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Consumer attitudes towards plant breeding combining ancient wheat with modern varieties

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ABSTRACT

This study aimed to explore the awareness and attitudes of Swedish consumers towards conventional plant breeding and the specific case of crossing conventional varieties with ancient varieties. The analysis was based on data obtained from a questionnaire-based survey (N = 999) conducted in Sweden in September 2023. The questionnaire covered demographics, the ranking of qualities that can be enhanced by plant breeding, attitudes and beliefs regarding the consumption of cereals developed by plant breeding, plant breeding neophobia (PBN), awareness of ancient cereals, and attitudes and beliefs towards consuming cereals resulting from crosses of ancient and modern varieties. The results indicated that plant breeding was primarily associated with qualities supporting cultivation and mitigating effects of climate change, rather than qualities directly related to food, eating and personal health. Nevertheless, (smaller) clusters of consumers also recognised sensory and health/nutrition benefits. Plant breeding neophobia (PBN) did not differ with age, was higher among women, but decreased with higher educational level. The results illustrate that most respondents were aware of ancient cereals, with awareness increasing alongside higher age and education level. Attitudes and beliefs towards eating modern cereals (developed through plant breeding), as well as a crossing between modern and ancient cereals, were generally neutral to slightly positive. However, the crossing option was perceived to result in food products that were comfortable, health-promoting and safe to eat, compared to conventional varieties. Male gender and higher education were positive predictors of attitudes, whereas PBN negatively influenced attitudes towards eating food developed through plant breeding. A similar pattern was found regarding attitudes towards cereals resulting from crosses of modern and ancient varieties. The conclusions and identified values are expected to assist stakeholders and policymakers in effectively communicating the qualities of plant breeding and new varieties to the public.

1. Introduction

Wheat is a major contributor to human nutrition and one of the world's largest and most economically important crops (Shewry and Hey, 2015). It contributes to food and nutritional security by providing significant physical attributes (e.g. taste, flavour, aroma, and colour) (Heiniö et al., 2016) and nutritional value (e.g. protein, minerals, phytochemicals, and amino acids) (Johansson et al., 2020). Wheat-based foods are widely consumed; however, several aggravating circumstances have adversely affected cultivation and sales in recent years. These include the impacts of ongoing climate change and related weather challenges (IPCC, 2014; IPCC, 2021), issues with plant protection products (Carrasco and Medina, 2022), the loss of biodiversity (Willett et al., 2019), and a growing number of consumers experiencing allergic reactions to wheat (due to the presence of antinutrients), as well as irritable bowel syndrome (IBS) triggered by specific wheat components (Hayes et al., 2014). FODMAPs (fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) and ATIs (amylase-trypsin

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inhibitors) are two distinct groups of short-chain carbohydrates and proteins found in wheat that can contribute to IBS, particularly in sensitive individuals (Boakye et al., 2023). Consequently, there is presently a growing demand for the development of new varieties that can adapt to changing climate conditions (IPCC, 2014; Lopes et al., 2015), enhance and maintain genetic diversity (Esquinas-Alcázar, 2005; Swarup et al., 2021), and meet consumer preferences for health-promoting wheat products with enhanced and/or modified physical and nutritional qualities. Such improvements aim to reduce negative health impacts, including allergic reactions and IBS symptoms.

Conventional plant breeding has been a foundational agricultural practice in Europe and remains a sustainable method for improving crop end-use qualities, including physical and nutritional attributes (Johansson et al., 2023). Modern wheat varieties, which dominate global cultivation, are the result of such plant breeding technologies. These developments have advanced the understanding of genetic mechanisms and the roles of numerous genes/alleles in influencing key physical and nutritional traits in wheat. These traits include taste, flavour, and aroma (Quílez et al., 2006; Pico et al., 2015); high grain protein content; minerals (Uauy et al., 2006; Wiebe et al., 2010; Crespo-Herrera et al., 2017); phytochemicals (Tian et al., 2022); and amino acid profiles (Fang et al., 2022). With conventional plant breeding, desirable traits in wheat can be identified, utilised, and developed, allowing for physical and nutritional improvement.

Besides modern wheat varieties, there is also cultivation of ancient wheat/cereals. Unlike modern wheat, these ancient wheat/cereals constitute a broad range of varieties developed without the use of contemporary plant breeding interventions (Camacho Villa et al., 2005). However, the introduction of modern varieties in the 20th century led to the decline of ancient cereals (in the Global North, including Sweden) (Ortman et al., 2023; Newton et al., 2011). Recently, ancient wheat/-cereals have regained increased interest among growers, consumers and industrial stakeholders, not least as they have been reported to hold specific sustainability attributes (Veteläinen et al., 2009; Boukid et al., 2018; Mahon et al., 2016; Wendin et al., 2020; Zamaratskaia et al., 2021). Nevertheless, consumer awareness of ancient cereals, particularly specific varieties such as Dinkel, Emmer, Einkorn, etc., remains relatively low compared to their familiarity with conventional wheat cultivars (Wendin et al., 2020).

