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Unexpected Events in Food Production are the New Normal? Results of an Industry Survey on Factors, Influencing Resilience in Food Production and Food Value Chains

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Abstract

In this paper, resilience is defined as the ability of food production entities to respond to, withstand and learn from short-term shocks and long-term stresses. Little ist known about the resilience in the food production sector. There also is a lack of information on which resilience measures companies see the greatest need for investment. Therefore, the focus of the explorative survey was to gain insight into current challenges and influences on the resilience of primary food producers and food processors, to identify topics for resilience management and related gaps.
Representatives from 84 companies in food production in Germany responded on topics of resilience, including factors that influence product safety and availability of machinery, status of preparation for disruptive events and possible measures to improve resilience.
The responses collected were analyzed descriptively. The results showed that most companies believe that they are not well prepared for disruptive events and that they require measures to improve their resilience. Most indicated that organizational factors such as the company's production capacity or the availability of raw materials, among others, have a particular influence. Every second primary food producer plans to adapt or optimize machinery and equipment as a resilience improvement measure. While slightly more than half of the respondents from the food processing sector implement measures for information procurement and training, or intend to implement such measures in the future. This area is seen as the most important aspect for improving resilience by respondents from primary food production. Overall, it also became clear that there is a need for tools to assess and evaluate resilience.

Keywords: Food chain resilience; Food production; Resilience assessment; Business continuity

1 Introduction

The European food industry is an important part of the global food supply and faces a variety of challenges that can disrupt its operations and affect food availability, quality, and safety. Maintaining food safety and supplying people with food are systemically relevant tasks (Gerhold et al., 2019). To ensure this despite dependence on globally ramified, volatile networks, compa-

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nies and supply chains involved in production should have a high degree of resilience to disruptive events (Fan et al., 2021; FAO, 2021; Tendall et al., 2015). To best address these challenges, resilience in the food industry deals with key aspects such as ensuring and maintaining the security of supply, adaptability, proactive resilience management and economic stability.
The understanding of resilience in complex systems was significantly influenced by the introduction of the term in ecology by *C. Holling*. Adaptation of vegetation to environmental conditions, mutual symbiosis, flexibility and agility are core elements of his model and can be applied to diverse systems in science and engineering (Holling, 1973).
Roosevelt et al. (2023) summarises the relevant influences on food system resilience in eight factors:

- economic factors: including the influence of wealth distribution and economic readiness to resilience;
- political factors: including the political commitment and government readiness to build resilience food systems;
- social factors: demographic issues, social readiness and socio-cultural wellbeing;
- physical infrastructure to produce and distribute food, highlighting that resilient food systems intensify output of food stuff by technological innovations;
- information capacity, which includes the increasing digitalisation and connectivity of data;
- environmental factors, which focus on land, soil and marine health, water resources and ecosystem stability;
- agriculture: diversity and redundancy in production and output and improved technologies; and
- nutritional capacities which focused e.g. on imports, costs, storage of food and per capita food production.

In most cases, the resilience assessment of any system is based on the five phases of the resilience cycle according to Thoma (2014). The quantification of socio-technical systems is carried out by mapping a performance or availability over time (Hiermaier et al., 2017, 2019; Ossevorth et al., 2022; Thoma, 2014). These conceptual strands shape our current understanding of resilience in the food industry: resilience is the ability of a system not only to return to regular functioning as quickly as possible after a disruptive event, but also to be more robust than before. It anticipates risks as much as possible, prepares for them, can overcome them quickly and learns from them. Sustainable food systems therefore have resilience mechanisms incorporated. These components are:

- coping capacity (Cabell & Oelofse, 2012);
- adaptive capacity (St. Clair et al., 2023) and;
- learning capacity. Resilient systems incorporate internal feedback mechanisms, maintain redundancy and promote responsive governance and diversification at almost all levels (Cabell & Oelofse, 2012).

