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Reversing the trend of agrobiodiversity decline by co-developing food chains with consumers: A European survey for change

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ABSTRACT

Agrobiodiversity is in rapid decline, due to the intensification of agriculture and the development of food value chains based on industrial processing techniques. However, consumers are not generally involved in developing solutions to reverse this trend and their relation to agrobiodiversity remains largely unknown. As part of a European project, and with the aim of involving consumers in guiding research, innovation and policies, a large online survey ($n = 2397$) and focus groups ($n = 82$) were carried out in seven countries to gather consumers' preferences and aversions regarding the use of agrobiodiversity in food chains in relation to their environmental concerns, food consumption practices and knowledge. Using the majority judgment approach typically used to improve political votes, different options for using of agrobiodiversity in food chains were proposed to citizen-consumers. Results first showed that the decline of agrobiodiversity is a concern for consumers, but does not guide food choices. Then, the alternative options for using agrobiodiversity in food chains, previously documented as favourable to its conservation and development, received positive votes from a large majority of respondents, regardless of their socio-economic category. However, the research showed that respondents seem to have limited knowledge on the subject. This study calls for more research and policies to support alternative options for using agrobiodiversity in food chains. It also encourages the co-development of agrobiodiversity-based markets with citizen-consumers as well as the creation of food environments conducive to learning on agrobiodiversity.

1. Introduction

Biodiversity is in rapid decline. This includes both wild biodiversity, and agrobiodiversity which comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals (FAO, 2019). This decline is due to land-use changes resulting from agricultural intensification, the concomitant expansion of food value chains based on industrial processes requiring homogeneous

raw material, and climate change pressures accelerating the process (De Vries et al., 2018; FAO, 2019; IPBES, 2019). Since the 1900s, some 75 % of plant genetic diversity has been lost as farmers around the world have abandoned their multiple locally adapted cultivars and breeds for genetically uniform, high-yielding varieties adapted to mass industrial processing (FAO, 1999). As a result, 60 % of human energy intake in the world comes from 3 species: wheat, rice, corn (FAO, 2012). Citizens are increasingly becoming concerned by wild biodiversity decline,

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especially encouraged by the general press, which reported the loss of bird species and insects documented in many studies (see, for example, Seibold et al., 2019). However, consumers' relation to agrobiodiversity remains largely unknown (Bantle and Hamm, 2014). Moreover, they are generally excluded from the development of solutions to reverse the decline in agrobiodiversity. At best, they are seen as buyers of food based on agrobiodiversity, and relegated to the end of the chain as actors who have no influence on the functioning of entire value chains responsible for the decline of agrobiodiversity, or on the design of new chains that are more favourable to agrobiodiversity.

The DIVINFOOD European action-research project aims to develop food supply chains valuing Neglected and Underutilised Crops (NUCs), for and with consumers, both to contribute to reverse the decline of agrobiodiversity and to meet their expectations for healthy plant-based food (Lappo et al., 2015). NUCs are plant species that are currently utilised at small scale and, although valued at local level, are forgotten, abandoned or rarely explored by researchers and others involved in the research and development of agriculture and food systems, for various reasons (e.g., low economic competitiveness, lack of adequate cultivation practices and reduced consumer appeal) (Azam-Ali, 2010; Padulosi et al., 2021). In the first months of the project (Spring, 2022), a large European on-line survey was organised to collect information on the preferences of consumers regarding different options for using agrobiodiversity in food chains, in relation to their environmental concerns, food consumption practices and socio-demographic profiles. To complement this quantitative data, focus groups were organised with consumers in several countries to help interpret the results and focus on specific NUCs (legumes or minor cereals). Building on the perspective of food democracy, through which citizens regain control over the food system to enable its sustainable transformation (Lang, 1998; Petetin, 2016), this process aimed to empower consumers to guide the activities of research and innovation, as well to provide recommendations for public action about agrobiodiversity-based value chains, both in DIVINFOOD and for the European Farm2Fork strategy and local food policies.

The aim of this paper is to identify ways to develop food chains that are conducive to agrobiodiversity, by answering the following research question: how do consumers prefer agrobiodiversity to be used in food chains, according to their food consumption practices and their knowledge of plant species and varieties?

In the first part of the article, we highlight the two main directions developed in the literature on the relationship between consumers and agrobiodiversity, and propose to combine them in order to strengthen the role of citizen-consumers in the co-development of biodiversity-based value chains. In the second part, we present our research methods, and our innovative methodology for capturing consumer opinion, based on the majority judgment method (Balinski and Laraki, 2011) which is typically used only in political voting. We also explain the way we tried to assess consumer knowledge about agrobiodiversity. In the third part, we present the main research findings, which we discuss in the fourth part, from both a scientific and practical perspective.

2. Literature review

The relationship between consumers and agrobiodiversity has been analysed in the scientific literature along two main lines, which we explain in more detail below.

2.1. The consumer as a buyer of agrobiodiversity

The first line of studies addresses the preferences of consumers for landraces, as a lever for agrobiodiversity preservation (Botelho et al., 2018). Studies generally use the 'willingness to pay' approach, aiming at identifying the maximum price a customer is willing to pay for a product or service. In a study in Italy, for example, the topic of agrobiodiversity

was investigated through choice experiments. This involved surveying 920 consumers to determine their willingness to pay for old local tomato varieties (landraces) instead of commercial varieties and to establish how much they value these products based on their preferences. The results indicate that consumers are willing to pay a higher price for old local tomato varieties (an additional €0.90 per kg), which, say the authors, reflects their increasing attention to sustainable food and their willingness to contribute to the conservation and enhancement of agrobiodiversity (Posadinu et al., 2022). This study confirmed previous results obtained with the same approach applied on traditional apple varieties in Portugal (Botelho et al., 2018), traditional tomato or carrot varieties in Spain (Brugarolas et al., 2009; Gracia et al., 2020; Pérez-Caselles, 2020) and vegetable farmers' varieties in different European countries (Meier and Oehen, 2019). In line with these results, but adopting other approaches (e.g. behaviour theory), other studies focus on consumers' perception about biodiversity, and how this may guide their food practices in a more sustainable direction. For instance, a recent study examined Eurobarometer data to test the correlation between opinions on biodiversity and purchasing behaviours of individuals in the EU (De Boer and Aiking, 2021). This study showed that people who are concerned about biodiversity loss also stated that they buy local and organic products. Drawing on leading studies in the field, the authors conclude that this is a viable way for consumers to help mitigate biodiversity loss.

2.2. The consumer as a citizen contributing to agrobiodiversity conservation

The second line of studies refers to the role of consumers in agrobiodiversity conservation and development, in farms, gardens or along supply chains. For instance, in participatory breeding programmes, consumers, in collaboration with farmers and researchers, are in some cases involved in the on-farm characterization of a large diversity of landraces, not registered in national variety catalogues and not marketed, with the objective to make new varieties more adapted to local conditions and organic farming available to farmers (Ceccarelli and Grando, 2020). Consumers also seemed to support the revitalisation processes of such landraces by preserving them in their gardens through cultivation, even though home gardens were long neglected hotspots of agrobiodiversity (Galluzzi et al., 2010). Additionally, consumers using alternative food networks have been highlighted as key supporters of neglected crops conservation, not only as simple consumers in search of typical and tasty products (Simoncini, 2015) but also as citizens co-developing alternative supply chains, as in the case of Slow Food or Community-supported agriculture initiatives (Slow Food Foundation for biodiversity, 2008; Kosnik, 2018), even if the commodification of products they enact may undermine the agrobiodiversity they seek to protect (Lotti, 2010).

