative impacts on quality or taste profile"

First Consumer Expert Workshop Focus Group #2

"... increasing the protein content might also increase a certain type of, let us call it, disease in the population such as intolerance to gluten"

First Consumer Expert Workshop Focus Group #1

When asked to discuss the **potential impacts, risks, and benefits** of the CropBooster-P options, participants associated options for "*Improving nitrogen uptake*" and use and "*Improving phosphorus use efficiency*" to the efficiency of fertiliser use, soil quality, and reduced production costs. They also attributed "*Improving plant water use*" and "*Improving heat stress tolerance*" to efficient resource use. Besides, they agreed that "*Producing healthy omega-3*" and "*Improving antioxidant content*" would have both a market (e.g., demand and price premium) and health benefits (e.g., diet and nutrition).

"... when it comes to phosphorous and nitrogen, it is related to the efficient use of fertilisers or reducing the use of fertilisers, which might have a big impact on the cost of production for farmers, and the environment."

First Consumer Expert Workshop Focus Group #1

At least one stakeholder discussed all 15 CropBooster-P options and thought those strategies that directly benefit human and environmental health were the most relevant. Participants considered certain options relevant to specific European regions or local contexts (e.g., salt stress being significant to France, Spain, and Italy). In contrast, they considered other options to vary in importance. For instance, they felt that "*Improving biomass digestibility*" was necessary to improve feed quality and biofuel's energy processing efficiency, but not for human food and nutritional security.

Once they discussed all the CropBooster-P options, they also had the opportunity to highlight possible options that they felt were important through the "Option Card #16" activity. Participants during this activity mentioned several possible options. Illustrated in Figure 4 are some of the vital crop improvement strategies discussed during the Option Card 16 activity. These strategies suggested by consumer experts primarily pertain to agri-food system-level transformations and some farm-level interventions.

FIGURE 4 Consumer response workshop: Key themes in option card #16 (The darker blues suggests the more discussed themes)

3.2 | Key themes from the second consumer response workshop on new plant breeding techniques for crop improvements

Analysis of the second workshop revealed discussions about four key themes. Specifically, these are related to the (i) acceptability of selective breeding techniques, (ii) scepticism around NPBTs, (iii) potential risks and benefits of NPBTs, and (iv) re-emphasised the need for better regulation, their uncertainty, and current knowledge gap.

During the discussion regarding techniques for selecting a new plant variety, most consumer experts felt that these techniques were standard and used for several years. They also thought that these computer-based analysis techniques for selecting new plant varieties, like marker-assisted selection, would be **easy for consumers to accept** as they were primarily computer-based simulations. However, consumer experts raised concerns about the risks associated with human error and developing wrong models, leading to unintended consequences.

"I have no problem with any of these technologies. I think they are standard at this point. I mean, used in plant identification, and they have been used for several years."

Second Consumer Expert Workshop Focus Group #1

Consumers experts expressed their scepticism regarding the **acceptability** of NPBTs for creating new plant varieties through genetic variation. They voiced their concerns regarding technologies that they felt might be less acceptable to consumers. They felt that consumers were unaware of crop production and mentioned that they would accept these technologies if they were educated regarding the type of technology available and benefit from these NPBTs.

> "There has been a great deal of concern about CRISPR and reporting about what happens if CRISPR goes wrong. And then, of course, the examples of Crispr used on human beings. So, for those reasons, I am concerned that European consumers may have problems with that."
>
> Second Consumer Expert Workshop Focus Group #3

> "But, as you went to mutagenesis, my concern was about how consumers would perceive these technologies, especially the use of chemicals or radiation to change DNA in plants or animals. And then, as obviously as we know, and the same would be true with synthetic biology, I can just hear anytime people saying synthetic or something that does not sound natural, I would imagine many consumers would have problems."
>
> Second Consumer Expert Workshop Focus Group #2.

They also described a few **potential social, economic, and environmental risks and benefits** of these NPBTs. Table 1 shows some of the main risks and benefits perceived. Consumer experts felt that the benefits of the NPBTs would be tremendous while citing several potential economic and social risks.