Active disruption and resilience management take all key parts of the business processes into account. However, resilience is rather fluid, not a constant state and context-dependent (Beitnes et al., 2022).
How food production systems with different resilience mechanisms can differ from each other is illustrated in Fig. 1. using the qualitative example of the availability of production systems. The designs of the three production systems are comparable for the resilience phases

- prepare,
- prevent and
- protect,

as a reduction in availability begins at the same time. Examples of the different phases are:

- early warning systems (preparation),

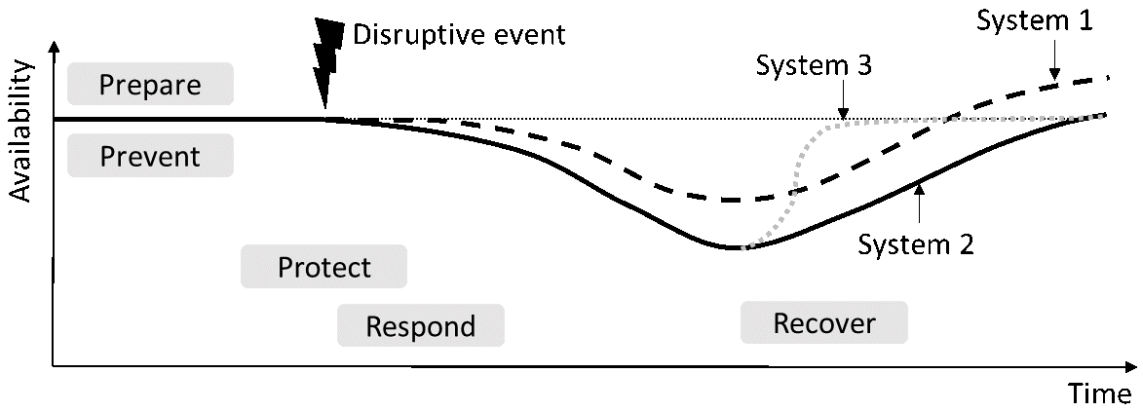

Figure 1: Exemplary, qualitative progression of the availability of three production systems with different resilience mechanisms: System 2 is characterized by low resilience. System 1 and 3 are characterized by higher resilience. In System 1 the availability is higher than before the disruption event ("bouncing forward"). In system 2 the availability after the disruptive event is the same as before ("bouncing back").

- mitigation of food safety risks (prevention) and
- hygiene zones (protection).

The differences in the system design show their effects when the disruptive event (e.g. food safety incident) occurs. In system 1, effective countermeasures (e.g. redundant system design) take effect in the respond phase, so that availability drops only slightly. The availability of systems 2 and 3, on the other hand, falls more sharply. In the recovery phase, the effects of the different system designs become even more apparent. System 1 and 2 are characterised by almost identical restart curves. In system 1, however, learning capacities are much more pronounced. It was possible to learn from the negative event, so that even higher availability is possible. System 3, on the other hand, shows a much steeper increase in availability. Faster recovery can be supported by hygienic design or operator assistance systems, for example. In the event of food safety incidents (physical, chemical, microbiological contamination, allergens), machines designed according to hygienic design criteria are easier to access, quicker and more effective to clean / disinfect (Group, 2018; Koutsoumanis et al., 2024; Mauermann et al., 2024). Operator assistance systems positively support the quality of training and shorten the duration of training. In the event of incidents, they support correct decision-making (Heinze et al., 2020).
To gain more insights into the current resilience of industrial food systems in Germany, representatives from food-producing companies, logistics and retail were surveyed on the topic of resilience, factors influencing process safety and robustness, the duration and frequency of disruptions, the state of preparation for disruptions and measures to improve resilience. This paper analyses the data, highlights resilience in food production and identifies current approaches and possible fields of action for improving resilience.

2 Materials and Methods

2.1 Study Design

The survey was prepared as an exploratory online questionnaire. The corresponding questions and partially assigned pre-defined answer options were derived based on the literature referenced in the introduction and on identified information gaps. Additionally, during the review process, the time required to answer the questions was tested to ensure that participants could complete the survey in under 15 minutes, thereby ensuring high response rates.

It should be emphasized that the survey was not limited to a specific group of people (subject matter experts) in the companies in order to achieve a high number of participants. This meant that the survey was distributed publicly and no individuals whose positions in the company were known were approached. Section 3.5 discusses limitations resulting from this circumstance. An overview of all questions can be found in section 2.2 and in Table 1.