What these two lines of literature have in common is that they emphasize the role of consumers in the conservation and the development of agrobiodiversity. While the first direction is attentive to their preferences and perceptions in relation to agrobiodiversity, the second focuses on their role as citizens (with civic duties), as co-developers of agrobiodiversity-based food networks, as preservers of agrobiodiversity or as co-designers of crop varieties. We propose to combine these two directions, and consider the consumer as a citizen who co-decides how food chains should utilise agrobiodiversity, while at the same time trying to better understand how he/she, as consumers perceives, knows and consumes this biodiversity. Our work is thus in line with both research on consumer perceptions and practices related to sustainability (Mont and Plepys, 2008) and work on building food democracies by involving citizens in the orientation of food systems (Hassanein, 2003).

3. Methods

3.1. A quantitative European online survey

Our study on the preferences of consumers regarding agrobiodiversity use was intended to involve citizen-consumers (i.e. individuals considered both as consumers and citizens), in guiding research, innovation and policies on this issue. It began with a wide-ranging quantitative survey in Europe, co-constructed in English with DIVINFOOD partners, including two consumer associations accustomed to involving citizen-consumers in their activities. We chose to use an online questionnaire to reach a large population, although this method may lead to selection bias as it is prone to self-selection by respondents with smartphones or experience of answering online questionnaires. A pilot version was tested with a set of diverse citizen-consumers in France, and the final version was translated in seven national languages (Danish, French, Swedish, Portuguese, Italian, German, Hungarian). The survey was administered in seven countries (Denmark, France, Hungary, Italy, Portugal, Sweden, Switzerland), in both the national language(s) and in English. The difficulty of this method was that notions and phrases which make sense for the 7 countries had to be determined and agreed upon by all partners. It was also necessary to adapt the modalities of answers about socio-economic groups and education levels to each country, and then to reorganise them in categories valid for all seven countries to be able to process the data for all respondents.

The final version of the questionnaire was disseminated through DIVINFOOD members' personal and professional networks, national consumer associations, NGOs, local authorities, and social media. The online questionnaire was launched on the 7th of June 2022 and was terminated on the 20th of July. The objective was to propose an easy-to-answer questionnaire, that could be completed in 15–20 min, which was another methodological challenge in addition to the translation. In order to limit bias in the answers, the introduction to the questionnaire simply mentioned that the DIVINFOOD project aims to support the development of plant-based food chains in relation to environmental challenges, without specifying its focus on agrobiodiversity.

The survey had 4 sections, aimed at answering the research question and investigating the following issues: i) environmental concerns, to highlight how respondents perceive the disappearance or preservation of plant and animal species, ii) food consumption practices, to assess the importance of agrobiodiversity in respondents' food choices and their knowledge of the plant species on their plate; iii) evaluation of options for using agrobiodiversity in food chains, to identify their preferences and aversions all the way from breeding to marketing, iv) socio-demographic characteristics and food purchasing profile, to identify which food chains (long and/or short, organic shops) they regularly use and thus complete the description of their food consumption practices (see the questionnaire in Annex 1).

To address consumers' levels of knowledge of agrobiodiversity, one question asked them to describe the main plant species (up to 5) present in the last dish they ate. When the dish described included ≥ 3 plant species, we distinguished 3 levels of ability to list them: 1 (low), attributed to responses citing only one correct species but not the main species of the dish (e.g. wheat when it is pasta or pizza), and/or citing an element that is not a plant species (e.g. "egg" or "cheese", two elements that were often cited); 2 (medium), awarded when two correct species were cited, including the main species of the dish; and 3 (high), when three or more correct species were cited, including the main species of the dish, and no element that was not a plant species was cited. When the dish included ≤ 2 species (e.g., steak with fries and salad), we either did not score the answer when the list was correct, or scored 1 (low) when the list was incorrect (e.g., citing "fries" instead of potato). Indeed, in the case of simple dishes with 1 to 2 plant ingredients, listing them is not difficult in theory and therefore does not necessarily reflect the respondent's ability. On the other hand, we considered that not being able to list them or listing them incorrectly indicates a low level of ability. We

are aware that this way of scoring can create a bias, as people who managed to list the species of a simple dish could also have listed those of a more complicated dish. We will come back to this limitation in the discussion.

To invite respondents to evaluate different options for using agrobiodiversity in a food value chain, we used the 'majority judgment' approach developed in the early 2010s by researchers to improve voting in political elections (Balinski and Laraki, 2011). This method allows each voter to express an independent opinion on all candidates, not just one. Judgements are called through words, for example using the qualifiers "Excellent", "Very Good", "Good", "Average", "Poor", "Insufficient", "Reject". The vote thus consists of attributing one of the qualifiers to each of the candidates. Rather than an evaluation by a numerical score, this voting method can satisfy a need for expression, which is one of the components of a democratic feeling (Laslier, 2019). Moreover, the voter is not obliged to choose a single candidate but can express his or her support for several candidates or, on the contrary, his or her rejection of all the candidates. This approach makes it possible to highlight people's preferences without forcing them to artificially prefer one option over another (they can judge the two in the same way) and therefore without forcing them to choose at the expense of their values. For a study aimed at guiding research and innovation on the basis of consumer preferences, the added value of majority judgment approach is thus that it provides information as close as possible to people's opinions.

Following this approach, respondents were given information on what a food supply chain is, with 4 steps (breeding, production, processing, marketing). Each step had two options, except for the marketing step which was divided in three sections (information on products, information tools, selling channels), each one with two options. For each option, information was provided to help understand the nature of the choice and the main impact it would imply for citizen-consumers, as highlighted in the scientific literature (see Annex 1). The purpose of this information was to favour and measure informed judgment, rather than simply perception. In each step or step's section, one of the proposed options could be considered more alternative than the second proposed option, commonly implemented in food chains (see Table 1). The two options (alternative, conventional/traditional) were randomly proposed for each step or marketing section, to limit biases in answers. Each option had to be evaluated by the respondent, from 'excellent', meaning that the option is considered as excellent to be used in food chains by the respondent, to 'to be rejected', in case the option is assessed by them as not appropriate at all. Not answering regarding an option was possible but categorised as 'to be rejected' insofar as the respondent did not wish to evaluate it, for example out of disinterest or because the option means nothing to him/her, which, in both cases, led us to classify the option as not appropriate.

Table 1

List of candidate options to be evaluated by respondents (excellent, very good, good, passable, poor, rejected, no answer).

