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Farmers Feel the Climate Change: Variety Choice as an Adaptation Strategy of European Potato Farmers

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Abstract: Effects associated with a changing climate could severely threaten potato production in Europe. Hence, farmers need to take up adaptation measures to safeguard agricultural production. Collecting data from 553 farmers from 22 different European countries, our survey evaluates European potato farmers' perceptions regarding the influence of climate change on local potato production, and their willingness to implement adaptation strategies. An overwhelming majority of survey respondents had already experienced the effects of climatic changes on their potato production. Specifically, drought and heat were identified as the most significant threats. The planting of an adapted variety was the preferred adaptation strategy, while farmers were also willing to take up changes in agricultural management practices. Survey respondents predominantly considered yield stability as the most important characteristic of an adapted variety, closely followed by heat tolerance, disease resistance, drought tolerance, and yield potential. When choosing a variety, the personal experience of the survey respondents as well as the experience of their peers were identified as the most important sources of information. Our survey gives valuable insights into the challenges European potato farmers are facing in times of climate change. Supplying farmers with better-adapted varieties would be a well-targeted and well-accepted measure to advance climate change adaptation.

Keywords: farmer survey; climate change adaptation; potato; variety choice; adapted variety

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1. Introduction

The effects of human-induced climate change have been increasingly observed globally, nationally, and regionally in recent years, manifesting themselves in an increase in a wide range of extreme weather events such as heat waves, droughts, floods, wildfires, and heavy precipitation events [1,2]. In Europe specifically, more frequent and extreme heavy precipitation events [3,4] and more intense heat waves [5,6], as well as a changing drought frequency [7] and drought severity [8] have already been observed, albeit with significant spatial variation. Agriculture is especially affected by these extremes. Areas relevant to arable farming in Europe are projected to experience more frequent multi-year droughts

in the future, which will have a negative impact on yield [9]. A changing spectrum of plant diseases and increased occurrence of plant pests—due to milder winters—will also make arable farming in Europe more difficult in the future. In order to retain their high yield and high yield quality, European crop farmers will have to adjust to the changing climatic conditions.

The potato (*Solanum tuberosum* L.) is one of the world's most important food crops, alongside wheat, rice, and maize [10,11]. In 2020, estimated global potato production amassed to around 359 million tons, of which Europe accounted for 37.9% of the production share [12]. In the EU-27, 55.3 million tons of potatoes were harvested in 2020, from a cultivated area with a size of 1.7 million hectares. This corresponds to an estimated 1.7% of all arable land in the EU. Potato production in the EU generated a value of around EUR 12 billion in 2020, which made up around 3.1% of the total value of EU agricultural production. The four biggest potato producers in the EU are Germany, Poland, France, and the Netherlands, who collectively produced two-thirds (66.0%) of the EU total yield in 2020 [13]. The majority (90.0%) of the nearly 1.5 million individual potato producing holdings in the EU in 2016 were growing potatoes on an area of less than one hectare, with small farms being especially typical in Poland and Romania. In 2016, only 2.6% of all EU farms cultivated potatoes on an area of 10 hectares or more, exemplarily in the Netherlands and Denmark. However, these holdings accounted for 61.6% of the total EU potato acreage. About 1.3% of all potato-producing holdings in the EU were producing under organic farming conditions in 2016, corresponding to approx. 20,000 farms. Of these, the majority can be found in the three member states Poland (23.8%), Austria (14.7%), and Germany (14.0%) [13].

Over a total growing period of 105–145 days, approximately 500–700 mm of water is necessary to achieve satisfactory yield, although these values vary greatly depending on localization [14,15]. The potato prefers a temperate climate and develops best at around 20 °C. High temperatures have a negative impact on tuber development and significantly decrease yield [16–18]. A temperature above 25 °C during the growing season causes the crop to stop tuber formation and favors vegetative growth, leading to further losses in tuber quality [19]. The potato is generally considered drought-sensitive [19–21]. In addition to its direct effects on the crops, climate change also has a major impact on the geographic distribution of pests and pathogens and their interactions with plant hosts, including changes in host susceptibility [22]. Longer growing seasons at higher temperatures allow for more multiplication cycles of insects, thereby putting a higher pest and pathogen pressure on the crop [16].

Globally, more than 4000 potato varieties are known [11,23], while the EU plant variety database currently lists 1679 varieties (these include varieties for consumption and for starch production purposes). Naturally, only a small number of these listed varieties is actually available and/or relevant to farmers. For example, the top ten grown varieties in the five European potato-producing countries, Germany, France, the United Kingdom, the Netherlands, and Belgium, constitute 35.6%, 35.8%, 39.9%, 45,0% and 83.4% of all cropped potato area, respectively [24]. However, these widely used potato varieties may not be suitable for future changing climatic conditions, as breeding was carried out under current, often optimal, conditions, and future challenges from specific or combined abiotic stresses were not considered [25].