Ancient cereals are recognised for a wide range of beneficial traits, such as stability and resilience to extreme weather conditions (Newton et al., 2011; Yahiaoui et al., 2014), high genetic diversity (Kingsbury, 2011), and desirable taste and health-promoting characteristics (Zamaratskaia et al., 2021; Johansson et al., 2021). While these qualities have primarily been discussed in the context of expanding the cultivation of ancient cereals, recent findings suggest that incorporating genetic material from ancient cereals into modern wheat varieties could enhance their traits and overall performance (Haas et al., 2019). Current plant breeding programmes prioritise disease resistance and high yield, often at the expense of physical and nutritional value (Helguera et al., 2020). Until now, these desirable qualities of ancient wheat/cereals have mainly been discussed in the context of expanding the production of ancient cereals per se. However, recent findings suggest that novel modern wheat varieties could gain significant advantages from integrating genetic material from ancient cereals.

An aggravating circumstance to such developments is consumer attitudes, particularly food technology neophobia, a reluctance to try foods developed using new technologies (Evans and Cox, 2006; Evans et al., 2010; Siegrist and Hartmann, 2020). Thus, the bare use of technology in food production and development is often perceived as a contradiction (Giordano et al., 2018). Instead, food naturalness is of high importance for these consumers, both during the cultivation process, as well as in relation to technologies used in production (Roman et al., 2017). To choose ancient cereals instead of modern varieties can thus be interpreted as an expression of a consumer trend (in developed countries), reflecting an interest in novel products and tastes connected to principles such as artisanal and "unmodified". These preferences align closely with the findings of Longin and Würschum (2016), who argue that the rediscovery and reintroduction of ancient species resonate with this consumer trend. Closely connected to the idea of naturalness is also the concept of "nostalgia", associated with food being seen as true and authentic (Dimara and Skuras, 2005).

As previously described, modern plant breeding technology and its achievements hold the possibility to transfer desirable characteristics from ancient cereals to novel varieties, and thus, e.g. help mitigate antinutrients and introduce resilient qualities (e.g. drought resistance) from ancient to modern varieties. It could, however, be assumed that the idea of using plant breeding in the context of ancient cereals may be perceived as contradictory, or even controversial, among consumers and actors linked to the cultivation and utilisation of ancient cereals. This perception likely arises from the dominant narrative surrounding ancient cereals, which has often been to actively reject modern varieties and plant breeding technologies (Louwaars and Jochemsen, 2021).

Considering the strong emphasis on technology in relation to plant breeding, it could thus be argued that plant breeding stands in stark contrast to both naturalness and nostalgia. However, it should be emphasised that studies have identified a great diversity in consumer acceptance for different food technologies (Siegrist, 2008), with higher acceptance of, e.g. aquaponics (Giacalone and Jaeger, 2023) compared to genetically modified (GMO) foods (Eurobarometer, 2019; Siegrist and Hartmann, 2020). Previous studies also stress that the future success of high-tech production systems depends on the ability to overcome consumer rejection and neophobic reactions to such products, which are often perceived as unnatural (Broad et al., 2021; Anders et al., 2021).

The importance of plant breeding technology in mitigating the effects of climate change has been addressed by the European Commission in the Farm to Fork (F2F, 2020) strategy, which states that innovations in plant breeding and crop production can contribute to a more sustainable food system (F2F, 2020). However, since plant breeding is a tool that evidently builds on the use of technology, this underscores the importance of taking consumer acceptance into account to fully realise the potential benefits of this technology.

To summarise, ancient cereals may possess qualities that are beneficial to consumers and can enhance conventional wheat varieties. However, incorporating these qualities into modern varieties requires plant breeding interventions. This development may face challenges due to a lack of consumer acceptance and negative attitudes towards such products. Furthermore, little is known about consumers' attitudes and beliefs regarding foods developed using these technologies. Building on this contextual backdrop, this study aims to explore the awareness and attitudes of Swedish consumers towards conventional plant breeding, and the specific case of crossing conventional varieties with ancient varieties to transfer genes of interest.

In order to answer the overall aim, the following research questions were formulated.

RQ1: What qualities do consumers rank as important or less important in the context of plant breeding?

RQ2. How does acceptance of plant breeding differ by age, gender and education?

RQ3. How aware are consumers of ancient cereals, and does this awareness differ by gender, age or education?

RQ4. What attitudes and beliefs do consumers express towards eating modern cereals or cereals developed by crossing ancient cereals with conventional cereals?

RQ5. What is the impact of age, gender, education and plant breeding neophobia on attitudes towards eating cereals developed through plant breeding or by crossing modern and ancient cereals?

2. Method

2.1. Survey participants

Data were collected during September 2023 in Sweden using an online questionnaire in Swedish (consumer panel, provided by PFM Research, Sweden). Measures were taken to ensure equal representation across gender and age categories. Implementation of the survey followed the Swedish University of Agricultural Sciences' policy for processing personal data (https://www.slu.se/en/about-slu/contact-slu/personal-data/). The data were coded prior to delivery to ensure anonymity. The general international code and guidelines on market and social research established by the International Chamber of Commerce (ICC/ESOMAR, 2016) were followed.

The questionnaire covered six themes (described in detail below, 3.2–3.6): 1. demographics (gender, age, education), 2. ranking of qualities that can be enhanced by plant breeding, 3. Attitudes and beliefs towards eating cereals developed through plant breeding, 4. Plant breeding neophobia (PNB), 5. Awareness of ancient cereals (e.g. Dinkel, spelt, Einkorn, Emmer) and finally 6. Attitudes and beliefs towards eating cereals resulting from crossing (through plant breeding) ancient cereals with modern varieties.