Step // options	Conventional	Alternative
Breeding	New varieties selected from recent breeding techniques	Locally selected and/or traditional varieties
Growing	Environment-friendly agriculture without a legally-binding standard	Labelled organic farming
Processing	Making food by mixing ingredients	Making food from minimal processing of raw material
Marketing	Detailed information about plant species and varieties, production methods used to make food	Summarized information through a score
	Information given on the package	Information given through a digital application
	Sales by supermarkets	Sales by farmers and small-scale processors of your region

Respondents were not obliged to answer any of the questions of the survey. Data in national languages was translated back into English using an automatic translator to facilitate processing. This had a limited impact on the results, as the open-ended questions were few and only concerned words, not sentences. The quantitative data was processed through the free statistical software R. In order to identify clusters of participants having similar evaluations of the proposed options for using agrobiodiversity in food chains, respondents' answers were transformed into scores (from 'excellent' = 6 to 'to be rejected' = 1, and with the 'no answer' modality = 0) and submitted to a Hierarchical Cluster Analysis by using the Ward's method (developed with Factoextra package in R). The chi-square tests of independence were then performed to assess whether the clusters were significantly different according to the respondents' socio-demographic characteristics and the purchasing profile. Socio-demographics characteristics used in chi-square tests were gender, age, socio-economic category, diploma, country, living area (functional urban area vs. rural area, see below). Purchasing profiles have been classified in 4 categories, according to the number of channels regularly used to buy food (<3 = non-diversified; ≥ 3 = diversified), and the use of at least one short or organic channel (<1 = conventional; ≥ 1 = alternative). When Chi-square *p*-value test was found to be significant (at level of *p* < 0.05), residuals were observed to determine which modalities of the variable were statistically over or under-represented among the different clusters.

In addition, a specific open-access software package developed in France, CorText Manager® (Breucker et al., 2016), was used to assign respondents to a rural area or a 'functional urban area', which corresponds to the combination of a town and its commuting zone (home-work journeys) and better reflects the context in which urban dwellers live than simply locating their residence within the administrative boundaries of a town (OECD, 2012). To carry out this task, the software geocoding function was used, i.e. the elements of the address written by the respondents were first classified and then matched with reference geographic databases (e.g., Lavalle et al., 2015).

3.2. Focus groups to support quantitative data interpretation and address the use of specific NUCs

To complement the online survey, eight focus groups with 7 to 15 people were organised between August and October 2022 in regions where DIVINFOOD partners are implementing a living lab (Hossain et al., 2019) to co-develop NUCs-based food chains, representing 5 countries (Denmark, France, Hungary, Italy, Portugal). These groups focused on specific NUCs (legumes or minor cereals) and were dedicated to support the interpretation of the online survey data, through an in-depth discussion about the different options for using these crops in food chains (considering the same options as in the online survey): while the online respondents could only evaluate the options individually, focus group participants were asked to explain their opinion of these options.

The meeting had three main sections, tailored for a 2-h duration: 1) Introduction and understanding the concept of NUCs, based on the presentation of a picture of the legumes or the minor cereals considered in the living lab, in order to collect participants' opinions and knowledge about these NUCs, capture their perception about the decline of agrobiodiversity and share the needed information for them to understand the subject of the focus group; 2) Sharing of knowledge about the organisation of a supply chain, from asking participants in sub-groups to draw a typical supply chain providing the bread they can eat every day, to assess their knowledge about the different steps of a food chain and favour a common understanding of what a food chain is; and 3) Discussion about the different options for using and spreading NUCs in food chains, from breeding to marketing. This discussion on the use of NUCs was supposed to be the main part of the meeting.

Some focus groups only gathered consumers while others were open to professionals and/or academics involved in food chains; some focus

groups were in person, others online or hybrid; most of the focus groups were organised separately but in one case, the discussions were developed during an event (e.g., bread festival in Hungary). This diversity (see Table 2) is explained by the fact that some living labs have been operational for some time, while others have only begun to emerge. Some living lab coordinators therefore took the opportunity of this focus group exercise to also collect data from key stakeholders to build their

Table 2
Description of the participants in the eight focus groups.

Focus groups/country	NUCs	Number of participants	Format	Types of participants
Denmark 1	Faba bean, lentils, grey pea, blue lupine	7	In-person	<ul style="list-style-type: none"> Consumers 4 female/3 male Age between 30s and 70s 2 high socio-economic category, 5 lower
Denmark 2	Faba bean, lentils, grey pea, blue lupine	8	In-person	<ul style="list-style-type: none"> Consumers 7 female/1 male Age between 30s and 40s 4 high socio-economic category, 4 lower
France 1	Meat bean (local bean)	8	In-person	<ul style="list-style-type: none"> Consumers 4 female/4 male Age between 20s and 70s 3 high socio-economic category, 3 lower, 2 students
France 2	Lingot bean (local bean)	9	In-person	<ul style="list-style-type: none"> Consumers, farmers, chefs 6 female/3 male Age between 20s and 70s 3 high socio-economic category, 6 lower
Hungary 1	Einkorn	14	In-person during a festival	<ul style="list-style-type: none"> Consumers 7 Female/7 male Age between 20s and 70s 1 high socio-economic category, 12 lower, 3 students
Hungary 2	Einkorn	10	In-person	<ul style="list-style-type: none"> Consumers 10 Female/0 male Age between 20s and 70s No information about socio-economic categories
Portugal	Grass pea	11	Hybrid: In-person and online	<ul style="list-style-type: none"> Consumers, researchers, business representatives, students 7 female/4 male Age between 20s and 70s 5 high socio-economic category, 4 lower, 2 students
Italy	White lupine	15	Online	<ul style="list-style-type: none"> Consumers, business representatives, researchers, students 8 female/7 male Age between 20s and 60s 8 high socio-economic category, 4 lower, 3 students

network. In addition, some living labs cover a large geographic area, which required an online meeting in order to include citizen-consumers from all over the area. Recruitment was done through the personal and professional networks of DIVINFOOD's partners, and announcements on social media (except in the festival where the recruitment was made on the spot), with the ambition to reach a diverse range of profiles in terms of age and socio-professional categories.

The focus groups were organised in compliance with the the EU General Data Protection Regulation (GDPR), aimed at the protection of the participants data (which entailed the provision of an information sheet on the project and the use of the data, obtaining the agreement of the persons recorded in a document and a signed consent in the case of recording). Each focus group was run by a partner of the DIVINFOOD project, with a moderator and a person taking exhaustive and accurate notes. In two focus groups, audio recordings were used to support the analysis. The qualitative data was processed by each partner responsible for a focus group, through a summary of the speeches made in each of the 3 sections of the meeting, highlighting the convergences and divergences between the participants, and specifying which type of participant said what.

4. Results

4.1. Respondents in Europe are diverse, beyond the trends observed in previous food surveys

The online questionnaire was completed totally or partially by 2397 respondents, with participation from all 4 regions of Europe, even if France is over-represented (see Table 3). Women represent about 68 % of the respondents who specified their gender ($n = 1663$ respondents who completed the question). Women are typically more concerned by food, and food surveys are generally more completed by women. 43 % of the respondents ($n = 1652$ who indicated their age) belong to the 30–49 years age category, with the other age classes correctly represented (≤ 29 years: 18 %; 50–64 years: 26 %; ≥ 65 years: 12 %). The rate of intellectual and scientific professions is high in the sample (46 % of the 1653 respondents who specified their profession), and higher than in the general population in the 7 countries. This reflects the stronger willingness of higher socio-economic categories to complete research surveys but is also due to the networks through which the survey was disseminated (i.e., research networks). Nevertheless, skilled to low skilled employees and workers are correctly represented (31 %) in the European sample, which also includes students (7 %), who are one of the key targets of the project. Moreover, 31 % of respondents did not specify their socio-economic category and previous experience of DIVINFOOD researchers shows that respondents from lower socio-economic categories are more reluctant to declare their belonging than persons from higher socio-economic categories. 49 % (Sweden) to 82 % (Hungary) of the respondents live in urban functional areas (for $n = 1612$ who declared their location of residence, municipality or postal code). This proportion is higher than the national average in all 7 countries in the project, with the exception of Sweden.