Most researchers emphasize that adaptation measures must be taken up to offset the negative impact of a changing climate, such as rising temperatures, increased occurrence of drought, and the emergence of new pests and pathogens, on agricultural production [9,16,26–28]. Many different adaptation strategies have been proposed, in particular to reduce the impact of drought. These include the shifting and adjusting of planting dates to more favorable conditions [29], choosing better-adapted varieties [16,27,29,30], and better water management, such as implementing efficient irrigation measures [31], securement of additional water supplies and improving soil moisture retention [32].

Despite the projected benefits, it is unclear whether farmers are able and willing to take up adaptation measures. Not only do they need to meet the financial requirements, but they also need to perceive climate change as a serious threat [33,34]. Additionally, the actors at hand need to be aware of their adaptive capacity, i.e., that it is within their power to take up effective adaptive actions [35,36]. Farmer surveys are a useful tool to assess the views, the roles, and the needs of the key actors who can implement climate change adaptation measures, i.e., the farmers [37], and help to inform debates if more and/or better adaptation and development policies are needed [34].

In the frame of the Horizon 2020 project ADAPT (Accelerated Development of multiple-stress-tolerant Potato, https://adapt.univie.ac.at/, accessed on 8 September 2023), we conducted a survey among European potato farmers. The survey allowed us to connect directly with farmers, learn about their needs and concerns related to climate change, and build a mutual understanding of the issues at hand. In detail, which adaptation measures farmers are willing to implement, whether farmers consider variety choice as a valuable adaptation tool, and which needs and constraints exists when choosing a variety to adapt to climate change related abiotic stresses were investigated.

2. Materials and Methods

2.1. Survey Setup and Data Collection

The goal of the survey was to assess how the European potato farmers perceive the impact of a changing climate on their local potato production and what adaptation measures they are willing to implement.

The survey included 18 individual questions (plus one additional question, if the previous question was answered with yes; see Supplementary Material S1), clustered into three thematically defined sets. Participants in the survey were unaware of the clustering of the questions. The first set of questions aimed at assessing European potato farmers' perception of climatic changes and experienced impact on potato production (Questions 1–4). Only participants who positively answered the question "Do you believe that in the last 10 years changes in climatic conditions have affected your potato production?" (Question 1) were then given the multiple-choice follow-up question "Which effects(s) related to climatic changes do you feel has (have) increasingly impacted your potato production in the last 10 years?" (Question 2).

The second set of questions assessed the different adaptation strategies that European potato farmers are pursuing and gathered more in-depth information about the adaptation strategy "variety choice" (Question 5–8). Here, survey participants could opt to not select any answers to the multiple-choice question "How important do you consider these characteristics for the choice of an adapted variety?".

The third set of questions aimed at gathering information about the survey participants and included questions about their potato growing site conditions (Questions 9–16), as well as information about the participants themselves, including their location of potato production (Question 17), their potato-growing experience (Question 18) and their age group (Question 19).

The survey was accessible online over a period of nearly five months, from 4 December 2020 until 30 April 2021. The survey was accessible via a link, or by scanning a QR code. Survey participants were first asked to select one of ten possible language options for the survey (Bulgarian, Dutch, English, French, German, Greek, Polish, Serbian, Spanish, Slovenian) and were then led to a landing page. Here, they were informed about the purpose of the survey, the ADAPT research project and its funding, the privacy and confidentiality of their data, and that the participation in the survey was voluntary and anonymous. Participants of the survey remained anonymous and recorded data did not include any personal identification. It was not possible to identify the source of the information at any time. The survey was started by clicking on a separate "Start questionnaire" button. Time to complete the survey was estimated at below 15 min.

To reach as many potential survey participants as possible, multiple national and international institutions in direct contact with potato farmers were contacted and asked to use their dissemination channels (i.e., newsletter, blog entry on institution homepage, social media post, etc.) to distribute the link to the online survey. Institutions that distributed the link to their stakeholders were, among others, potato-breeding companies, trade associations, national and regional chambers of agriculture, and potato producers' associations.

It is important to note that replies to some questions might vary greatly between respondents from different countries. Hence, replies to these questions broken down by country can be found in the Supplementary Material S3.

2.2. Survey Participants: Key Characteristics

The online survey was closed on 30 April 2021. A total of 553 people from 22 different European countries had completed the survey by the closing date. Most replies were registered from Austria (n = 159), followed by the Netherlands (n = 93), Germany (n = 79), France (n = 57), Switzerland (n = 53), Slovenia (n = 36), Belgium (n = 21), Poland (n = 19), Spain (n = 15), and the United Kingdom (n = 6). Additionally, two potato farmers each from Serbia, Greece, and Slovakia answered the survey. We also registered one survey participant each from Bulgaria, the Czech Republic, Denmark, Estonia, Hungary, Ireland, Italy, Luxembourg, and Sweden. Since participation in the survey was voluntary and participants were not selected systematically, answers given cannot be considered representative or random samples of the respective countries. Due to the widely varying sample sizes among countries, the results are presented based on general descriptive statistics.