2.2 Survey questions

The survey covered four sections, each consisting of questions on specific topics. To classify different perspectives on resilience, the first block (A) asked about the positioning of the companies in the value chain. The second block (B) focused on identifying the potential disruptive factors that may impact the company's operations. The last block (C) aimed to investigate the measures that companies take to enhance their resilience. Questions in this block helped to understand what steps they were taking to prepare for potential disruptions.
The assigned questions were mostly single- or multiple-choice questions with predetermined answer options. In some cases, free text input was requested, if the option "other" was chosen. An overview of all questions assigned to the blocks with selectable answer options can be found in Table 1. Initially, in block A, participants had to assign their company to either primary food production or secondary food processing or packaging. At the beginning of block B, the influence of various factors on ensuring process and product safety and quality was be evaluated. Therefore, the question served the purpose of identifying the greatest risks for them and their products. The following factors were provided and explained by examples in the questionnaire:

- Technical (e.g., availability and reliability of machinery and equipment, operating resources)
- Social (e.g., direct/immediate human errors, availability and level of training of personnel)
- Organizational (e.g., capacity of suppliers, own production capacity, availability of raw materials, logistics processes, dependence on import and export channels, dependence on the supply network, dependence on specialized sources, cold chain, communication)
- Ecological ((e.g., climate change, weather, contaminants (chemical, physical, microbial, allergens), residues, diseases, fires))
- Economic (e.g., innovation/price pressures, social/cultural changes, political/regulatory changes, geopolitical upheavals, price/currency fluctuations)
- Turbulences and assaults (e.g., natural disasters, geopolitical upheavals, price/currency fluctuations, pandemics, theft, vandalism, terrorism, sabotage, espionage, epidemics)
- Other

These factors were compiled for the survey on the basis of a literature review. Table 2 summarizes the models that were used as a reference for establishing these factors.
The information was summarized and simplified in order to do justice to the intended scope of the exploratory survey and the target group addressed. The result was a collection of factors listed above together with examples. Each factor was rated as having "no influence", "low influence", "noticeable influence", "high influence" or "very high influence". The subsequent question was explicitly posed only companies that were assigned to food processing or packaging in the first block.
In the final block C, participants were first asked to assess how well prepared their company was for the occurrence of disruptive events. The response options were "good", "sufficient" or "insufficient". The following question asked for a statement on the willingness to invest in resilient process design. It was possible to answer with "yes" or "no". The next question followed on from this and aimed to record planned or existing investments that serve or have served to increase resilience. The participants were given a selection of specific investment areas to choose from. Examples of investment areas include the

Table 1: Overview of all surveyed questions. MC = multiple choice, SC =single choice, 1 = version primary food production, 2 = version food processing or packaging

Section	Type	Subject of question	Answering options		Contained in questionnaire
(A)	SC	specification of the industry affiliation	primary food production food processing or packaging food logistics food retailing		1, 2
	SC	size of the company based on the number of employees	less than 10 employees between 10 and 49 employees between 50 and 249 employees more than 250 employees		
(B)	MC	estimation of the influence of various factors on the guarantee of processes and product safety/quality.	technical social organizational ecological economical turbulences other	no influence, low influence, noticeable influence, high influence, very high influence	1, 2
	SC	estimation of duration and frequency of unplanned downtime	less than 2 minutes between 2 minutes and 1 hour between 1 hour and 5 hours between 5 hours and 12 hours more than 12 hours	never, rarely, sometimes, often, very often	2
(C)	SC	estimation of own preparation for disturbances	good sufficient insufficient		1, 2
	SC	willingness to invest in resilient processes	yes no		1, 2
	MC	planned or implemented investments	adjustment or optimization of machinery and equipment, digitization of process chains information gathering and further education communication technologies other formation and strengthening of networks greenhouse cultivation indoor cultivation, vertical farming		1, 2 1 1 1

"digitalization of process chains", "communication technologies" and the "adaptation or optimization of machines and systems".

3 Results and Discussion

Companies from primary food production, food processing and packaging, logistics and food retail in Germany were surveyed for the study. The questionnaire with up to 39 questions was conducted over a period of 11 weeks in the fourth quarter of 2021. The survey was accessed 1155 times and 84 questionnaires were completed in full. Subsequent expert interviews to further detail the answers were conducted with four companies and their representatives who provided their contact details and willingness to engage in further exchange when completing the survey. Specifically, managing directors and heads of quality management and sustainability from primary food production and processing companies were interviewed.
Collected responses were analyzed descriptively. The following section discusses the most important results and findings derived from the evaluation of the individual sections of the survey.