> "If we can manage the risks, I think the effects are tremendous in terms of improved nutrition, greater efficiency of production, ability to deal with drought or salinity or climate change in a broader sense. So, I can see a great benefit."
>
> Second Consumer Expert Workshop Focus Group #1

> "I think that the risks are not with [developing] crops in themselves, but rather with the use of these new technologies... we cannot control what is going on. I think it could be a risk if a lot of small farmers start doing their genome editing."
>
> Second Consumer Expert Workshop Focus Group #2

The act of revealing NPBTs currently available for each CropBooster-P option did not change how they prioritised them. They still considered "*Improving the size of harvestable parts*" and "*Altering the growing season*" as the least important while "*Improving the use and movement of nutrients*" as the most important. Regarding "*Improving nutritional quality*," they felt that "*Increasing vitamin and mineral content*," "*Increasing antioxidant content*," and "*Decreasing negative and toxic compounds*" were the most essential strategies. They also felt that increasing water, phosphorous, and nitrogen use and efficiency was critical for improving crop sustainability.

> "Increasing the size of the harvestable parts is not needed and not something consumers are looking for. And maybe also altering the growing season for some crops and some food, it is not something that might be accepted from a consumer point of view."
>
> Second Consumer Expert Workshop Focus Group #1

> "I would prioritise whatever has to do with sustainability and reducing the pressure that Europe can put on other countries for

TABLE 1 Risks and benefits of NPBTs

NPBTs	Social	Economic	Environmental
Risks	Control and traceability of NPBTs	Feasibility	Cross fertilisation between genetically modified and natural species
	Food safety issues	Price premiums	
		Production costs	
Benefits	Improved nutrition		Improved production efficiency
			Resilience to climate exposure

production and also on the resources available in Europe and within Europe."

Second Consumer Expert Workshop Focus Group #2

"The improving water use comes to mind for two reasons. It is a concern that I think is easy for consumers to understand in terms of sustainability. It is easy to communicate. The fact that you can use crop modelling, I think, is much more acceptable."

Second Consumer Expert Workshop Focus Group #3

Finally, they re-emphasised the need for **better regulation**, the uncertainty in prioritising due to the **variation in impact and geographical scope** and the need for **better communication**.

"I think we just need a better legislation system in place. I think anything unfamiliar to consumers, risky or not; it will not be accepted."

Second Consumer Expert Workshop Focus Group #2

"I very much agree that you need to go and explain in language that people understand. If you do that, I think most people should be able to engage and understand what is being talked about."

Second Consumer Expert Workshop Focus Group #3

3.3 | Key themes from the societal stakeholder' workshop on crop improvement strategies and the acceptability of new plant breeding techniques

Societal stakeholders mentioned that **increasing crop yields** to meet the demand of a growing population and a changing European market is vital for future-proofing Europe's food and agriculture sector. They also highlighted urbanisation as a challenge to produce sufficient food globally, putting pressure on agriculture. In addition, they claimed **rural–urban migration**, changing labour dynamics, and land availability for farming in rural areas were significant problems for the agricultural sector, exacerbated by the pandemic, which needs innovation to keep it viable. Participants also cited external pressures on agriculture, generally related to **climate change**. In particular, they raised concerns about increased weather variations, extreme temperatures, precipitation, drought, and floods as leading issues. These effects were seen causing (a)biotic stress in crops, leading to crop losses and reduced yields, while suggesting that the simultaneous impact of a changing climate could introduce new pathogens into a region, causing severe biotic stresses that make the agricultural system vulnerable.

"...I think the biggest challenge for the European Union is to be more open towards food production because it happens that we import much food from other countries."

Societal Stakeholder Mediterranean Workshop Focus Group #2

"... we have to provide farmers with new ways to make agriculture viable; otherwise, we are going to have a huge problem..." [related to agricultural labour dynamics and rural–urban migration]

Societal Stakeholder North-West European Workshop Focus Group #2

"... with climate change will come more precipitation in certain areas and more drought in others. That means a shift in pathogens that have not been seen in certain areas before."