The majority (30.2%) of farmers who participated in our survey belonged to the age group 55 to 64 years, followed by the age group 45 to 54 years (28.8%). Around one fifth of all participants (21.3%) answered that their age was between 35 and 44 years, while 13.6% of survey participants are grouped into the age bracket of 25 to 34 years. Considerably less represented were the ages above 65 (4.9%) or below 24 years (1.3%).

The vast majority of survey participants (91.9%) had been growing potatoes for more than five years and can hence be considered experienced potato farmers.

A total of 75.4% of farmers reported that they produce potatoes in a conventional way (n = 417), while 13.9% (n = 77) of respondents grow their potatoes under organic conditions. A mixed farming system of both organic and conventional production was used by 8.9% (n = 49) of respondents.

Main production targets were table potatoes, which were grown by 62.7% of respondents, followed by consumption potatoes grown for the processing industry (32.2%) and seed potatoes (30.9%). About one fifth (18.6%) of respondents answered that they were specifically growing potatoes for the starch industry.

Farmers were asked how much acreage (in hectares) they use to grow potatoes. Answers to this question showed great variation, with most farmers reporting that they were growing potatoes on between 21 and 50 hectares (22.8%), 9 to 20 hectares (22.1%), or on 3 hectares of acreage or less (20.8%). A total of 14.8% of respondents assigned between 3 and 8 hectares to growing potatoes. Larger farms were also represented in our data set, as 10.3% of respondents were growing potatoes on acreage of 51 to 100 hectares, 4.0% on 101 to 150 hectares, and 5.2% reported that they were using more than 150 hectares for potato farming.

3. Results

3.1. Growing Conditions Reported by Surveyed Potato Farmers

Farmers who took the survey were asked to report on multiple key questions regarding climatic and/or growing conditions on their farm (Table 1). Around three quarters of all respondents answered that the soil water retention capacity of their soil is low, low to medium, or medium. Up to one quarter of the farmers reported an annual precipitation of less than 500 mm, while over half of all survey respondents (61.8%) relayed that their medium annual precipitation is in the range of 500 to 900 mm. Only a minority of farms

(34.7%) were fully equipped, with the possibility of irrigation. Our data show that most respondents experienced high temperatures for more than seven consecutive days over the growing season. For the vast majority (94.6%), there was a high or medium probability that temperatures exceeded 26 °C for a weeklong period during the growing season, while 77.2% of respondents thought it was likely that temperatures could even exceed 30 °C. Only around one fifth responded that there was a low probability that temperatures would exceed 30 °C for seven consecutive days during the growing season.

Table 1. Overview of key climatic and/or growing conditions survey participants face in their potato production. Farmers had to report on (a) the soil water retention capacity of their soil, (b) the medium annual precipitation of their growing region, and (c) whether they had the possibility to irrigate their crops. Additionally, survey participants had to self-assess the probability of maximum temperatures reaching >26 °C and >30 °C for more than seven consecutive days over the growing period in their growing region, respectively.

(a) Soil Water Retention Capacity (n = 553)			**(b) Medium Annual Precipitation (n = 553)**			**(c) Possibility of Irrigation (n = 553)**		
	n	%		n	%		n	%
low	43	7.8	<300 mm	10	1.8	yes	192	34.7
low–medium	110	19.9	300–500 mm	115	20.8	no	273	49.4
medium	245	44.3	500–700 mm	196	35.4	partially	88	15.9
medium–high	105	19.0	700–900 mm	146	26.4			
high	37	6.7	>900 mm	46	8.3			
unsure	13	2.4	unsure	40	7.2			

(d) probability of maximum temperature >26 °C for more than 7 consecutive days during growing period (n = 553)			**(e) Probability of maximum temperature >30 °C for more than 7 consecutive days during growing period (n = 553)**		
	n	%		n	%
high	361	65.3	high	175	31.6
medium	162	29.3	medium	252	45.6
low	17	3.1	low	108	19.5
unsure	13	2.4	unsure	18	3.3

3.2. Climate Change Related Difficulties for European Potato Farmers

The overwhelming majority of farmers (89.2%) responded that changes in climatic conditions have been affecting their potato production in the last ten years.

More specifically, most farmers perceive drought and heat as the greatest threat to maintaining potato production, both in recent years and in the future (Table 2). Half of the respondents stated that they consider the occurrence of pests and pathogens induced by climatic conditions to negatively impact yields both in recent years and in the future. Heavy precipitation affected the potato production of 42.6% of questioned farmers in the last ten years, but only 37.6% anticipated this effect in the future. Around or less than 15% of survey participants perceived late spring frosts, flash floods, soil erosion, and early autumn frosts as a threat to past or future potato production.