3.1 Specification of the industry affiliation

Of the 84 completed questionnaires, 4 each were in the areas of food logistics and food retailing. Due to this low of responses, these 8 results were not included in the evaluation. Initially, they were included in the design and distribution of the survey because, as described at the beginning, resilience affects the entire value chain and the whole networks involved.
The considered areas of primary food producers and food producers and packagers represent an even and correspondingly significant sample with 43 % and 57 % respectively of the remaining 76 participants.

3.2 Estimation of the influence of various factors on the guarantee of processes and product safety and quality

In Section B, survey participants were asked about the potential negative impact of various failure modes on ensuring the safety, quality, and quantity of their products.
To structure the causes of disruptions, those surveyed could choose different factors already introduced in Table 1 (see section B).
More than 70 % of the food processing and packaging companies surveyed responded that all of the above factors have an effect (see Fig. 2). For 93 % of the processing and packaging companies in the food industry, organizational influencing factors such as dependence on the supply network, dependence on specialized sources, cold chain, and communication, represented the greatest potential of disruption causes on the guarantee of safety, quality and quantity of their products.
For the primary food production companies that responded, organizational factors were cited as a cause of disruption for two-thirds. Environmental factors were rated as the greatest cause of disturbance to primary producers.
Relatively speaking, many primary producers similarly reported that environmental factors as well as economic factors and turbulence have an impact. Compared to processors, however, they mentioned the technical, human, and organizational factors significantly less often. Technical factors were cited as having a significantly lower impact on resilience. One suspicion might be that this is due to differences in the complexity and robustness of the machine technology used or the level of mechanization.

3.3 Estimation of preparation for disturbances

When asked to what extent the companies they represent are prepared for disruptions, only about one-fifth of all primary producers responded "*good*," while about one-third expressed their company is "sufficient". More than 40 % reported being only *insufficient* prepared for dis-

Table 2: Summary of considered models from literature for the factor identification.

Reference	**Content to be highlighted regarding the targeted categorization**
Vlajic et al. (2012)	Differentiation of internal and external sources describing the vulnerability of food value chains. Financial sources, market sources, legal sources, infrastructural sources, societal sources, and environmental sources are the external sources. Managed systems, managing systems, information systems, and organization structure are the internal sources.
Pettit et al. (2010)	Describes various vulnerability types and associated examples for a conceptual framework for assessing supply chain resilience. The categories listed are turbulences, deliberate threats, external pressures, resource limits, sensitivity, connectivity, supplier/customer disruptions.
Centre for Logistics and Supply Chain Management and Cranfield School of Managemen (2003)	Sums up 4 risk levels for resilient supply chains: Level 1 – process/value streams, level 2 – assets and infrastructure dependencies, level 3 – organizations and inter-organizational networks, level 4 – the environment
Chopra and Sodhi (2004)	Describes risks in assignment to risk groups that need to be managed to avoid supply chain breakdown. The following groups are specified: Disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, capacity

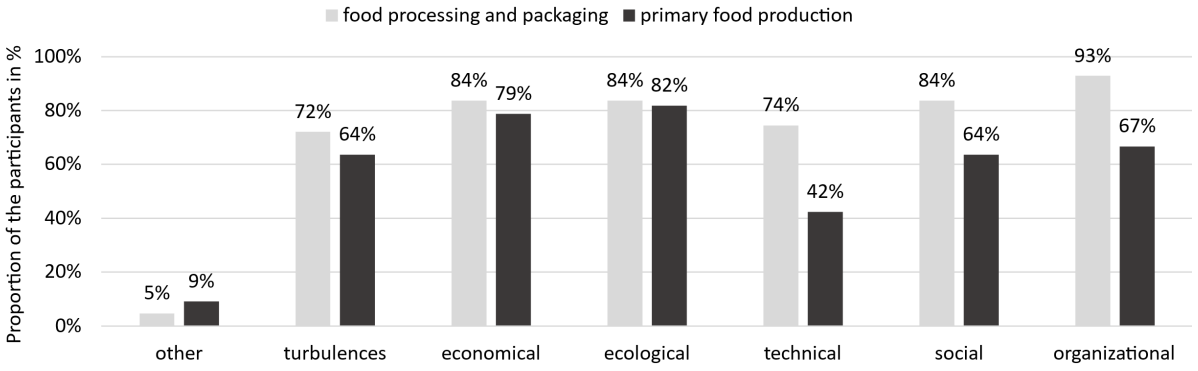

Figure 2: Assessment of the effects of various causes of disruptions.