In total, 1000 complete datasets were registered and used for the analysis. Demographic information (gender, age and level of education) is presented in Table 1. Due to the low number of respondents in the category "Other" (N = 1), results are presented only for men and women. The respondents' age ranged from 18 to 90, with a mean age of 48 years (SD = 18.1). When comparing the study sample to the Swedish population at large, the gender ratio was consistent with the Swedish population at large (SCB, 2021). However, the age distribution deviated slightly, with a higher representation of older participants compared to the population at large. In terms of education, the study sample consisted of a slightly more educated group compared to the general population.

2.2. Ranking of qualities that can be enhanced by using plant breeding

Participants were asked to identify qualities they believe could benefit from the application of conventional plant breeding in developing cereals (wheat, barley, oats and rye). To ensure a common understanding of conventional plant breeding, all respondents were provided with a short text (developed by the project team):

> '*Conventional plant breeding refers to the changes that humans have made, and are making, to grains (wheat, barley, oats and rye) to adapt them to our needs and preferences. Conventional plant breeding does not include technologies used in GMO (genetically modified organism). Plant breeding can be used to develop a variety of qualities in cereals (wheat, barley, oats and rye)*'.

Table 1
Demographic characteristics of the study sample (N = 999) in relation to the Swedish population (SCB, 2021).

	Study sample		Swedish population
	N	%	%
Gender			
Men	502	50.2	50
Women	497	49.7	50
Age groups			
(1) 18–24 years	82	7.2	8
(2) 25–34 years	162	16.2	14
(3) 35–49 years	250	25.0	19
(4) 50–64 years	275	27.5	18
(5) 65 and older	230	23.0	20
Education			
Elementary school	48	4.8	11
High school	338	33.8	45
Post-secondary education (not university)	176	17.6	–
University	437	43.7	44

Respondents were then presented the following 13 qualities (multiple choices allowed): taste, texture, appearance, nutritional content, contributes to your health, contributes to sustainability, ensures that harvests become larger (yield), makes crops resistant to diseases and pests, crops can withstand, for example, drought, heavy rain, heat or cold, cereals can be grown with less pesticides, properties that make it easy for the industry to further refine the product, removes substances that cause some people to be allergic to the product, possible to grow across all regions of Sweden (from north to south) and finally, the option (14): none of the above.

2.3. Attitudes and beliefs towards eating cereals developed by conventional plant breeding

To assess beliefs and attitudes towards eating cereals developed through conventional plant breeding, connotative meaning was measured using a semantic differential test (Funk et al., 2020; Hartmann et al., 2018; Michel et al., 2021). Sixteen adjectives were presented as eight bipolar pairs. The question was formulated as follows: For me, eating cereals developed by using plant breeding is: bad | good, uncomfortable | comfortable, negative | positive, untasty | tasty, unhealthy | healthy, useless | useful, unsafe | safe, undesirable | desirable. Respondents were provided with a sliding scale, ranging from 0 to 100, for each pair, in line with the implementation by Michel et al. (2021). Participants marked their answer by dragging a cursor along a scale to reflect their position.

2.4. Plant breeding neophobia (PBN)

To measure neophobia (negative attitudes) towards plant breeding, a Plant Breeding Neophobia Scale was developed. The original scale, which was designed to measure food technology neophobia (Cox and Evans, 2008), was modified here to evaluate neophobia towards plant breeding specifically, instead of food technology. To our knowledge, this is the first study to adopt and modify this scale for evaluating attitudes towards plant breeding. Questions related to information/media were deselected, as this area was not deemed relevant to the study's objectives. The included items were rated on a 5-point Likert scale, ranging from strongly disagree (1) to strongly agree (5), with higher values indicating higher levels of plant breeding neophobia. Prior to answering the questions, participants were reminded of the definition of conventional plant breeding (see 3.2). Eleven questions were included, with items marked (R) reverse-coded for analysis. Prior to further calculations, Cronbach's alpha was calculated, yielding a coefficient of .89.

1. There are plenty of tasty foods available, so we don't need to use plant breeding to produce more.
2. The benefits of plant breeding are often grossly overstated.
3. Plant breeding decreases the natural quality of food.
4. There is no sense in using plant breeding to develop new food because the ones I eat are already good enough.
5. Plant breeding is something I am uncertain about.
6. Societies should not depend heavily on plant breeding to solve its food problems.
7. Plant breeding may have long-term negative environmental effects.
8. It can be risky to switch to newly developed plant varieties too quickly.
9. Foods developed through plant breeding are unlikely to have long-term negative health effects (R).
10. New products created using plant breeding can help people maintain a balanced diet (R).

11 Pant breeding gives people more control over their food choices (R).

2.5. Awareness of ancient cereals and attitudes towards eating cereals originating from a cross between modern and ancient varieties

Awareness of ancient cereals was assessed through the question: Are you aware of ancient cereals, e.g. Dinkel, spelt, Einkorn, Emmer? Respondents could select either yes or no.

Since it was assumed that not all respondents would be aware of ancient cereals, an explanation was provided before presenting questions relating to attitudes and beliefs:

Modern varieties of cereals have been changed through the use of conventional plant breeding. Ancient grains (e.g. Dinkel/spelt, Einkorn, Emmer) form a category of cereals that have not been changed by such plant breeding interventions (Giambanelli et al., 2013). Ancient grains are assumed to have good nutritional and taste qualities (Zamaratskaia et al., 2021) and be resistant to, for example, drought (Stagnari et al., 2008). These properties could be beneficial even for modern types of grain. Crossing cultural cereals with modern varieties can optimise qualities and characteristics in new cereals. Such a crossing method is often used in conventional plant breeding.