Despite voicing that changes in climatic conditions have affected their potato production in the past, only 47.7% of surveyed European potato farmers believed that observed climatic changes pose a threat to maintaining potato production at their farm. Moreover, 24.1% of respondents believe that climatic changes do not threaten their potato production, while the remaining 28.2% farmers were unsure about the threat that climatic changes may pose on maintaining potato production at their farm.

Table 2. Responses given by survey participants to the questions: (a) "Which effect(s) related to climatic changes do you feel has (have) increasingly impacted your potato production in the last 10 years?" and (b) "In your opinion, which effect(s) related to climatic changes will negatively affect your future crop production the most?" Multiple choice was enabled for these questions. Only participants who answered the question "Do you believe that in the last 10 years changes in climatic conditions have affected your potato production" with "yes" were able to answer the question (a), while question (b) was given to all survey participants.

	Last 10 Years (n = 493)		**Future (n = 553)**	
	n	%	n	%
drought	431	87.4	438	79.2
heat	407	82.6	405	73.2
pests and pathogens induced by climatic conditions	263	53.3	285	51.5
heavy precipitation	210	42.6	208	37.6
late spring frosts	76	15.4	56	10.1
flash floods	62	12.6	55	9.9
soil erosion	47	9.5	50	9.0
others	33	6.7	38	6.9
early autumn frosts	6	1.2	9	1.6

3.3. Adaptation Strategies to Climate Change of European Potato Farmers

To assess which actions farmers are willing to take up to adapt to a changing climate, survey participants were asked which adaptation strategies to climate changes they are willing to implement. Here, planting of an adapted variety was clearly the primary adaptation strategy and selected by 73.2% of farmers (Table 3). Planting an adapted genetically modified or genome-edited variety was a potential option for around a quarter (24.8%) of all survey participants. Changes in agricultural management practice were considered another possible climate change adaptation strategy. Here, implementing irrigation (44.8%), changing the planting and harvesting date (44.7%), and adopting different tillage practices (43.9%) were equally popular. Around one third (32.0%) of survey participants considered changes in crop rotation an adaptation strategy they were willing to implement.

Table 3. Responses given by survey participants to the question: "Which adaptation strategies to climate changes are you willing to implement?" Multiple choice was enabled for this question.

n = 553	**n**	**%**
planting an adapted variety	405	73.2
irrigation	248	44.8
change of planting and harvesting date	247	44.7
tillage	243	43.9
change in crop rotation	177	32.0
planting an adapted genetically modified or genome edited variety	137	24.8
others	24	4.3

In a follow-up question, we asked more specifically whether farmers believe that the impact of climatic changes on potato production could be reduced by the choice of an adapted variety. Here, three quarters (74.0%) of survey participants agreed that planting an adapted potato variety could lessen the negative effect of climate change on potato production, while one fifth of respondents was unsure of its actual impact. However, only a small minority (5.8%) disagreed with this statement.

3.4. Variety Choice as an Adaptation Measure

To understand what farmers are looking for in an adapted variety, we asked survey participants in a follow-up question to rate certain potato characteristics regarding how important they consider each characteristic for an adapted variety (Table 4).

Table 4. Responses given by survey participants to the question: "How important do you consider these characteristics for the choice of an adapted variety?" For this question, a scaled-response matrix design was used, where survey participants had to rate each characteristic from most relevant (1) to least relevant (4). Respondents were able to not give a reply to each characteristic. Data are displayed in % of replies given for each characteristic. Characteristics in the table are ranked depending on the most replies assigned either value 1 or value 2 (top).

	n	1—Very Relevant	2	3	4—Not Relevant	Unsure
yield stability	543	63.9	27.8	5.9	2.2	0.2
heat tolerance	543	56.7	33.0	7.2	2.6	0.6
disease resistance	546	62.5	27.1	7.0	2.9	0.5
drought tolerance	541	53.2	35.9	8.1	2.2	0.6
yield potential	545	51.9	34.9	10.8	2.0	0.4
pest resistance	536	56.2	27.4	12.3	3.4	0.7
dormancy and storability	539	40.6	40.1	13.9	4.8	0.6
time of maturity	530	19.2	46.0	27.0	6.2	1.5
tuber shape	531	16.8	42.7	26.4	13.0	1.1
skin and flesh color	524	18.3	29.4	26.9	24.4	1.0
starch content	526	14.1	32.7	35.9	15.2	2.1
sugar content	505	5.7	25.7	39.8	24.4	4.4

Survey participants considered yield stability the most relevant characteristic of an adapted variety, with 91.7% of respondents rating this characteristic either very relevant (1) or relevant (2). Further highly rated characteristics were heat tolerance (89.7%), disease resistance (89.6%), drought tolerance (89.1%), and yield potential (86.8%). Pest resistance, as well as dormancy and storability, were considered slightly less relevant when choosing an adapted variety, although above 80% of respondents still rated these characteristics relevant or very relevant. Farmers participating in our survey considered time of maturity and tuber shape less relevant, with skin and flesh color, starch content, and finally sugar content being the least relevant characteristics for farmers when choosing an adapted variety.