ruptive events. This highlights the real need for action and optimization. A similar picture emerged when reviewing the data collected for the food processing industry (see Fig. 3). Around a third reported that they are prepared either well or *sufficiently*. However, another third declared that they are prepared *insufficiently*. This also revealed a need for optimization.

3.4 Investments in resilience

Considering that less than one third of the companies surveyed considered themselves well prepared for disruptions, the question arose as to their willingness to invest in more resilient processes. When asked about targeted investments to ensure resilient processes, 67 % of participating primary food producers and 84 % of participating food processors and packers answered yes. The need for action in the companies has already been recognized, as further survey results showed. Two thirds of producers agreed that they were striving to invest in more resilient processes. On the processors side, more than 80 % indicated a willingness to invest.
Which areas should be invested in to make the company and its value chain more resilient remained an open question, as resilience assessment were not part of this study. In this study, almost three quarters of all primary food producers responded that they wanted to invest in information gathering and education to improve the resilience of their companies (see Fig. 4). Those surveyed also declared that they were striving to invest *in the digitalization of process chains*, in *communication technologies* and in *formation and strengthening of networks* in order, for example, to build up supplier redundancies.
Among the food processing and packaging companies, 88 % expressed a primary interest in investing in the *adjustment and optimization of their own equipment and machinery* (see Fig. 5). In contrast to primary producers, only 54 % of food producers surveyed said they would like to:

- invest *in information gathering and training education* to make their processes more resilient (see Fig. 5);
- more than two thirds of processing companies also strived to invest in the *digitalization of process chains* and;
- more than a third planned to invest in *communication technologies*.

Following the online survey, selected expert interviews were conducted with various representatives from the primary food production and food processing and packaging sector. In these interviews, it became clear which resilience measures were preferred by primary food producers:

- information platform with relevant geographical and meteorological information in order to be able to manage food production and harvesting accordingly,
- platform for the exchange of relevant political and economic information in order to recognize changes in the political and economic framework conditions at an early stage and to be able to proactively adapt their own production and planning and,
- communication tool that offers just-in-time access to all individual participants in the value chain, in order to be able to react quickly to disruptions.

It also became clear in the discussions that companies did not yet have the tools they needed to assess and evaluate their own resilience. However, these tools are urgently required to identify their own opportunities for action and optimization. In collaboration with partners, the authors are already addressing this recognized need by developing and evaluating a resilience evaluator for the food industry (Elles et al., 2023; Häring et al., 2021).

3.5 Limitations of the study

As the sample size was rather small, with only 76 participants consisting of both primary food production and food processing and packaging, the results should not be generalized to all companies of the food supply chain. As no companies from logistics and retailing were involved, influences from that part of the supply chain and interdependences are missing from the picture. By