To conclude, even if certain categories of gender, age, socio-economic categories and living areas are over-represented among

Table 3
Number of respondents to the online survey by country and European region.

European region	Country	Number of respondents
Northern Europe	Denmark	229
	Sweden	60
Eastern Europe	Hungary	544
Western Europe	France	1183
	Switzerland	71
Southern Europe	Italy	172
	Portugal	138
Total		2397

respondents who completed their socio-demographic characteristics (about 70 %), the survey reached a diversity of profiles from the different parts of Europe.

4.2. Agrobiodiversity is a concern for a significant number of respondents

Of seven problems related to environmental degradation (climate change, air pollution, etc.), the disappearance of certain plant or animal species has been cited by 41 % of the respondents ($n = 2375$ who completed the question) as their first or second choice, after climate change (cited by 71 %) and the pollution of water, lakes and rivers (44 %) (see Fig. 1).

The disappearance of certain plant or animal species, which is part of the decline of agrobiodiversity, is thus an important concern of respondents. Moreover, supporting food production that contributes to the preservation of neglected and underutilised varieties has been cited by 31 % of respondents ($n = 1724$ who completed the question) as their first to third choice, among 10 impacts proposed. This impact is thus the 4th most chosen, after the contribution to consumer health (cited by 63 %), the positive impact on climate (57 %) and the contribution to rural development (49 %) (see Fig. 2).

4.3. Food choices are not driven by agrobiodiversity

However, even if agrobiodiversity preservation is a concern, <10 % of respondents ($n = 2103$ who completed the question) chose a food product in relation to the varieties or breeds it comes from as their first to fifth choice, among 17 proposed items. Classic criteria like 'price' and 'taste' have been cited by more respondents (respectively 53 % and 47 %). Nevertheless, other criteria, considered important to preserve agrobiodiversity in previous studies (see, for instance, De Boer and Aiking, 2021), are also taken in account by a large part of the sample, namely 'produced in your region' (cited by 70 % of the 2103 respondents as their first to fifth choice) and 'organic label' (51 %) (see Fig. 3).

4.4. Consumers seem to have limited knowledge on agrobiodiversity

As mentioned in the methods section, knowledge of agrobiodiversity was captured from the description of the last dish eaten. Out of 2032 respondents who declared their last meal and tried to list the plant species it contained, 1699 answers were scored: 824 (48 %) were scored 1 (low), 216 (13 %) were scored 2, and 659 (39 %) were scored 3 (high). Respondents were therefore divided into 2 contrasting groups: those who were able to list the agrobiodiversity on their plate (score 3), and those, more numerous, who were less, or were not (scores 1 and 2). In particular, the majority of respondents who said they had eaten pizza or pasta did not list wheat (either bread wheat or durum wheat), so their answers were scored 1 (low). The socio-demographic characteristics and the purchasing profile do not differentiate these two groups, nor does the fact that respondents declared a vegetarian dish (e.g., 'vegetarian lasagnes', 'rice noodles with sauted vegetables'). Without having a direct claim of being a vegetarian, we might have assumed that respondents indicating vegetarian dishes would be more likely than others to know plant species, which, in these cases, are the only ingredients in their dish (and not an 'accompaniment' to animal proteins). Another interesting finding is that <10 % of respondents with a high score on species were able to identify varieties. This tends to reflect an even more limited knowledge about species' varieties, which require more knowledge than the identification of plant species.

This approach to consumers' knowledge must be treated with caution, as it is highly dependent on the dish consumed and may reflect reflexes rather than abilities (e.g., forgetting to mention wheat when you have eaten pasta). However, this question of knowledge about agrobiodiversity opens up scientific and practical avenues, to which we will return in the discussion.

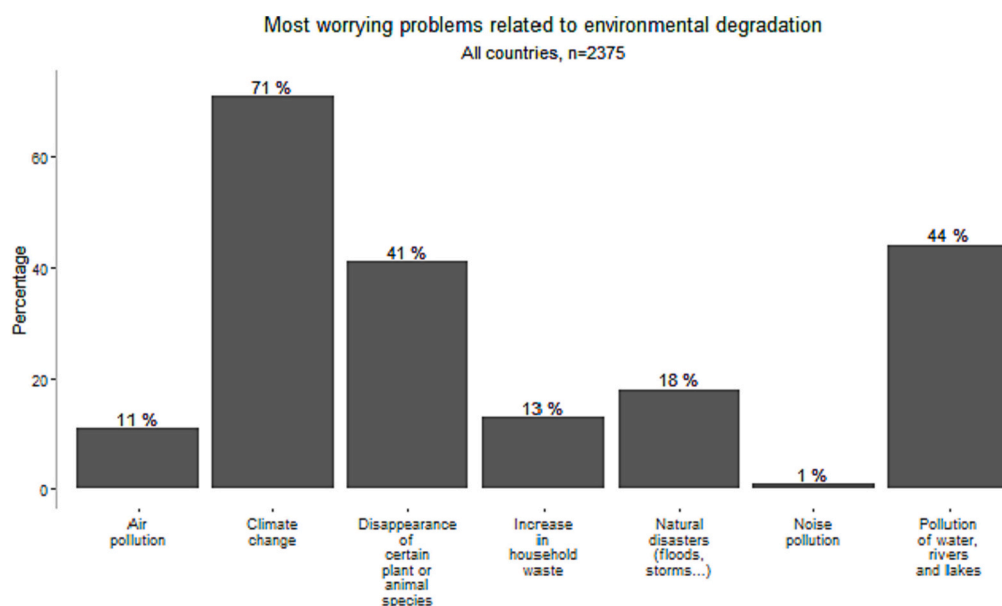


Fig. 1. Most worrying problems related to environmental degradation (percentage of respondents who select the response options; n = 2375, up to 2 choices).