When choosing a variety for planting, the majority of respondents rely on their personal experience (81.2%), or on the experience of their peers by gathering information in discussions with colleagues (57.3%). Breeding companies (38.2%), plant variety examination offices (33.5%), technical associations or institutes (32.0%), processors (30.6%), and retailers (28.4%) were also considered as a source of information. Less important as a source of information for the choice of a variety were farmers' representatives/farmers' associations (21.0%) or agricultural fairs (15.4%). Other information channels were indicated by a minority of survey participants (7.6%). Interestingly, we observed considerable differences between countries when asking the farmers about their sources of information about new and better-adapted varieties (see Supplementary Material S3).

4. Discussion

Surveys are a useful tool to provide a general overview of the issues at hand and provide a snapshot of the current sentiments among the respondents. It has to be taken into account that the answers of the participants are based on subjective experiences, and could be temporarily or permanently influenced by external factors, e.g., media coverage of current drought events, ongoing heat waves, personal interest in the topic, etc. [38,39]. It cannot be ruled out that the participants' responses in our survey were influenced by the factors mentioned above. Both the voluntary nature of the survey at hand and potential bias in the replies must be considered when interpreting the results.

The results gathered by our survey give a good general insight into the challenges that European potato farmers are facing, with a focus on the effects of climate change, and their preferred strategies to mitigate these effects. European potato farmers feel in particular the impact of drought and heat on their potato production. Growing an adapted variety was

their most preferred adaptation strategy, with yield stability, heat tolerance, and disease resistance being especially desired traits.

4.1. European Potato Farmers often Grow Potatoes under Sub-Optimal Conditions

Potato yield is strongly determined by a combination of water availability and temperature, among multiple other factors [16,19]. The gathered results indicate that the majority of participants in our survey are potentially challenged by heat and drought stress during the growing season, as they are currently growing potato under sub-optimal conditions, with either low soil water retention capacity, low precipitation, no possibility of artificial irrigation, high temperatures during the growing season, or a combination of these being the yield-limiting factors (Table 1).

As the potato is a cool-season crop, heat can also be considered a limiting factor for potato production. Studies on the impact of a changing climate on potato production identified heat stress as a major factor affecting yield, as the potato tends to halt tuber development under heat stress [17,19]. Many respondents can consequently be expected to face dramatic potato yield losses with a progressively changing climate, as they had declared a high or medium probability of maximum temperatures reaching more than 26 °C and even more than 30 °C for more than seven consecutive days over the growing period (Table 1). In line with this, a decrease in future global potato yield rates can be expected due to increased temperatures, although great spatial variability must be considered. Hijmans [29] calculated a global potential potato yield decrease of 18% to 32% if no adaptation measures are implemented. The yield loss was mainly attributed to global temperature increase, which was assessed to be between 2.1 and 3.2 °C by 2040–2069. However, upon taking up sufficient adaptation measures, global potential potato yield is predicted to decrease by only 9% to 18%. As warmer temperatures accelerate leaf senescence and impact tuber bulking, significant declines in potato yields are also predicted at the regional level [40]. Here, the need for adaptation measures to offset significant yield reductions are being discussed, with the most promising being, again, the use of an adapted variety with later maturity, which is able to maintain green leaf area for longer.

The potato is considered drought-sensitive [21]. This sensitivity might be caused by its short and shallow root system [16,41]. Global warming has, inter alia, an amplifying effect on the occurrence of drought conditions [42]. As a result, drought occurrence in Europe in the 21st century is projected to increase [9]. Hence, low water availability caused by low precipitation and low water-retention capacities of the soil might have a negative impact on potato yield. In our survey, around a quarter of the European potato farmers indicated an annual precipitation below 500 mm and a low soil water retention capacity (Table 1). Here, the possibility of irrigation could potentially offset any drought-caused yield losses. However, only around one third of survey participants reported that they have the possibility to irrigate their potato acreage. The future importance of applying irrigation to maintain potato yield rates on currently non-irrigated areas has already been pointed out in the works of Daccache et al. [31,32], as purely relying on rainfall will become increasingly risky. This is in line with the findings of Trnka et al. [43], who also emphasized the increased risk associated with a sole reliance on rainfed crop production. Exemplarily, in England and Wales, the area of arable land that is well or moderately suited for rainfed potato production is expected to decline by 88% and 74% by 2050, respectively, under the most likely climate projections. In these cases, the use of irrigation systems is necessary to maintain potato yield. With water availability for irrigation secured—either by winter-filled on-farm reservoirs or by procuring (additional) water licenses—potato production could remain on the acreage currently used for rainfed production [31]. However, while theoretically possible in Europe, the expansion of irrigation systems comes with substantial financial and ecological costs [32,44,45].