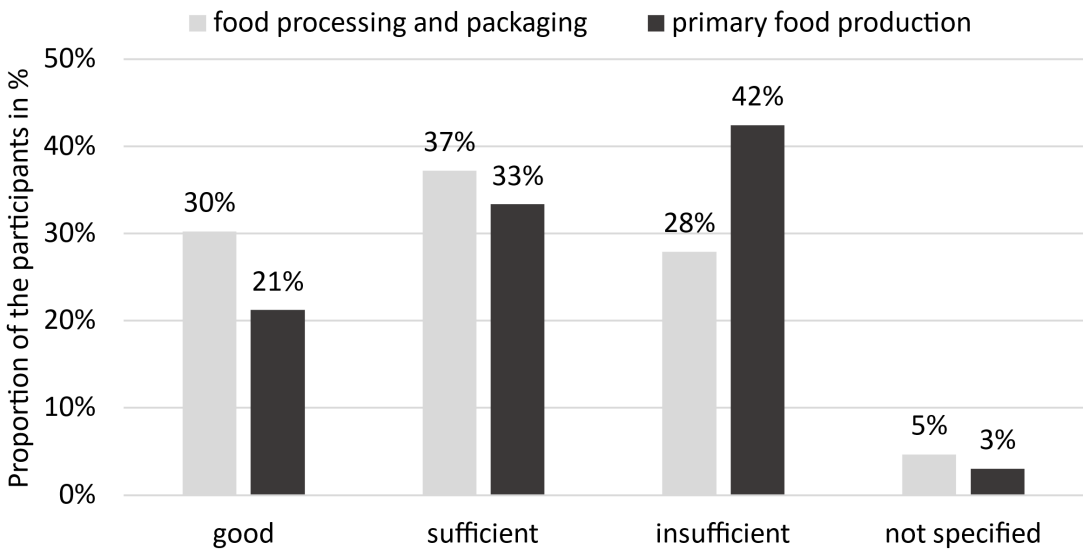

Figure 3: Assessment of preparation for disruptions.

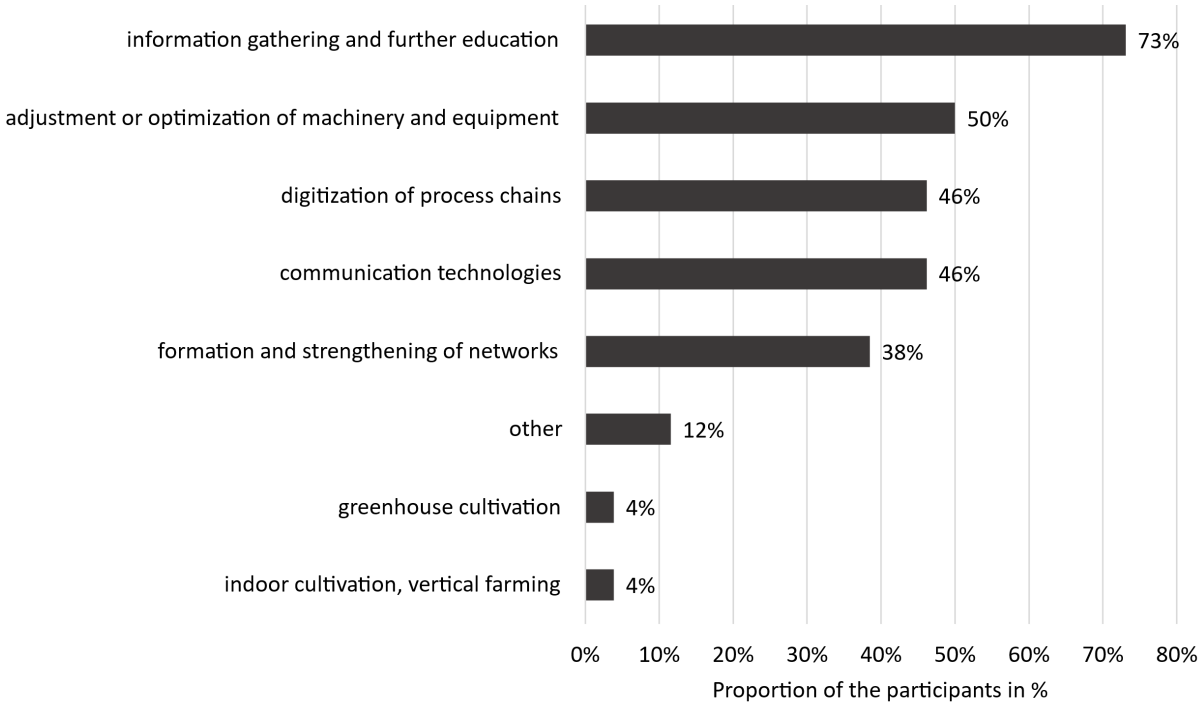

Figure 4: Targeted investments to ensure resilient processes food processing and packaging" to "primary food production"