To assess beliefs and attitudes towards eating cereals developed through crossing conventional plant breeding, connotative meaning was assessed through a semantic differential test, following the method described in 3.3. The statement was formulated as: For me, eating cereals developed by crossing ancient cereals with modern varieties seems to be: bad | good, uncomfortable | comfortable, negative | positive, untasty | tasty, unhealthy | healthy, useless | useful, unsafe | safe, undesirable | desirable.

2.6. Statistical evaluations

Calculations of descriptives (mean values and frequencies), Pearson correlations, independent samples t-tests, one-way between groups ANOVA, Chi-square Test for independence, paired samples *t*-test and linear regression analysis, were conducted in SPSS (version 29) (IBM; USA). A detailed indication of usage is provided in the results section (3.1-3.5).

3. Results

3.1. Qualities consumers rank as important and less important when using plant breeding

The results (see Table 2) show that the highest ranked qualities (for using plant breeding) are mainly related to production and cultivation.

Table 2
Consumers' ranking of areas where they think it is good to use plant breeding (ranking high (1)-low (13)). Multiple choices were allowed.

Description of quality	N
1. That what is grown is resistant to diseases and pests	560
2. That cereals can be grown with less pesticides	557
3. That what is grown can withstand, for example, drought, heavy rain, heat or cold	488
4. Nutritional content	487
5. That the harvests become larger (yield)	470
6. Contributes to sustainability	470
7. That it is possible to grow across all regions of Sweden (from north to south)	432
8. Taste	412
9. Contributes to your health	383
10. Texture	282
11. Properties that make it easy for the industry to further refine the product	263
12. Removes substances that cause some people to be allergic to the product	249
13. Appearance	186
14. None of the above	121

These include resistance to diseases and pests, reduced use of pesticides, and resistance to environmental stresses such as drought, rain, heat and cold. Yield and nutritional content are also highly valued. Industry-related qualities, the removal of allergic substances and appearance, on the other hand, are ranked the lowest. Among all respondents, 88 % indicated at least one of the listed qualities (1–13) as relevant; however, 12 % selected option (14), indicating that none of the qualities were relevant to the use of plant breeding. The composition of respondents in terms of gender, age, education and levels of plant breeding neophobia was explored to understand whether this subgroup deviated significantly from the population at large. The results showed that 41 % were men and 59 % were women, with a mean age of 51.65 years. Their education levels were as follows: elementary school 6.6 %, high school 35.5 %, post-secondary education (not university) 24 %, and university 34 %. The mean level of plant breeding neophobia in this group was 3.47, *SD* = .72. Compared to the general population, this group contained more women, was slightly older, had a marginally lower level of education, and finally, exhibited a higher degree of plant breeding neophobia (compared to results presented in Table 1).

The relationships between the 13 qualities were further investigated using a matrix of Pearson correlations. Preliminary analyses were performed to ensure that the assumptions of normality and linearity were not violated. The results (see Table 3) reveal strong correlations between several qualities (marked in red in Table 3), representing three quality clusters: 1) sensory-related qualities (taste, texture and appearance); 2) health and nutrition; and 3) cultivation-related qualities (resistance to pests and adverse weather conditions and reduced use of pesticides).

3.2. Differences in plant breeding neophobia due to age, gender and education

To calculate the differences between men and women, an independent samples *t*-test was conducted. The results showed that men expressed a significantly lower plant breeding neophobia compared to women ($t(997) = -6.17$, $p=<.001$(two-tailed)). To explore differences between the age groups and levels of education, one-way between groups ANOVAs were conducted. There was no statistically significant difference among the five age groups $F(4, 994) = 1.95$, $p = .1$. However, a significant difference at the $p < .001$ level was identified for education: $F\ (3,\ 995) = 6.22$, $p= < .001$. The effect size, calculated using eta squared, was .02, indicating that the actual mean differences between the groups were quite small. Nonetheless, post-hoc comparisons using the Tukey HSD test indicated that the mean score for elementary school was significantly different from that for university ($p = .01$) and that the university group also differed significantly from the post-secondary education group ($p = .01$). A summary of the results is provided in Table 4.

3.3. Consumer awareness of ancient cereals and differences by gender, age and education

Consumer awareness of ancient cereals differed among various groups of respondents (Table 5). In general, more respondents (57.4 %, N = 573) were aware of ancient cereals (e.g. Dinkel/spelt, Einkorn and Emmer) compared to those who were not aware (42.6 %, N = 426). To examine associations between gender, age and education, Chi-Square Tests for independence were conducted for each of these demographic factors.

The results revealed no significant associations between gender and awareness of ancient cereals, χ^2 (1, n = 999) = 1.73, $p = .18$, $phi = -.04$ (with Yates' Continuity Correction). The outcome for age revealed a significant association between age and awareness of ancient cereals, χ^2 (4, n = 999) = 15.51, $p = .004$, $phi = .13$ (with Pearson Chi-Square). This indicates that awareness of ancient cereals was higher among older respondents compared to younger ones. Finally, for education, the result revealed a significant association with awareness, χ^2 (3, n = 999) =

Table 3
Correlations between the consumer ranking of 13 qualities (small = .10-.29, medium = .30–49, large = .50–100).