It is important to note that some yield prediction models do not consider the positive effect of CO_2-fertilization caused by an increased amount of atmospheric CO_2, which is very pronounced and beneficial for the C3 crop potato [46,47]. With CO_2-fertilization taken

into account, the model set up by Raymundo et al. [48] still predicted a global tuber yield reduction of 2% to 6% by 2055, and a 2% to 26% reduction by 2085, depending on future emission pathways, but without considering adaptation methods. Another model, used by Jennings et al. [49], accounts for CO_2 fertilization and longer growing seasons. Here, with the use of applied adaptation methods (varying planting windows, adapted crop varieties) a potential increase in average global potato yield of 9% to 20% by 2050 is projected. The authors also stress that some regions will benefit in the future while others will struggle to maintain current potato yield levels.

While the increase in irrigation might generally offset some negative impact of a rising temperature, it can be anticipated that farmers already growing potatoes under challenging conditions will further struggle in the future and will experience potato yield losses, especially if water or nitrogen limitations do occur [48,50]. Hence, most researchers expect a spatial shift in potato production associated with a changing climate. In any case, high temperatures and occurring droughts will be yield-limiting factors in European potato production. It is predicted that potato production in the Northern Hemisphere will decline in southern regions, while northern regions will benefit from longer growing seasons and the extension of the frost-free period [16,51]. In Central and Eastern Europe, it is projected that rising temperatures will offset the CO_2 fertilization effect by 2050, resulting in reduced yields, while Northern Europe will be able to increase potato yields due to longer growing seasons. In any case, high temperatures and occurring droughts will be yield-limiting factors in European potato production, with Southern European areas becoming fully dependent on irrigation to maintain the production level, which will further establish Northern Europe as the main area for European potato production [52].

4.2. European Potato Farmers Encounter Multiple Climate-Change-Related Difficulties When Growing Potato

In our study, an overwhelming majority of nearly 90% of survey respondents reported that changes in climatic conditions had affected their potato production in the last decade. This finding is in line with other surveys, which could show that European farmers—albeit not necessarily specialized in potato production—are aware of a changing climate and are already experiencing changes in climatic conditions in their area, even if other studies usually reported a lower agreement of survey participants to this question. As recently reported, 84.3% of surveyed Romanian farmers said that climate change caused fluctuations in their agricultural production to a small or great extent [53]. In a survey conducted by Jantke et al. [54], 53.9% of participating farmers (livestock and crop production) from Germany agreed with the statement that the effects from climate change are already noticeable today. In a questionnaire that focused on agricultural production in the northern circumpolar regions, 84.0% of farmers had noticed the effects of climate change [55]. In another study among German farmers that were specialized in plant production, 78.0% of survey participants stated that the effects of a changing climate have had an impact on their crop production [56]. In a different study conducted by the same authors, 85.0% of German cereal farmers reported that climatic changes had affected their crop production [57].

Out of the observed climate-change-related effects, drought and heat were mentioned by more than 80% of the surveyed farmers to have impacted potato production in the last 10 years (Table 2). The perceived increase in drought and heat conditions are in line with current meteorological data, which demonstrate anthropogenic-climate-change-related rising summer temperatures and more frequently observed heat waves [58], as well as the unprecedented severity of current drought events in Europe [9]. Interestingly, the percentage of farmers who expected that heat and drought stress would negatively affect their potato production the most in the upcoming 10 years is slightly less than those that experienced it in the past. However, the vast majority of surveyed farmers still expect drought and heat stress to be the main negative influence on future crop production. This corresponds with most potato yield models that project negative effects of heat and drought stress on future potato production [29,52].

Around half of participating farmers reported that the occurrence of pests and pathogens induced by climatic conditions had affected their potato production in the past, and that they would expect a negative impact in the future. While the impact that new or established pest insects will have on future potato yield are mostly not factored into the aforementioned potato yield prediction models, research findings predict that a temperature rise will result in longer growing seasons, which enables potato pests to undergo more multiplication cycles [16]. Additionally, warmer temperatures enable the geographical expansion of potato pests [28]. Among the prevalent potato pests, especially the Colorado potato beetle (*Leptinotarsa decemlineata*) and wireworms (*Elateridae*) are expected to benefit from the predicted changing climatic conditions [59,60].

As weather events become more extreme, heavy precipitation and associated flooding also become more likely [58]. The negative effect of the occurrence of these heavy precipitation events has been noted by 42.6% of survey participants.

Our findings are in agreement with other surveys conducted among European farmers, highlighting once more that European farmers are already aware of certain biotic and abiotic stresses caused by a changing climate. In particular, drought, heat and heavy precipitation were frequently mentioned in other surveys [56,57]. Our survey shows that the perception of the changing climate of most European potato farmers aligns with current meteorological predictions. The awareness of a changing climate is the first step to take up adaptive action.