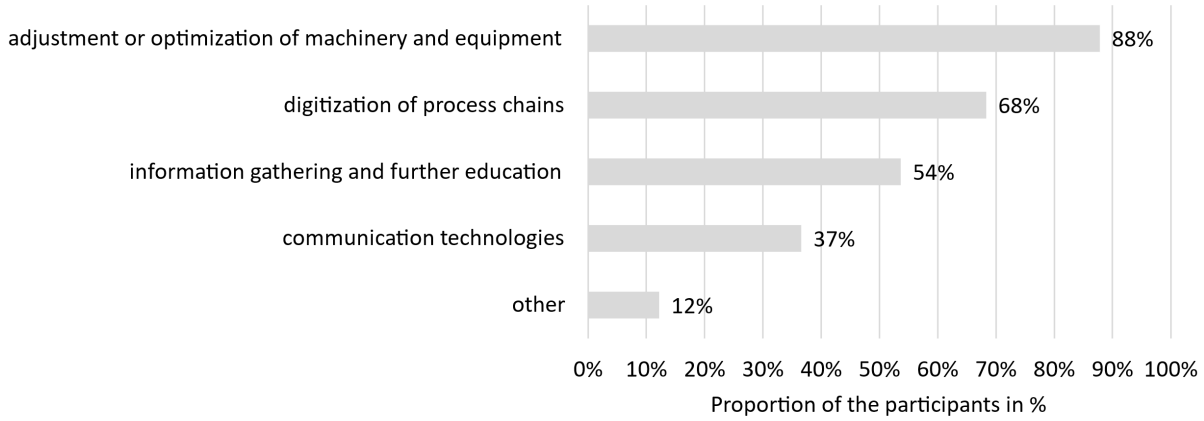

Figure 5: Targeted investments to ensure resilient processes from primary food production.

expanding further surveys, the transferability of the results could be increased. In addition, it would also be made possible to capture more differentiated views depending on specific company segments.
Another limitation is the exclusive distribution of the questionnaires in the German-speaking countries. This ignored a bit of the international character of food value chains. It would therefore be advisable to conduct a more international survey in the future.
Furthermore, during the evaluation of the results no distinction was made according to which products the respective companies grew or processed. Although the companies were assigned to product groups by the survey, their inclusion in the analysis was not useful due to the small sample size. Consequently, it was also not possible to obtain product-specific statements on the subject.
As the survey was conducted anonymously, it was not possible to determine whether in some cases more than one person per company took part. Although there was no indication, it was not ensured that all results originated from different companies. Accordingly, heterogeneity must therefore be assumed. As described at the beginning, the survey was generally not tied to specific roles or positions of the respondents in the company. It can therefore be assumed that the survey answers recorded came from people in different company departments. Moreover, statements cannot be evaluated separately according to this departmental affiliation, as the position of each participant was not recorded separately.
Due to the limitations outlined, the survey should be considered as a first indication of risks and measures regarding resilience considered by companies of primary food production and food processing/packaging as representatives of the food supply chain.

4 Conclusions

Resilience is a controversial term but is rated as a useful concept that helps to analyse the capacities of food systems to prepare for, respond and adapt to stresses. There is an awareness of the need to go beyond pure efficiency thinking and business continuity management and look at future-proofing food production processes.
The survey results showed that numerous factors (e.g. technical, social, economic and environmental) affected the resilience of food processors and primary producers The challenges on the organizational and social side were also reflected in companies' willingness to invest. On the one hand, investments were being made in the digitization and optimization of the machinery to draw conclusions about better networking along the value chains. The digitalization of processes contributed to an agile response to

changing conditions. Approaches included machine learning algorithms for decision support or digital twin technologies for tracking and tracing. However, cross-company data exchange requires trustworthy, effective and transparent data exchange. On the other hand, investments in training and further education were mentioned to ensure the safety and reliability of processes. The importance of skilled workforces for safe and resilient production was particularly evident. Targeted training and further education including topics such as general hygiene, personal hygiene, cleaning, disinfection, hygienic design, can counteract the increasing shortage of skilled workers and thus contribute to increasing resilience.
This survey provided initial impressions from the food industry, where the covid pandemic has created additional challenges such as restricted supply routes, staff shortages and political restrictions. However, although not directly applicable to other short- and long-term challenges such as advancing climate change and the emergence of geopolitical conflicts and wars, awareness of the added value of a holistic approach to minimisation of losses and failures along the value chain seems to have been raised.

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