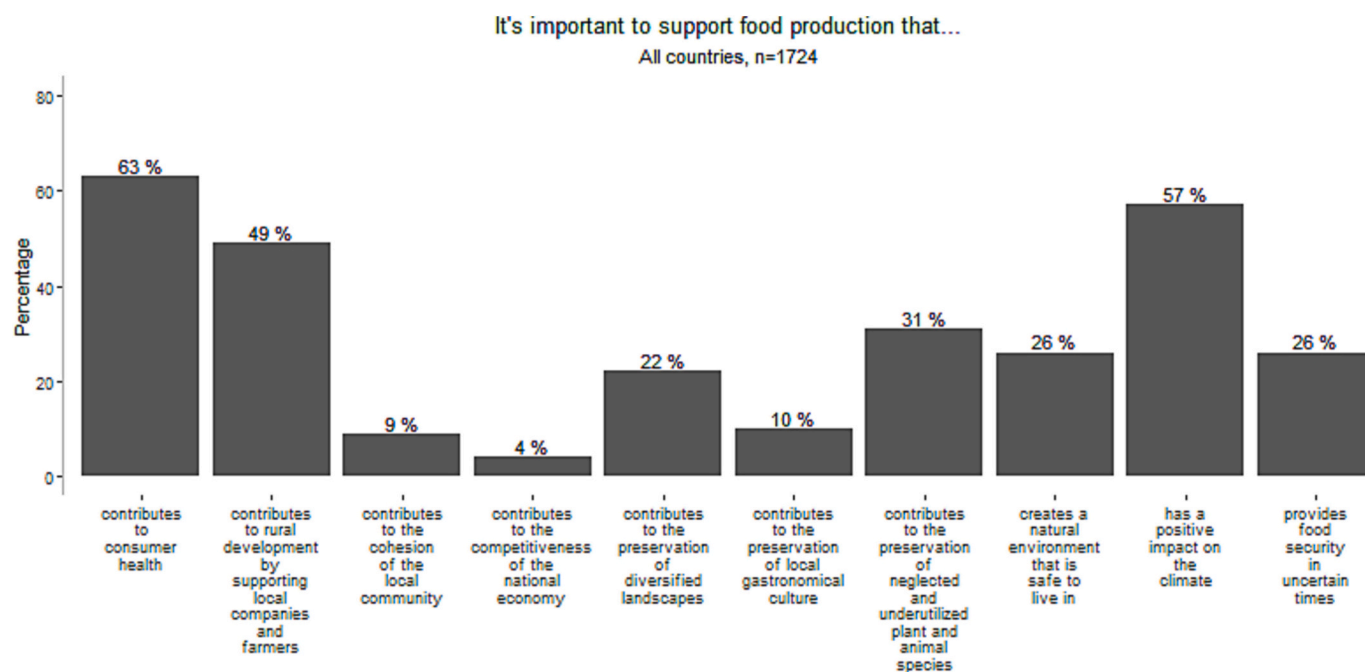


Fig. 2. The main contributions to be made by food production according to respondents (percentage of respondents who select the response options; n = 1724, up to 5 choices).

When asked what led them to eat a new species or variety that they had not known before, respondents cited going to a farmers' market, eating at a restaurant or buying a vegetable box as the main circumstances, in addition to travelling and gardening ($n = 1076$). This highlights the role of specific food supply chains in increasing consumer knowledge of agrobiodiversity.

4.5. Alternative options received more positive votes, but with variations between social clusters

The production of food from locally selected and/or traditional varieties, with organic labelling and mild-processing methods and sale by farmers or small processors in their region was rated as 'excellent' to

'good' by >84 % of respondents ($n = 1724$ who completed the question). <60 % voted in favour of the corresponding conventional option (see Fig. 4).

Most of the respondents thus strongly support practices that are alternative to the conventional way of using agrobiodiversity in food chains. These alternative practices have been highlighted as more favourable to the preservation and enhancement of biodiversity (De Vries et al., 2018; FAO, 2019; De Boer and Aiking, 2021). On the other hand, the different options for providing information on the biodiversity present in food products elicited more mixed votes: alternative options were evaluated less positively than conventional options, but the latter were evaluated positively by fewer people than alternative ones related to breeding, growing and processing (see Fig. 4).

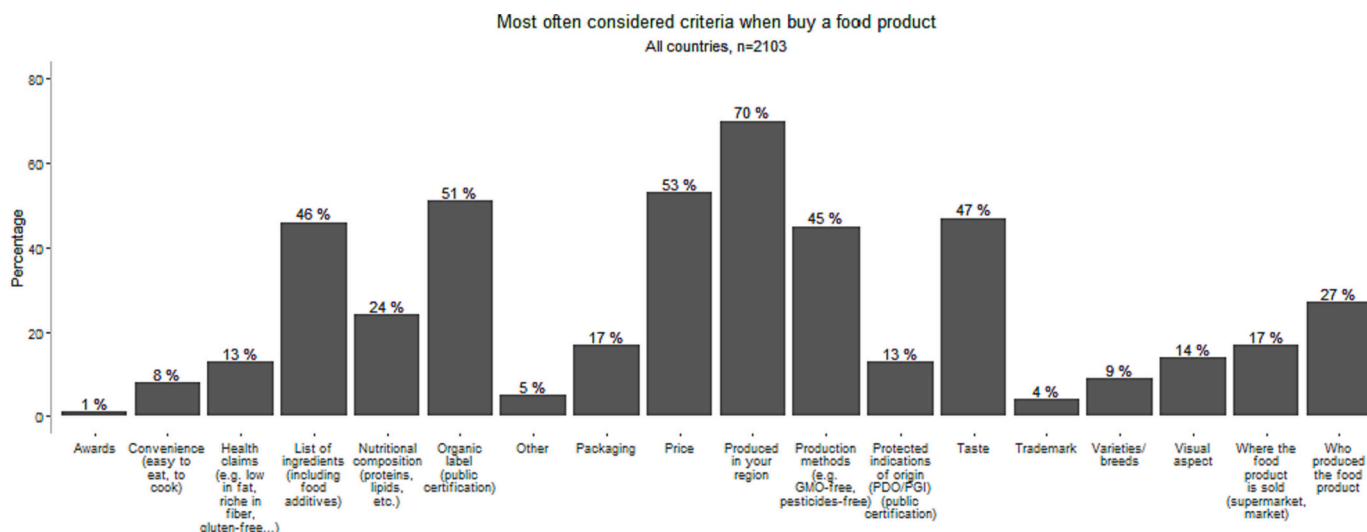


Fig. 3. Most often considered criteria when buying a food product (percentage of respondents who select the answer modalities, n = 2103, up to 5 choices per respondent).