4.3. European Potato Farmers Prefer Variety Choice as an Adaptation Strategy

As the climate is changing, agriculture needs to adapt to counteract the negative impact of rising temperatures, increased occurrence of drought, and the emergence of new pests and pathogens [9,16,26–28].

In our survey, most European potato farmers reported that they were willing to plant an adapted variety as an adaptation strategy, followed by implementing irrigation systems, changes of planting and harvesting dates and implementing different tillage practices (Table 3). Being an easy, affordable, and fast-to-implement action, variety choice is an obvious first adaptation method to take up, and the willingness of European farmers to pick a better-suited crop variety has been documented in other surveys, too [53,56,57]. Interestingly, survey respondents were overwhelmingly reluctant to use genetically modified varieties—which might be the result of the long-lasting controversial debate of growing genetically modified crops in Europe. While irrigation is seen as a possible adaptation method to implement by about half of the survey participants, it is associated with higher economical input and higher environmental impact, and might not be available for every farmer [32,44,45]. Realistically, multiple of the aforementioned adaptation methods will have to be implemented in the future to mitigate the negative impact of a changing climate on worldwide potato production [25].

Researchers also emphasize that variety choice, as well as breeding programs to supply new and better-adapted potato varieties, are an important part of an extensive adaptation strategy towards climate change. Here, multiple traits can be addressed, i.e., early maturity, resistance to biotic stresses like pests and diseases, and resistance to drought stress and heat tolerance [16,27,29,30]. However, globally, heat and drought stress will likely have the biggest impact on potato production [25]. Drought-sensitive potatoes tend to have a short and shallow root system [16,41] and rapidly change their foliage under drought conditions [20,61]. When grown under natural conditions, drought and heat stress usually affect the potato crop simultaneously, resulting in both effects being examined together. However, it is important to keep in mind that the negative impact of drought stress can potentially be mitigated with the use of irrigation systems or potentially does not occur when the soil displays good soil moisture before and at the time of the heat stress period [17].

Here, an adapted variety could provide stable yields with little input or technical change. However, depending on the prevalent environment and/or climatic conditions, what constitutes or what characteristics make up an adapted potato variety might differ according to the respective environment. In a potato ideotype proposed by George et al. [25],

the researchers highlight the need for early maturity, enhanced size and water uptake capacity of the root system, epicuticular waxes, and heat shock proteins to overcome heat- and drought stress. Our survey shows that European potato farmers also put a high emphasis on heat and drought tolerance when choosing an adapted variety, with disease and pest resistance as well as yield potential also being sought after traits (Table 4), while quality parameters were deemed less important. Yield stability was named the most important characteristic for the choice of an adapted variety, which was also ranked as the most important variety trait in the two surveys conducted by Macholdt and Honermeier [56,57].

However, it is important to point out that breeding new varieties alone can only be one puzzle piece in the climate change adaption system. Potato breeding is a multi-level, multi-target approach, and it usually takes around ten years until a new variety reaches the market. The challenges in potato breeding are also characterized by the exceptional importance of tuber quality parameters that need to meet consumers' and market expectations. Although many farmers indicated their willingness to grow an adapted variety, Burke and Lobell [62] identified multiple factors that might prevent farmers from taking up this adaptation method. Among these were the limited availability of alternative varieties, the cost or perceived risk associated with changing varieties, and the challenge of determining a well-adapted variety.

Due to the high number of registered potato varieties in Europe, the challenge to choose the right variety becomes pressing. For this, European potato farmers rely on different sources to inform themselves. Our results show that the majority relies on their own personal experience and the recommendations of other farmers. Information provided by breeding companies, plant variety examination offices, technical associations or institutes, processors, and retailers were also considered to a certain extent. All these sources may be equally relevant to distribute information about new and better-adapted variety choices to the farmers. Interestingly, our results revealed that the ranking of the preferred information sources varies between countries, but there was a clear convergence concerning personal experience and the exchange with other farmers. That farmers preferably rely on their own personal experience and the experience of their peers when educating themselves about new farming techniques has been demonstrated in multiple studies, e.g., in regards to organic weed management [63], implementation of no-till farming [64], and new sustainable soil practices [65]. Regarding variety choice, the results of our survey are in line with the results of another survey from Germany, where farmers also predominantly rely on personal experience as their preferred source of information when choosing a variety. In comparison to personal experience, German farmers considered state plant variety offices, technical colleagues, and federal plant variety offices to be less relevant as a source of information, while the non-independent actors, "breeding companies" and "agricultural traders", were least relevant when choosing a variety [56].