Societal Stakeholder Eastern European Workshop Focus Group #1

They mentioned that these effects required improved agricultural practices to **reduce food loss** as much as possible. At the same time, they raised the issue that waste reduction is essential to maintain sufficient food production levels.

"...a lot of what we have today, climate change, comes from the way we produce [food], and because we produce more than we need and do not use it which results in wastes."

Societal Stakeholder North-West European Workshop Focus Group #2

Regarding future-proofing needs, we asked societal stakeholders to brainstorm about future-proofing strategies for crop improvement. The participants used the *Mural* shown in Figure 5 to brainstorm crop improvement strategies. They wrote down strategies they felt were necessary on sticky notes, described their role in future-proofing crops and placed them on the Venn diagram corresponding to the

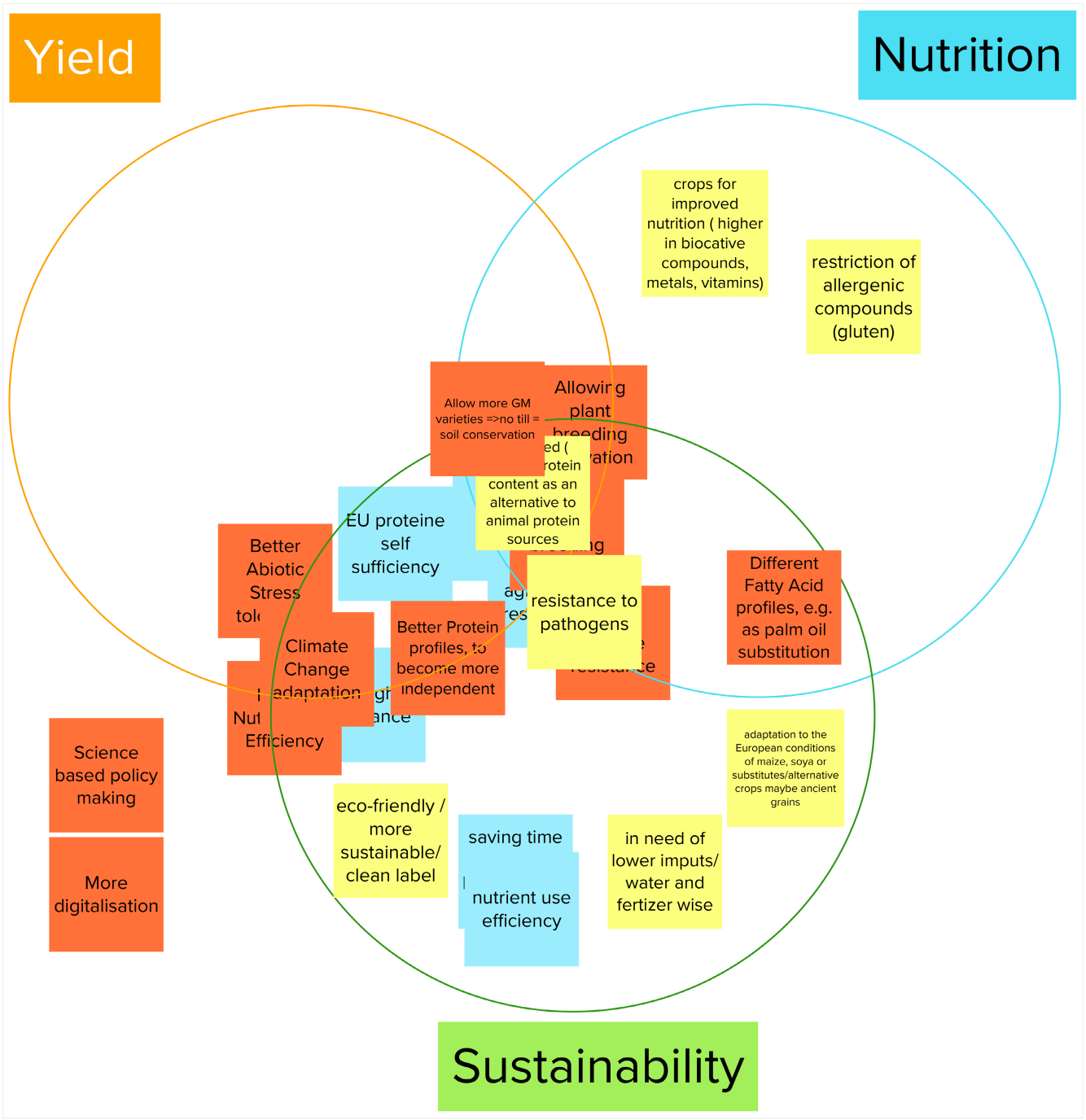


FIGURE 5 Brainstorming activity results from the first focus group (NB crop improvement strategies identified by different societal stakeholders have different post-it colours)

crop improvement goal(s) it would achieve. Figure 5 is an illustration of the results of the brainstorming activity on future-proofing needs for Europe's food and agriculture sector. It shows the North-West European Workshop results by Wageningen University, and Table 2 lists the strategies depicted in Figure 5. Societal stakeholders elaborated strategies that improve the agri-food system's resilience, production efficiency, and competitiveness. They mentioned that **improving the agri-food system's resilience** was unavoidable as it plays a vital role in transforming the food and feed system. Participants recognised the increasing role of **digital technology** in agriculture. They reflected on the role of digitisation in identifying and responding to threats in the agri-food production chain. It allows farmers to monitor their crops comprehensibly and make more targeted decisions about harvest. They considered that such digital technologies could improve agricultural production independently (and not requiring) from improved plant breeds.

TABLE 2 List of strategies as shown in Figure 5

Participant 1: Orange post-it	Participant 2: Yellow post-it	Participant 3: Blue post-it
Allow more GM varieties	Improve protein content as an alternative animal protein source	Bio-aggressor techniques
Allow plant breeding innovations	Resistance to pathogen	New breeding techniques
Better disease resistance	Adaptation to EU conditions	EU protein sufficiency
Better abiotic stress tolerance	Lower input and fertilisers	Drought resistance