Table 3. Correlations between the consumer ranking of 13 qualities (small= .10-.29, medium= .30-49, large= .50-100).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1.Taste	-												
2.Texture	.56**	-											
3.Appearance	.40**	.50**	-										
4.Nutritional content	.40**	.34**	.22**	-									
5. Contributes to health	.38**	.34**	.24**	.50**	-								
6.Sustainability	.27**	.26**	.16**	.41**	.40**	-							
7. Harvests become larger	.22**	.30**	.24**	.25**	.17**	.25**	-						
8. Resistance to diseases and pests	.22**	.20**	.17**	.28**	.16**	.30**	.43**	-					
9. Withstands e.g. drought, heavy rain, heat or cold	.23**	.21**	.16**	.27**	.17**	.34**	.40**	.58**	-				
10.Can be grown with less pesticides	.23**	.20**	.14**	.33**	.26**	.35**	.32**	.54**	.50**	-			
11. Make it easy for the industry to further refine the product	.22**	.30**	.27**	.22**	.23**	.20**	.37**	.33**	.35**	.24**	-		
12. Remove substances that cause allergies	.21**	.23**	.25**	.24**	.31**	.29**	.21**	.29**	.32**	.32**	.33**	-	
13. Possible to grow across all regions of Sweden (from north to south)	.22**	.23**	.16**	.28**	.25**	.36**	.31**	.33**	.39**	.44**	.29**	.36**	-

Table 4
Results for plant breeding neophobia (PBN), separated by gender, age and education. Scale of PBN (1–5), 1 = very positive to plant breeding, 5 = very negative to plant breeding.

	N (999)	Plant breeding neophobia
Gender		
Men	502	2.80 ± .76
Women	497	3.08 ± .70
Age groups		
(1) 18–25 years	82	3.10 ± .51
(2) 26–34 years	162	2.88 ± .65
(3) 35–49 years	250	2.99 ± .73
(4) 50–64 years	275	2.92 ± .76
(5) 65 and older	230	2.88 ± .85
Mean value age	999	2.94 ± .74
Education		
Elementary school	48	3.18 ± .58
High school	338	2.97 ± .71
Post-secondary education (not university)	176	3.05 ± .69
University	437	2.83 ± .78

19.34, p=<.001, $phi = -.14$ (with Pearson Chi-Square). This suggests that awareness was higher among respondents with a higher level of education.

3.4. Consumer attitudes and beliefs towards eating modern varieties vs eating crossbreeds of modern and ancient cereals

To answer RQ4 and explore differences in attitudes and beliefs towards: a) eating (modern) cereal developed through conventional plant breeding and b) eating cereal resulting from a cross between ancient cereals and modern varieties, semantic differential scales (mean values with 95 % confidence intervals) were calculated. See Appendix for calculations for a and b. The implementation is in line with Michel et al. (2021). The results are presented in Fig. 1 and illustrate that for both a) and b), all eight pairs fall within the neutral or slightly positive range.

To identify significant differences in expressed attitudes and beliefs towards a) and b), paired samples t-tests were conducted for the two alternatives and the eight adjective pairs; see Appendix for an overview of the calculations. Significant differences were found for three adjective

Table 5
Results for awareness (yes/no) of ancient cereals, separated by gender, age and education.

	Awareness of ancient cereals	
	Yes 573 (57.4 %)	No 426 (42.6 %)
Gender		
Men	277 (55.2 %)	225 (44.8 %)
Women	296 (59.6 %)	201 (40.4 %)
Age		
(1) 18–25 years[a]	35 (42.7 %)	47 (57.3 %)
(2) 25–34 years[a,b]	80 (49.4 %)	82 (50.6 %)
(3) 35–49 years[b,c]	147 (58.8 %)	103 (41.2 %)
(4) 50–64 years[c]	167 (60.7 %)	108 (39.3 %)
(5) 65 and older[c]	144 (62.6 %)	86 (37.4 %)
Education		
Elementary school[a]	22 (45.8 %)	26 (54.2 %)
High school[a,b]	168 (49.7 %)	170 (50.3 %)
Post-secondary education (not university)[a,b,c]	102 (58.0 %)	74 (42.0 %)
University[c]	281 (64.3 %)	156 (35.7 %)

[a,b,c] $p < .05$ (2-tailed).

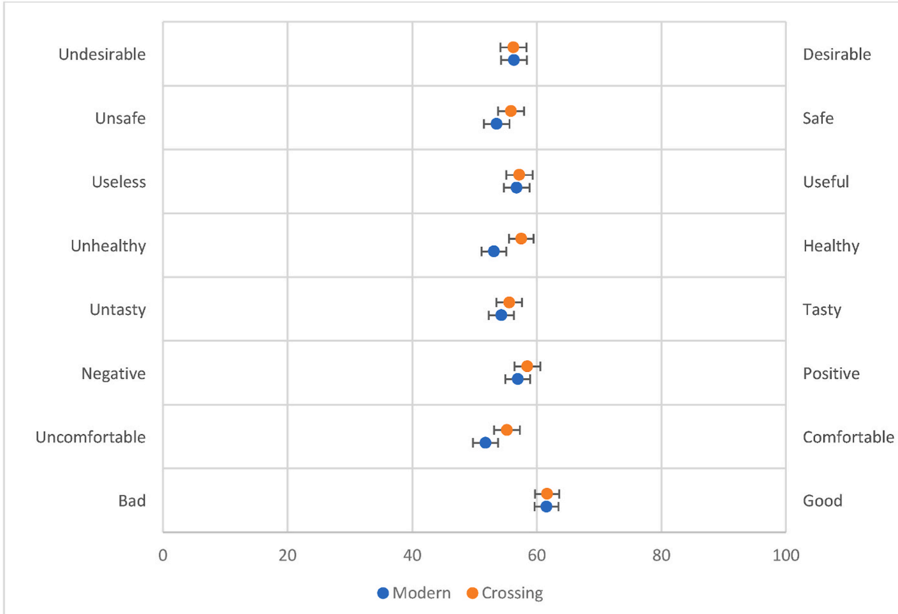

Fig. 1. Differences in attitudes and beliefs towards eating (modern) cereal developed through conventional plant breeding vs eating (crossing) cereal resulting from a cross between ancient cereals and modern varieties. Semantic differential scales (mean values with 95 % confidence intervals) for the two alternatives are presented.