Information about a variety is crucial when choosing the potato variety most suitable for planting in each farmer's respective growing area. However, it is also important to know from where farmers obtain their information to inform themselves about new and better-adapted variety choices. In our study, less than half of the surveyed farmers rely on information from breeding companies, plant variety examination offices, technical associations, or institutes or farmers' representatives/farmers' associations when choosing a variety. Breeders developing new, better-adapted potato varieties should be aware of the different sources of information that farmers regard as highly relevant, to better promote their product and to better enable adaptation via means of planting an adapted variety. To improve the communication and knowledge transfer of those institutions to farmers, multiple potential actions have been proposed in previous studies. Among these are the inclusion of the trait highly desired by farmers, "eco-stability", as a parameter during official variety testing and to include the results in the official Plant Cultivar Catalogue, which is freely available to farmers [57]. In addition, the transfer of agricultural research findings directly to the farmers should be promoted, potentially via established cooperation between institutional partnerships and farmer networks, in a planned and coordinated

manner [56]. Other researchers stress the importance of establishing farmers' knowledge networks, where farmers come together and learn from their peers, but also highlight the need to identify and cooperate with farmer influencers to increase the credibility of the distribution of newly gathered information [65]. Similarly, Skaalsveen et al. [64] also single out the importance of influencers as targets for disseminating important information. Intermediaries and knowledge brokers between hubs of knowledge—who are well accepted by their peers—could play a key role in accelerating the uptake of new farming practices.

5. Conclusions

As the effects of a changing climate have been abundantly noticeable in Europe in the recent past, the need for implementing adaptation methods has been increasingly discussed in socio-political discussions. The project ADAPT focusses on developing new strategies to make potatoes fit for the challenging growth conditions of the future. In this context, we were interested in the European potato farmers' perception of the local impact that a changing climate has on their potato production. In addition, we wanted to know about adaptation measures that they are willing to implement and identify information channels that they use.

Based on the survey results, it becomes evident that European potato farmers already face multiple climate-change-related difficulties which impede their crop production. Many farmers reported already sub-optimal conditions for potato growth, such as low annual precipitation, low water retention capacity of the soil, and/or the lack of irrigation. With a progressively changing climate, it can be assumed that these farmers will be the first to be further negatively impacted. Based on the replies given in the survey, the majority of European potato farmers already report challenging climate conditions in recent years, and also expect to experience them in the future. Here, mainly heat and drought have been mentioned to have the biggest impact on potato production. These perceptions are in accordance with meteorological predictions of more heat and drought in future. European potato farmers have a good understanding of future challenges on their crop production and are aware of potential mitigation strategies.

Among these, the preferred adaptive measure was variety choice, which allows farmers to take up a quick, relatively cost saving, and easy to implement adaptation method. When asked about genetically modified varieties, the responding farmers indicated some reluctance to grow them. At any rate, European farmers have a broad selection of potato varieties at their disposal, with new varieties entering the market every year. To allow for a targeted use of new and better-adapted plant varieties, it is of great interest to understand the farmers' needs and constraints when choosing a variety. Our survey showed that European potato farmers desire yield stability, most likely because this gives them greater predictability in regard to revenue. Farmers also value heat- and drought-stress resistance, and also look for varieties with pronounced biotic stress resistance, possibly since they expect that yield stability most likely can be achieved by planting varieties that focus on these traits. Overall, quality parameters were deemed less important for variety choice by the farmers.

Being aware of a changing climate stimulates European potato farmers to take up adaptive actions. Naturally, farmers will play the most important role in embracing and implementing available adaptation methods, and our survey shows the willingness of European farmers to take up adaptation measures. The survey gives insights into potential mitigation strategies, and also clearly indicates the need to develop new strategies to support the farmers in addressing the challenges ahead. Choosing an adapted variety is an important adaptation strategy in crop production, and one of many decisive actions that must be taken up to reliably produce stable yields in times of a changing climate. In order to distribute specific information about new and better-adapted varieties to farmers, their current sources of information for variety choice is of interest. In our survey, the preferred source of information for farmers is either their own experience or the experience gathered by their peers. Here, we still see considerable potential for improving the flow of information from the

supply side of new, better-adapted varieties to the demand side, i.e., farmers. However, the possibilities offered by planting an adapted variety should not be overestimated. A holistic, well-thought-out, and planned approach using all available adaptation measures will be necessary to ensure a stable future supply of potatoes in Europe.

Our survey gives us valuable insights into the present challenges European potato farmers are facing in the times of climate change, and their level of awareness of potential mitigation measures. We also learned which adaptation measures they are willing to implement. With its work program, ADAPT fulfils the farmers' needs by developing new pipelines for the targeted development of stress-tolerant potato varieties in a holistic approach. The results of the survey show that the expected outcome of the project should support farmers when implementing adaptation measures.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/cli11090189/s1, PDF document S1: Questionnaire, PDF document S2: Detailed Answers, PDF document S3: Country specific answers for Q7: Which source of information do you use in your choice of variety?

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