Climate change adaptation	Eco-friendly/sustainable/clean label	Less fertiliser use
Better nutrient use efficiency	Restrict allergenic compounds	Nutrient use efficiency
Better protein profiles	Improve crop nutritional profile	
Different fatty acids		
Digitisation		
Science-based decision making		

> "... Digital technologies can estimate when the yield is ready and when there is a loss. So, it is more about just optimising the land that we already have rather than, you know, manipulating the seed itself to create more per area...".
>
> Societal Stakeholder North-West European Workshop Focus Group #2

They voiced the need to **protect and improve soils, foster local food production, encourage a shift to sustainable diets, and promote ecolabelling**. They suggested these strategies as necessary to increase market competitiveness through sustainability transitions and reduce consumption, environmental pollution, and mitigation of greenhouse gas emissions.

> "Investigations were carried out, including by satellite, in which soil quality and the consequences of intensive agriculture were assessed in certain areas of Europe. Also, considering the stress induced by global warming, the situation is far from good."
>
> Societal Stakeholder Eastern European Workshop Focus Group #1

> "I think now is the time to think about the local production and it from this unit, we have to develop in the future because the local produce takes care of the local economy."
>
> Societal Stakeholder North-West European Workshop Focus Group #2

> "... in [country], ... 700 Kg per person/every year [food consumed] is consumed which is very high... we have to push people towards a dietary shift not to reduce food but to improve their diet by reducing some foods and increasing the consumption of other foods...".
>
> Societal Stakeholder Mediterranean Workshop Focus Group #1

Regarding crop improvement strategies, societal stakeholders in most focus groups discussed "***Increasing protein content***" as an essential plant breeding strategy for reducing Europe's protein imports. They also suggested that "***Improving fatty-acid content***" in plants that grow in Europe's climate and soils could help achieve palm oil independence, reducing deforestation in South America. In addition, participants raised those plant breeding strategies that aimed at more effective and efficient use of resources as essential. In particular, given the droughts, **improving water use**, and the need to limit fertiliser use, **nutrient use efficiency** was considered essential in promoting environmental sustainability and mitigating greenhouse gas emissions. They also recognised the need to "***Improve photosynthesis***" to improve yields significantly.