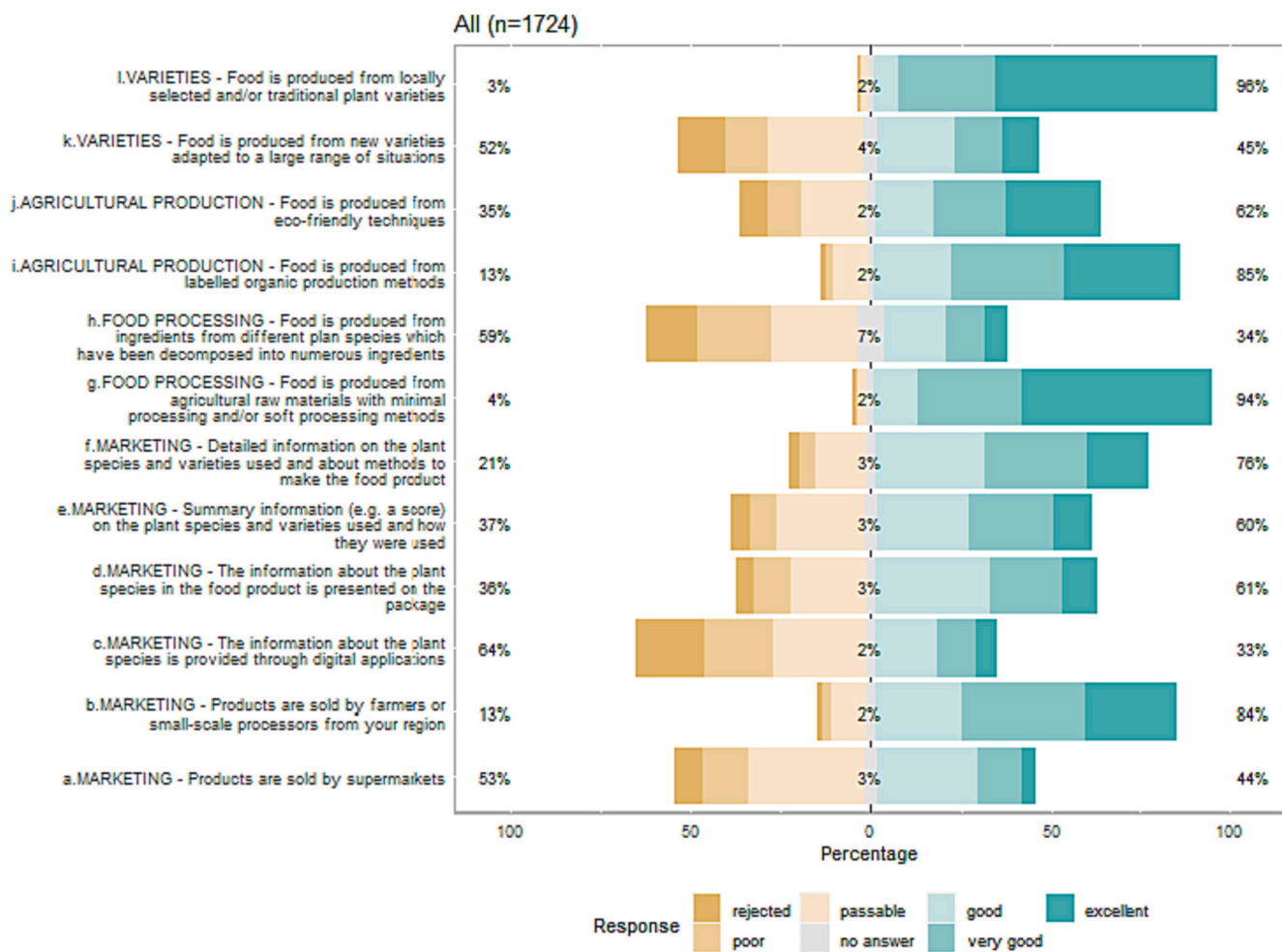


Fig. 4. Respondents' votes on the different options for using agrobiodiversity in food chains (n = 1724) (Graph produced using the Likert package in R).

As detailed in the methods section, respondents with similar evaluations for all options were grouped into social clusters (see Fig. 5), which are described below:

- The first cluster of respondents (35 %, in red in the Fig. 5), whom we named 'indifferent citizen-consumers' in relation to their votes, is more positive than the others about both the alternative and conventional options proposed for each step or sub-step. For instance,

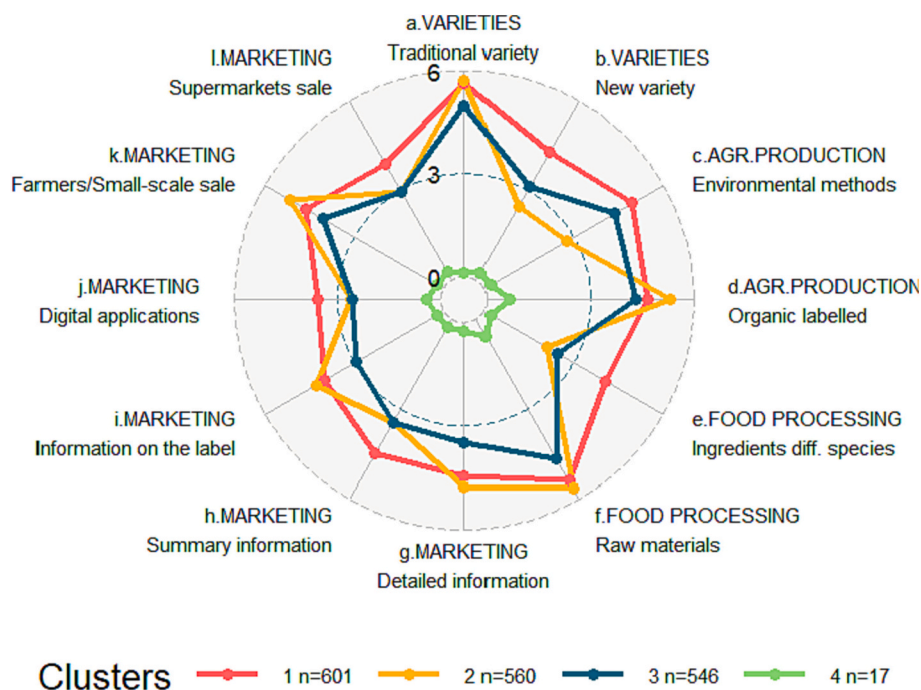


Fig. 5. Average vote per cluster for the different options for using agrobiodiversity in food chains ('excellent' scored 6; 'rejected' scored 1; 'no answer' scored 0) ($n = 1724$).

members of this cluster assess positively both sales by farmers and by supermarkets. They are younger than the average, and are more likely to be students and to live in Portugal than members of the two other clusters.

- The second cluster (33 %, in yellow) of 'alternative citizen-consumers' is more positive than the others about the alternative options, except for e-labelling. The proportion of 'diversified-alternative' purchasing profiles is higher than in the other two clusters. Members of this cluster are more likely to live in France, and less likely to live in Denmark, Hungary and Portugal.
- The third cluster (32 %, in blue) of 'traditional citizen-consumers' is as positive as the others in matter of local/traditional varieties use but less positive than the others about the alternative options in processing and marketing. The proportion of older people is higher than in the two other clusters. Members of this cluster are more likely to live in Denmark and Hungary, and less likely to live in France.
- The fourth cluster (in green) contained only 17 participants who answered 'no answer' or 'to be rejected' for all or almost all options. It was too small to be described.

Socio-economic categories (except for students), levels of diploma and living areas (functional urban area/rural) do not discriminate the clusters: according to the sample, these variables do not affect the votes for the options for using agrobiodiversity in food chains. The survey therefore reveals a high degree of convergence between participants' votes, but also some nuances. It is interesting to try to understand the opinions behind the votes, which was the objective of the focus groups.

4.6. Participants voted both as citizens and consumers

Discussions within focus groups gave insights for understanding the opinions about the different options for using agrobiodiversity in food chains. As mentioned in the methods section, in order to grasp knowledge about the organisation of supply chains, and promote a common understanding among participants of focus groups, moderators first asked them to describe in detail how the bread people usually eat is made. In three focus groups the first steps of the chains were not

identified, which shows that selection of varieties and farming may be not well known by citizen-consumers. Participants were then asked to assess both the conventional and alternative options for using NUCs, legumes or minor cereals depending on the living lab (see Table 2), at each step from breeding to marketing, but also to explain their evaluation.