pairs, indicating that when conventional wheat is crossed with ancient varieties, the product is believed to be significantly more comfortable, healthy and safe to eat compared to the conventional modern variety.

3.5. The impact of plant breeding neophobia on attitudes towards eating conventional cereals or crossbreeds between ancient and modern varieties

To explore the impact of plant breeding neophobia, age, gender and education on attitudes towards eating cereals produced through conventional plant breeding, as well as those resulting from a cross between ancient grain and modern varieties, linear regression was conducted. The results are presented in Table 6. The findings are separated into two categories: 1) attitudes towards eating conventional modern varieties and 2) attitudes towards eating crossbreeds (a cross between modern and ancient cereals), in relation to the impact of education, gender, age and plant breeding neophobia. These attitudes were measured based on the mean values for respondents' attitudes towards either eating cereals developed through plant breeding and attitudes towards eating cereals resulting from a cross between modern and ancient cereals, also developed through plant breeding.

Attitudes towards eating conventional cereals developed through plant breeding differed significantly by level of education, with respondents who had elementary school as their highest educational level showing lower attitudes compared to the baseline (university as the highest educational level). The significant prediction for gender shows that attitudes were negatively predicted if the respondent was a woman. For age, the results show that increasing age had a negative effect on attitudes. Finally, plant breeding neophobia negatively predicted attitudes towards eating cereals developed through plant breeding.

For attitudes towards eating cereals resulting from a cross between modern and ancient cereals, there were significant differences based on educational backgrounds, with all educational levels showing lower attitudes compared to the baseline (university as the highest educational level). Gender did not have any significant prediction, but age showed a negative prediction, meaning that increasing age had a negative effect on attitudes here, too. Additionally, plant breeding neophobia negatively predicted attitudes towards eating cereals developed through the crossing of modern and ancient cereals.

4. Discussion

This study analysed Swedish consumers' awareness of ancient cereals, as well as attitudes towards conventional plant breeding and the specific case of crossing conventional varieties with ancient varieties using plant breeding. Several factors and qualities were explored, including the ranking of qualities that can be developed through plant breeding, attitudes towards eating cereals developed through plant breeding, plant breeding neophobia, awareness of ancient cereals and, finally, attitudes towards eating cereals developed by modern plant breeding or cereals resulting from the crossing of ancient and modern varieties. Interestingly, the study was able to clearly identify differences among various groups of respondents regarding their attitudes towards

Table 6
Results of linear regression analysis for attitudes towards: 1: Eating conventional modern varieties and 2. Eating crossbreeds (a cross between modern and ancient cereals) in relation to the impact of education, gender, age and plant breeding neophobia.

Predictor	1.Conventional					2.Crossing				
	B	SE	Beta	*t*	*p*	*B*	SE	Beta	*t*	*p*
(constant) University	131.72	3.91		33.65	<.001	129.58	4.17		31.09	<.001
Elementary school	−9.85	3.62	−.07	−2.72	.01	−15.34	3.85	−.11	−3.98	<.001
High school	−3.22	1.73	−.05	−1.86	.06	−6.04	1.84	−.10	−3.28	.001
Post-secondary education (not university)	−3.34	2.12	−.05	−1.60	.11	−8.25	2.26	−.11	−3.65	<.001
Gender	−3.69	1.54	−.07	12.40	.02	.77	1.64	.01	.47	.64
Age	−.26	.04	−.16	−6.00	<.001	−.25	.05	−.14	−5.27	<.001
Plant breeding neophobia	−20.14	1.04	−.52	−19.39	<.001	−19.19	1.11	−.48	−17.34	<.001

the attributes analysed.

In general, participants clearly ranked qualities linked to production and cultivation (i.e. resistance towards diseases and pests, reduced use of pesticides, resistance to drought, rain, heat and cold), yield and nutritional content as those of highest importance and most influenced by plant breeding activities. In contrast, participants ranked industry-connected qualities, the removal of allergic substances, and appearance as the areas where plant breeding contributes the least. Historically, plant breeding activities have centred around issues related to increased yield, which also includes breeding for resistance to pests and diseases (Johansson et al., 2023). Pests and diseases are well known to reduce yield, contributing to the high interest in these traits from plant breeders, although these traits are also linked to a reduction in pesticides use (Russell, 2013). Recent predictions of climate changes have called for increased plant breeding efforts targeting robust crops that can withstand future weather conditions without a reduction in yield (Zivancev et al., 2024). Additionally, consumer attitudes towards novel food alternatives, health-promoting consumption and sustainability concerns may influence the future goals of plant breeding (Johansson et al., 2024).