> "... we see a huge amount of imports of soybean and other proteins into Europe... and I think becoming more independent of those imports, is advisable." [related to increasing protein content]
>
> Societal Stakeholder North-West European Workshop Focus Group #1

"it is [improving water-use efficiency] related to yield, but also sustainability in the sense that it allows a crop to be more adapted. Water uptake efficiency is crucial as water availability decreases in many regions."

Societal Stakeholder North-West European Workshop Focus Group #3

"I would say increase nutrient efficiency ... Some groups are trying to have this -omics approach to have a general view of how interconnected things are. ... and increasing it [nutrient use efficiency] you do not have to add many fertilisers like nitrogen and phosphorus."

Societal Stakeholder Mediterranean Workshop Focus Group #2

During the focus group discussions, we asked societal stakeholders about their views on NPBTs. They mentioned that those techniques that seek to develop new plant varieties **must be regulated**. They also mentioned that current regulation was outdated and treated NPBTs as traditional genetic modification. Nonetheless, they expect classical Genetic Modification (transgenesis, mutagenesis, and similar) and precision breeding techniques to be regulated separately. Participants also pointed out **regulators' hesitation** as a critical issue hindering the development of legislation tailored to this new generation of plant breeding techniques. They also claimed that the lack of precise regulation encumbers farmers and limits the EU agricultural sector's market competitiveness.

"I think the very hesitant approach of the EU, about the regulation or not of these techniques, does not contribute to consumer confidence in these technologies."

Societal Stakeholder North-West European Workshop Focus Group #3

In general, participants claimed to favour innovation. However, they expressed their **scepticism** and views on whether the public would accept them and contested the **acceptability** of a few techniques, particularly those for which they perceived risks that outweigh the benefits to the natural ecosystem. Techniques such as random mutation breeding and transgenic crops were **criticised** as imprecise.

"In my view, we should use all the innovation and make sure it is safe, but use it, and do the checks that we all agree on."

Societal Stakeholder North-West European Workshop Focus Group #1

"Because by throwing these chemical agents and radiation, you create so many mutations that might also create many unintended mutations. The organic movement sees potential risk in using this technique."

Societal Stakeholder North-West European Workshop Focus Group #3

"You said that these techniques are precise... this is not true if you consider the people working on human embryos. They claim not to make a genetic change to embryos as traits could be transferred to the future generation because the technology is not precise."

Societal Stakeholder Mediterranean Workshop Focus Group #1

Recalling the debate around genetic modification, which has primarily focused on risks, societal stakeholders raised the **issue of safety and traceability** as being of critical importance to avoid genetic modification pitfalls. They also mentioned that plant breeding **outcomes need to be communicated**, not the technique alone. They recommended communicating the outcomes to farmers regarding a new plant variety's traits, benefits, and impacts. This communication, in their view, was seen as how to raise awareness about the potential of new plant varieties. In addition, they discussed the importance of **informing consumers** and analysing consumer behaviour. In particular, they emphasised that benefits to the consumer, the current problems we face in agriculture, and the potential negative consequences (risks) should be shared as crucial steps to gain consumer acceptance of these NPBTs.

"It is vital to inform the society and consumers [regarding safety] because these discussions are useful for scientists to explain it to politicians, and society the safety of this method because it is necessary to avoid the same mistakes made during GMO's development."

Societal Stakeholder North-West European Workshop Focus Group #2

"...been mentioning it from the beginning that there is not enough communication with the consumer on these issues [new plant breeding techniques] ..."

Societal Stakeholder Eastern European Workshop Focus Group #1

4 | DISCUSSIONS AND CONCLUSION

To meet the global demands of providing nutritious, sustainable, and safe diets for a 10 billion population by 2050 while preserving affordability, reducing environmental impacts, and adapting to climate change will require accelerating the transition to sustainable agri-food systems. NPBTs can play a crucial role in future-proofing crops by increasing crop yields and resilience and improving plant nutritional quality, which can help achieve food and nutritional security and contribute to developing sustainable agri-food systems.