Most of the participants were more positive towards local/traditional varieties than towards new varieties as 'locality' and tradition appeared to be an important dimension when considering food. This was found even when some mentioned that they do not have the appropriate knowledge about breeding techniques and selection of varieties. However, while some more knowledgeable participants were explicitly skeptical about recent breeding techniques, others pointed out their interest to assure food security (by breeding more productive varieties) or adapt varieties to specific contexts (e.g., less water supply).

As far as farming options were concerned, both options were well assessed, but each was considered as more relevant for a specific chain. Participants were more in favour of environmentally-friendly techniques in short chains because the relationship between consumers and farmers, especially at the local level, helps to build trust, so they believe that certification is not necessary – a finding that has been highlighted in numerous studies (González-Azcárate et al., 2022). It was also mentioned that this could decrease the price of NUCs-based products. Participants who saw long supply chains as an opportunity for greater dissemination of NUCs emphasised the importance of organic labelling and legally binding standards. Some of them justified this with their fear of food processors who are cheating with the production methods (highlighted in the two focus groups in Denmark) or because this could be an option to reach premium consumers and convince them about the quality of the products (highlighted in one of the focus groups in Hungary). In most cases, it was important to the participants that information about production methods is available.

In matter of processing, participants favoured the alternative option because either they considered processed food unhealthy, or they thought that minimally processed food is closer to the traditional diet. However, students and urban participants judged positively the use of legumes in plant-based processed food (e.g., in vegetarian burgers),

revealing their interest in these products as a means of reducing meat consumption, linked to ethical values or climate concerns.

When asked about marketing, participants considered positively the option of providing detailed information about the plant species/varieties and the methods used to make food but they said that consumers would not have time to read it or that ‘average consumers’ would not be interested in these kinds of details at all. There was agreement on the fact that the basic information about the origin and production methods of the food should also be given. Moreover, if someone were interested, more information should be made available in the shop or online. Participants pointed out that they would be interested to know the additional values of specific species or varieties, particularly related to health/nutrition, rather than just their name, which is often not sufficiently evocative. To provide additional information, some consumers were totally against smartphone applications, while young participants were more favourable to this kind of information tool and some suggested providing access to additional information via a QR code on the packaging.

With regards to the marketing channels, answers were diverse. With a view to increasing the availability of NUCs, participants in five focus groups mentioned that they would prefer to make these products available not only in farms but also in supermarkets, where consumers can easily reach them. This would be especially important in cities (highlighted in the focus groups in Denmark), where consumers cannot easily drive to a farm for example. Many participants also explained that shorter channels are important to make NUCs better known and develop their reputation (highlighted in the focus groups in France), or to reach the conscious consumers through, for example, farmers’ markets, zero waste shops, food coops or community-supported farms (highlighted in one of the focus groups in Hungary). Moreover, the local dimension of selling appeared as important in all focus groups (particularly stressed in Italy). Online channels were also suggested as additional options.

More broadly, discussions highlighted the risk, particularly of the shortest chains, of becoming elitist and time-consuming. For all types of chains, many participants indicated that they would like to be informed about what is being done and what the impact is, but with different preferences or dislikes regarding the type of information and tools. All in all, it is worth to notice that the discussions surrounding the votes reflect the positions of participants who are both citizens, with values and concerns, and consumers, with preferences, food consumption practices, time and budgetary constraints.

5. Discussion

5.1. Involving consumers in the co-development of food chains

Consumers are rarely involved in the decision-making processes regarding food chains. Through a large online survey and focus groups, consumers were invited to express their preferences and aversions regarding the use of agrobiodiversity, from breeding to marketing. This approach is in line with initiatives to encourage the development of food democracy in which consumers can have an impact not only on what they eat, but also on how food systems operate (Booth and Coveney, 2015; Candell, 2022). In practical terms, the research and innovation project DIVINFOOD is building on these results to carry out – together with local players in the living labs – the studies, experiments and assessments needed to implement the alternatives favoured by most respondents, beyond their socio-economic category. However, implementation must also consider respondents’ resources and constraints as consumers, i.e., as buyers and eaters with a specific knowledge base.

The Eurobarometer survey on biodiversity loss carried out in 2014 had already identified this issue of knowledge (European Commission, 2015). When asked if they ever heard of the term “biodiversity” before, about 40 % answered “no”. Respondents were thus given a short explanation, and then were mostly able to answer follow-up questions,

as we did in the DIVINFOOD survey. Our assessment of consumers’ knowledge of agrobiodiversity, although it has some limitations, seems to confirm the low grasp of this subject by many respondents, including those who declared having eaten a vegetarian dish, and who could have been more aware about the plant ingredients in this dish. From a research perspective, this lack of knowledge means that when implementing willingness to pay approaches to agrobiodiversity, in particular, consumers really need to be well informed so that they understand the subject.

Many reports on biodiversity loss argue in favour of greater consumer education on this issue (see, for instance, Teufel et al., 2021). This, however, cannot be limited to indicating the names of plant species and varieties on food products’ packages as our research suggests this to be ineffective. Among possible solutions, school gardens have often been stressed as effective platforms to promote education on agrobiodiversity (Hunter et al., 2020). However, the ‘school food revolution’ (Morgan and Sonnino, 2008) seems to be more focused on the complex issue of sustainable food procurement rather than on knowledge issues, despite the expansion of local food policies that are claimed to have developed a more systemic approach (McRae and Donahue, 2013). More largely, acknowledging a knowledge gap calls for a new approach to agrobiodiversity-based market development.

5.2. Co-developing agrobiodiversity-based markets and food environments

Mainstream markets place little value on agrobiodiversity, particularly NUCs (FAO, 2019; Hunter et al., 2020). Faced with markets that fail to value biodiversity, two main economic and political approaches are usually put forward: the first is to impose taxes on players who reduce this resource, or to allocate subsidies to those who promote it, as partly done by policies for wild biodiversity through eco-schemes in the new European Common Agricultural Policy (CAP) (Heyl et al., 2021). The second approach is to develop public or private standards to differentiate products that preserve or improve this resource in the market, through geographical indications (Scaramuzzi et al., 2021) or private trademarks (Stamboulakis and Sanderson, 2020; Voglhuber-Slavinsky et al., 2023).