As shown in previous studies (e.g. Götze and Brunner, 2021), the qualities evaluated here were often chosen by the respondents in combinations, i.e. if a respondent marked one of the production and cultivation qualities as an important outcome of plant breeding, the same respondent typically also marked the other production and cultivation qualities. This type of response from the respondents resulted in three distinct clusters of the evaluated qualities: one for sensory qualities, a second for health and nutrition, and a third relating to cultivation. Thus, the findings of this study emphasise the importance of understanding the obtained results when analysing data from studies based on questionnaires. The fact that respondents' answers cluster in this way may impact the subsequent statistical treatment of the data, as summarised in previous publications (Bynen, 2012).

Interestingly, the result revealed a group (12 %) who felt that none of the suggested qualities were relevant for plant breeding. Compared to the general population of respondents, this group contained more women, was slightly older, had lower levels of education, and finally, exhibited higher plant breeding neophobia. The finding that age has an impact is in line with results presented by Lyndhurst (2009), who explained that younger persons tend to be less concerned, more positive, and see more benefits in food technology. Additionally, the fact that this group generally had negative attitudes towards plant breeding might indicate the reason why these respondents did not see the value in developing qualities through plant breeding. Considering the ongoing effects of climate change, solutions to mitigate these impacts may require rapid implementation. However, the introduction of new technologies that collide with consumers' understanding of safe and sustainable food could lead to consumer non-acceptance (Spendrup et al., 2024).

Besides understanding consumer attitudes towards plant breeding, an important part of this study was to establish a tool that enables the evaluation of consumer neophobia of plant breeding per se, rather than the more comprehensive perception of technology. To reach such a result, the food technology neophobia scale by Cox and Evans (2008) was applied and modified. To our knowledge, this is the first study to adopt this scale in such a way that it explicitly targets neophobia towards plant breeding. Based on the result of the Cronbach's alpha coefficient (.89), we argue that this modification provides a robust and trustworthy tool for examining consumer neophobia towards plant breeding.

Turning to the results for plant breeding neophobia (PBN), a significant difference was found based on gender and education, while age had no significant effect. Thus, women expressed higher PBN compared to men, and PBN was lower among participants with a university education compared to those with lower levels of education. Considering that this is the first study to explicitly examine plant breeding neophobia, there are no previous findings available for corroboration. However, when examining studies on food technology neophobia, it can be stated that the findings for gender in our study are in line with those presented by Schnettler et al. (2017) and Martins et al. (2019), who found that women tend to express higher food technology neophobia. The lack of a significant link to age aligns with the findings presented by Chen et al. (2013), Cattaneo et al. (2019) and Proserpio et al. (2020). It can also be concluded that the effect of education on food technology neophobia has been identified by Evans et al. (2010), Ortega et al. (2022) and Vidigal et al. (2015). However, as explained in the review by Wendt and Weinrich (2023), there are conflicting results regarding the impact of sociodemographic variables, highlighting the need for further research to clarify these matters.

The second major theme of the study focused on ancient cereals. The results for awareness showed that almost 60 % (57.4) of the respondents were aware of ancient cereals. Comparing these results with previous findings, it can be concluded that general awareness in the current study is lower compared to the results presented by Wendin et al. (2022) (for Swedish consumers), yet higher than the 47 % reported by Teuber et al. (2016) (for German consumers). It was also shown that awareness did not differ by gender, but was higher among older participants and those with higher levels of education. No previous results were found for awareness of ancient cereals in relation to gender, age and education, which hampers corroboration with these findings. However, it could be argued that the link between age and awareness reflects the fact that these cultivars were more common in the past (Ortman et al., 2023; Newton et al., 2011), and that this knowledge remains anchored within the older population. It could also be argued that the impact of education may align with findings suggesting that consumption of food with environmental and social attributes (Tobi et al., 2019), as well as handcrafted food (Rivaroli et al., 2020), are higher among consumers with a higher level of education.

Looking at attitudes and beliefs towards eating modern cereals (developed through plant breeding) and cereals resulting from a crossing between modern and ancient varieties, the results indicated that attitudes and beliefs fell within the neutral or slightly positive range. This suggests that none of the assessed attitudes and beliefs were negatively linked to plant breeding (for either system). Surprisingly, the results also revealed that when modern varieties were crossed with ancient cereals, the resulting products were perceived as more comfortable, health-promoting and safe to eat compared to the conventional varieties. One explanation for this may be a strong association between ancient cereals and qualities such as health and sustainability (Teuber et al., 2016; Zamaratskaia et al., 2021; Shah et al., 2021). It is thus argued that these positive qualities may overshadow any expected consumer scepticism (Siegrist, 2008) between technology (in this case plant breeding) and health promoting, nutritious and tasty food (Siegrist and Hartmann, 2020; Giordano et al., 2018). This suggests that consumers do not perceive a contradiction in combining ancient cereals with modern varieties; instead, such an approach appears to be viewed as a significant improvement, resulting in products that are perceived as more comfortable, health-promoting and safe to eat.

The last part of the study explored the impact of education, age, gender and PBN on attitudes towards eating (modern) cereals developed through conventional plant breeding. The results showed that being a young male with a university education positively predicted attitudes, whereas PBN negatively predicted attitudes towards eating food developed through plant breeding. Similar results were found for attitudes towards eating cereals developed through the second alternative, a crossing of modern and ancient cereals, with the exception of gender, which was not a significant predictor in this case. The identified effect of gender on attitudes towards plant breeding in the context of modern varieties aligns with findings from Spendrup et al. (2021). However, it is interesting that this effect could not be found for the crossing alternative. Taken together, these findings suggest that ancient cereals contribute qualities that affect attitudes differently in relation to gender compared to conventional modern varieties.