In this study, we analysed consumer experts, and societal stakeholders' perceptions of the (i) challenges the agri-food sector faces, (ii) risks and benefits of crop improvement strategies and new plant breeding techniques, and (iii) their expectations and acceptability regarding NPBTs and future-proofing strategies. We analysed these views and perceptions to detail consumers' and societal stakeholders' expectations, needs, and values for embedding in decision-making and highlight plausible and desirable strategies for guiding policy processes in the highly contested topic of developing new plant varieties via NPBTs.

Based on our analysis of the deliberations with consumers and societal stakeholders on crop improvements and the acceptability of NPBTs—we inferred that the most pressing challenges for Europe's agri-food sector were the impacts of climate change and meeting the food demands of a growing population. The issue of climate change affecting agriculture is well established in the literature, with several assessments highlighting climate change's impact on the food system (van Meijl et al., 2017; Vos & Bellù, 2019). Studies also support the claim that population growth and future food demand will continue encumbering the agri-food system (van Dijk et al., 2021; Vos & Bellù, 2019).

We also established that crop-level strategies such as improving water-use efficiency, heat stress tolerance, protein content and photosynthesis, and farm-level strategies such as promoting sustainable local farming, reducing food waste, and increasing resilience to biotic and abiotic stresses are crucial for future-proofing the agri-food system by both consumers and societal stakeholders. In addition, it was recommended for future-proofing crops that these crop-level and farm-level strategies are designed in combination to optimise local and global needs. Though there are studies that point to the importance of these crops- and farm-level strategies (Béné, 2020; Giller et al., 2021; Lenaerts et al., 2019; Murrell, 2017; Schipanski et al., 2016; Varshney et al., 2021), there is limited evidence that highlights combined crop- and farm-level strategy needs and its impacts (Stetkiewicz et al., 2022a) from a consumer expert and societal stakeholder perspective (Stetkiewicz et al., 2022b).

We also evidenced that consumer experts and societal stakeholders were sceptical about NPBTs used to develop new plant varieties (Scientific Foresight Unit, 2021). The most critical factors are the lack of (i) precise regulation, (ii) openness and transparency in communicating the risks and benefits of NPBTs, and (iii) general lack of communication between plant scientists, agri-businesses, consumers, and policy-makers limiting consumer confidence. Several studies discuss the poor and amateurish regulation limiting the development and deployment of NPBTs (Ahmad et al., 2021; Turnbull et al., 2021). There are also limited studies that suggest openness and transparency and a general lack of communication between societal stakeholders reducing consumer confidence (Pei & Schmidt, 2019).

In our analysis of the deliberations, we conclude that for future-proofing crops, the agri-food systems, and instilling confidence in society about NPBTs, decision-makers and governments need to

(i) Take a proactive role or a non-hesitant approach in regulating NPBTs separately and not under the GMO directive that ensures timely action before or immediately after signals of concerns emerge and without disrupting new plant breeding innovations.
(ii) Ensure openness and transparency in research and innovation in breeding new crop varieties.
(iii) Inform consumers about the effects of these breeding programmes and the risks and benefits of new crop varieties developed to instil confidence in society, future-proof crops, and accelerate the transition to sustainable agri-food systems

This study is the first of its kind that provides stakeholder and expert-driven direction on NPBTs and their acceptability for future-proofing crops in Europe. Our analysis of NPBTs complements studies that describe Europe's agri-food sector challenges and factors limiting the acceptance of GM crops. Our study provides new insights into (i) consumer and societal stakeholders' risk perceptions, (ii) their needs and expectations regarding future-proofing, and (iii) aspects that affect the acceptability of NPBTs. These insights and recommendations understood through these deliberative processes can help formulate fairer, more inclusive, and more equitable policies.