A third approach is to co-develop the market with a diversity of stakeholders, including consumers, involving them in activities that enable the co-creation of knowledge about the resource and collective innovation (Giuliani, 2012). These activities weave networks that support the promotion and enhancement of the resource while skilling people and structuring the market (Callon, 1998). Spurred by the survey results highlighting the lack of knowledge about agrobiodiversity, the DIVINFOOD project experiments with this third approach in nine living labs enabling the co-development of new markets for legumes and minor cereals. The aim of the survey and focus groups was not only to assess consumers’ preferences about agrobiodiversity use in food chains. It was also the opportunity to provide knowledge to respondents in order to encourage their critical participation in the project, i.e. their critical capacity to make proposals because they know the subject and the decisions on which they are invited to take part (Friedberg, 1972). Respondents were thus subsequently invited to take part to the project’s activities and decisions. The challenge, however, is to ensure that the consumer will not be only instrumentalised to serve private commercial interests, as has been seen in certain open innovation initiatives led by companies (Brandão, 2021). Consumers must also be considered as citizens, who are given the possibility to shape the market independently of their purchasing power, even more so in the case of a rare and threatened natural resource and public good such as agrobiodiversity (Jaeger et al., 2017). The co-development, with citizen-consumers, of a market for this good that combines private and public interests thus opens a major and innovative research field. Topics regarding the diverse instruments available (living labs, environmental contracts, participatory guarantee systems, local food policies, etc.) and the

indicators for evaluation to be developed (preservation of the resource, collective innovation, etc.) represent areas for further research. However, not all consumers can be involved in the co-development of the market. The issue is thus also to shape food environments that make it easier for consumers to acquire knowledge about agrobiodiversity, that means developing the settings which make food available and accessible to people in their daily lives (FAO, 2016) and ensuring that they promote agrobiodiversity (Gee et al., 2020). In this perspective, our survey highlighted the key role played by restaurants, farmers' markets and box schemes in helping consumers learn about new plant species, paving new avenues, in DIVINFOOD and more largely, for deploying agrobiodiversity-based food environments.

5.3. Supporting alternatives of agrobiodiversity use in research and policies

Alternative options for the use of agrobiodiversity in food chains received positive votes from the majority of respondents, independent of their socio-economic category. These results suggest the need to develop more research and innovation into these understudied alternatives and to go beyond marginal support for these alternatives in local to European public policies (FAO, 2019; Jones et al., 2021). Particular forms of markets - farmers' markets, restaurants and box schemes - appeared as the main drivers of new products consumption. These could be further analysed in terms of how they could serve both as levers for reversing the decline in agrobiodiversity and as pilot measures for companies in short food chains to reach consumer preferences (Cirone et al., 2023). In addition to short food chains, the focus group discussions also highlighted the importance of developing mid-tier chains capable of producing larger volumes of well-identified products that have better quality compared to the industrial products typically found in conventional marketing channels like supermarkets, and making them available in these conventional channels (Ostrom et al., 2017). However, the impact of the use of agrobiodiversity in short and mid-tier value chains still needs to be assessed in terms of its ability to fulfil the various concerns and preferences of citizens and consumers. In particular, there is an opportunity to disseminate and supplement data about the connection between agrobiodiversity, food and health, documented in many studies (Zimmerer et al., 2019), as consumers stressed the importance of the contribution of food and NUCs to health/nutrition issues, both in the survey and in the focus groups. Finally, echoing the debates about the impact of ecological labelling in Europe (Yokessa and Marette, 2019), information on agrobiodiversity use in food products and its impacts emerged as an issue raising questions, calling for more discussions and co-design with citizen-consumers.

5.4. Research limitations and perspectives

The research was ambitious, covering 7 countries and using both a quantitative and qualitative approach to identify and understand the preferences of citizen-consumers regarding the use of biodiversity in food chains. The choice was made not to rely on representative samples of the population in each country, because this would have been costly, but also because the survey was intended to involve consumers in the project's activities: people who voluntarily answered the questionnaire were likely to be mobilised later. On the other hand, each partner was instructed to distribute the questionnaire in a variety of ways so as to reach a wide range of profiles. Finally, the sample used in the quantitative analysis is unbalanced, with France over-represented, followed by proportions of women, people aged 30–49, higher socio-economic categories and residents of functional urban areas that are higher than the national averages for people who completed the socio-demographic profile questions (69 % of all respondents). With regard to the sample studied, the opinions on the options for using agrobiodiversity do not depend on socio-economic categories (apart from students). However, nuances were observed between countries as well as between age

groups, which may reflect a difference between generations. With a view to designing food chains that both value agrobiodiversity and meet the preferences of citizen-consumers, it will be very important to take into account the specific characteristics of countries, but also to look more closely at the opinion of young people, as they will be the main beneficiaries (if not actors) of these chains.

Another major limitation of the research concerns the assessment of people's knowledge of agrobiodiversity. This was a difficult subject to investigate using an online survey. We approached it through the ability to describe the species present in the last main dish eaten. As detailed in the methods section, in the case of people who declared a simple dish, we only scored uncorrect answers. Indeed, for those who were able to list the species, we thought that scoring their answer as correct would have introduced a bias insofar as we could not draw conclusions on their ability in the case of a complex dish. On the other hand, if they declared a simple dish and were unable to list the species, we could draw a conclusion. We could have decided not to score all the simple dishes, but that would have meant losing important information relative to our research focus. However, there was still a bias, as people who were able to list the species of simple dishes would have been able to do so for more complex dishes. The proportion of low scores in the sub-sample whose answers were scored does not therefore necessarily represent the proportion that could have been measured in the full sample, which, as we pointed out, is unbalanced. Furthermore, as indicated above, we measured the ability to list the species on one's plate rather than knowledge of agrobiodiversity. This approach therefore needs to be developed further, particularly as it has the potential to capture both the agrobiodiversity present on plates (particularly the proportion of NUCs, which is not covered here but which will be useful for the project), and the knowledge of this diversity on the part of eaters.

Finally, the last major limitation relates to the organisation of the focus groups: as indicated in the methods section, some of the project partners opened up these groups to professionals from the agricultural and/or food sectors. Although those ones were not in the majority and were not supposed to prevent the free expression of citizen-consumers, their presence may have created a bias. In addition, only two focus groups were recorded, and the socio-demographic data was sometimes not filled in completely, as the project partners were not necessarily familiar with research focus groups. It would have been interesting to include transcripts of the speeches to give a better idea of how the participants expressed themselves and the tone of their speeches. However, as a result of the focus groups, the partners had a better understanding of the research process, which helped to improve data production later on.

6. Conclusion

Rarely involved in the decisions about what happens within food systems, consumers of seven countries in Europe were invited to express their points of view regarding agrobiodiversity use in food chains, through a large online survey and focus groups. The originality of our approach was to capture, in four regions of Europe, the preferences of consumers regarding the use of agrobiodiversity in food chains with regards to their food consumption practices and knowledge, as consumers, as well as their concerns and votes on what should be done in food chains, as citizens. Studies about biodiversity issues are indeed often divided between citizen consultations on the one hand, and consumer studies on the other. Our approach advocates bringing together the two viewpoints, citizen and consumer, thus also combining the two main streams of research about the relation between consumers and agrobiodiversity: consumer as a buyer and consumer as a co-developer. The results are now being used to guide research and innovation in the DIVINFOOD project, and to formulate recommendations for economic, political and community players concerned by the loss of agrobiodiversity and looking for solutions. Moreover, even if the sample showed no correlation between socio-economic categories and votes

regarding options for using agrobiodiversity in food chains, except for students, it reflected the difficulty to reach “average” consumers from lower socio-economic categories. Co-developing NUCs-based markets in living labs is then also the opportunity to strengthen the relationship with this population, being attentive to the most vulnerable people in order to develop inclusive food chains and thus enlarge the scope of food democracy.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.spc.2024.02.032>.

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