This study used workshop focus groups to elicit information concerning crop improvements and future-proofing the agri-food sectors. These workshops allowed us to generate large amounts of expert knowledge (about

140 person-hours of knowledge exchange) to provide insights and recommendations for future research and decision-making. Although we are confident we presented the key information from the main themes discussed in this paper in sufficient detail, the necessity of reducing such a wealth of data to the content of an article means that some potentially relevant information is not interpreted in full. This is a general limitation for all qualitative research and thematic coding. In addition, eliciting a broad overview of consumer views can be tricky. Interviewing consumers in workshops is a good tool to identify some of the most salient insights and can generate a broad range of opinions (Fischer & Reinders, 2022). This method relies on relatively few participants, which makes it less suitable to provide a broad overview given the differences in consumers that are often larger within than between countries. Engaging consumer NGOs to represent consumers usually produces views that reflect the organisation's agenda and claims consumer views that tend to be more polarised than the view of the "silent majority." Therefore, we choose to ask experts focusing on consumer science within sustainable farming, plant breeding, and food and health about their opinions on consumers' responses. While this is limited by giving second-hand information, it allows the creation of a broad overview of currently deemed important issues, giving due weight to nuance and the silent majority.

We also engaged a purposive sample of experts, including many academics. A purposive expert sample is more commonly used, for example, when looking at farm-level and agri-business experts' perceptions of crop improvements (Stetkiewicz et al., 2022a, 2022b). Particularly when exploring and identifying the range of topics that matter, a purposive sample having access to the most relevant topics is often more informative than a representative sample across the population (Fischer & Reinders, 2022) which helped capitalise on the similarity of Europe but impose a limitation to the work that we could not focus on the differences between Europe. Nevertheless, the view of a purposive expert sample is not all-encompassing. In this study, we were limited to societal stakeholders mostly accepting the idea of large-scale food production as dissenting voices on NPBTs chose not to participate. In addition, the societal stakeholders interviewed were from three case study regions to gain an Eastern European, Mediterranean, and West European perspective on the issue of developing crops with new plant breeding techniques. Though participants in each region did have a difference in opinions, the study focused on emphasising the most deliberated themes based on our analysis. Despite these limitations, such studies are necessary to unravel the complexities of sustainability transitions and to design fair and just policies.

We engaged with consumer experts and responsible actors in the agri-food systems to consider their perceptions, expectations, and acceptability of NPBTs and provide recommendations that can contribute to creating fairer strategies and policies for future-proofing crops. These deliberations are necessary for contested topics (Machin, 2020; Solomon & Abelson, 2012) as they contribute to democratising and co-designing fair, ethical, acceptable, sustainable, and socially desirable policies (Christiano, 1997; Datta, 2012; Macq et al., 2020; Owens, 2000) and future research must consider citizens' views, values, needs, and expectations in policy formulation on NPBTs and developing new plant varieties as they are actors and problem owners of the sustainability transition of the agri-food systems.

ACKNOWLEDGEMENTS

We like to thank Mariana Rufino, Gijs Kleter, Will Sabine, Dörthe Krause, and Nick Vangheluwe for their thoughts and feedback on the workshops' protocols. The European Union's Horizon 2020 Research and Innovation Programme funded this research under grant agreement no. 817690.

CONFLICT OF INTEREST

Petra Jorasch is employed by Euroseeds, which is an industry umbrella organisation representing the seed and breeding sector. Amrit K. Nanda is employed by Plants for the Future ETP, which is a European Technology Platform representing academia, the seed and breeding sector, agricultural service providers, and farmers. At no point in time during the research activity, data collection or manuscript preparation, did their influence bias the outcome. None of the other authors have a conflict of interest.

DATA AVAILABILITY STATEMENT

The data collected via the focus group discussions (i.e. the codebook and the codes and references) can be made available upon request.

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SUPPORTING INFORMATION

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How to cite this article: Nair, A., Fischer, A. R. H., Moscatelli, S., Socaciu, C., Kohl, C., Stetkiewicz, S. S., Menary, J., Baekelandt, A., Nanda, A. K., Jorasch, P., Davies, J. A. C., & Wilhelm, R. (2022). European consumer and societal stakeholders' response to crop improvements and new plant breeding techniques. *Food and Energy Security*, *00*, e417. https://doi.org/10.1002/fes3.417