The results also indicate that attitudes towards eating cereals developed through both systems (modern and crossing) were higher among younger participants. This result contradicts findings by Spendrup et al. (2012), who concluded that older consumers (aged >65) were more positive towards conventional plant breeding. However, other studies have shown that acceptance of novel food technologies is generally higher among younger consumers (Lyndhurst, 2009). It can also be stated that higher education predicts more positive attitudes towards both systems. This is congruent with results presented by Allum et al. (2008) and Lewandowsky and Oberauer (2016), who identified higher education as a significant predictor of acceptance for controversial science topics.

Lastly, the finding that plant breeding neophobia predicts attitudes towards these two systems highlights that not all consumers see the benefits of plant breeding. This should be something to consider when communicating about the use and development of products originating from this technology. Increasing consumer acceptance and appreciation for the potential of plant breeding is crucial for ensuring food security in the context of a changing climate (Lammerts et al., 2018). Plant breeding technologies are expected to be of high importance when developing cultivars and crops that are resilient and adapted to new cultivation conditions brought about by climate change (Hickey et al., 2019; F2F, 2020).

One limitation of this study is that we did not give consumers actual products to taste and then follow up by interviews to explore their expressed attitudes and beliefs. Such an approach would likely have yielded richer insights into the pros and cons of the two systems. Furthermore, the design of the study should have been slightly modified by dividing participants into two groups, with one group focusing solely on modern varieties and the other on crossings. Additionally, the modified food technology neophobia scale by Cox and Evans (YEAR) should ideally have been pretested before its actual implementation in the study. Nevertheless, the outcome provides a robust impression. The findings of this study offer breeders, geneticists, millers, and bakeries essential knowledge and resources to effectively communicate the value of plant breeding and its links to both conventional and ancient varieties. The results are also relevant to policymakers, supporting the implementation of structural features to ensure food security for future consumers in a changing climate.

5. Conclusions

The majority of respondents were aware of ancient cereals, with no differences observed based on gender. However, awareness was higher among older participants and those with a higher level of education. It can also be stated that attitudes and beliefs towards eating modern cereals (developed through plant breeding) and cereals resulting from a crossing between modern and ancient varieties were within the neutral or slightly positive range. Interestingly, the results also showed that when crossing modern varieties with ancient cereals, such products were perceived as more comfortable, health-promoting and safe to eat compared to conventional modern varieties.

It can also be concluded that it is more common to link plant breeding with qualities supporting cultivation and mitigating the effects of climate change, rather than with attributes directly related to the concept of food, eating and personal health. Nevertheless, it was also shown that there are clusters of consumers who recognise other benefits of plant breeding (sensory aspects and health/nutrition aspects). The novel concept developed here, i.e. plant breeding neophobia (PBN), was found to be higher among women, lower among participants with higher educational levels, and did not differ due to age. Thus, being a young male with a university education positively predicted attitudes towards eating food developed through plant breeding, while PBN negatively predicted such attitudes. Attitudes among groups of respondents towards eating cereals developed through a crossing of modern and ancient cereals corresponded to those for food developed through plant breeding, except for gender, where no significant prediction was identified.

6. Implications for gastronomy

Wheat is the most important crop globally when considering land used for production, production amount, amount of trade, number of food products and food security. Accounting for 30 % of the calories and proteins in the human diet, wheat also provides a significant proportion of essential vitamins, minerals and bioactive compounds. Moreover, it affects a number of properties in its food products, such as flavour and nutrition. However, reports are increasing regarding consumers experiencing health-related and allergic reactions to wheat. In parallel, studies on the cultivation of ancient wheat/cereals show that some of these varieties hold specific beneficial traits related to taste and flavour, as well as potential health-promoting benefits, such as reducing adverse reactions to wheat. Consequently, it might be of relevance to transfer positive traits from ancient wheat/cereals into high yielding modern genotypes. In the present study, we explored consumers' attitudes towards using conventional plant breeding (through crossings) to develop new wheat varieties in which traits from ancient wheat are transferred into conventional varieties.

Since this development may be hampered by consumers' negative attitudes towards using technology– in this case, plant breeding– this study sought to identify qualities perceived as positive by consumers. The results indicate that stakeholders could benefit from emphasising values linked to sensory qualities, health, nutrition and sustainability, e.g. improved resistance, reduced use of pesticide, when communicating the benefits of plant breeding to the public. Notably, the respondents in this study did not see any negative effects of crossing modern varieties with ancient cereals. Instead, such crossings seem to add positive qualities to the resulting product. This suggests that using crossings may be a less provocative approach for developing novel wheat varieties that combine high yields, which contribute to food security, with high gastronomic and health-promoting qualities.

CRediT authorship contribution statement

Sara Spendrup: Investigation, Methodology, Writing – review & editing, Conceptualization, Formal analysis, Data curation, Writing – original draft. **Karin Wendin:** Methodology, Formal analysis, Conceptualization, Writing – review & editing. **Julia Darlison:** Writing – review & editing. **Adam Flöhr:** Validation, Formal analysis, Writing – review & editing. **Faraz Muneer:** Writing – review & editing. **Mahbubjon Rahmatov:** Writing – review & editing. **Eva Johansson:** Project administration, Funding acquisition, Writing – review & editing.

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

Differences in attitudes and beliefs towards modern cereals and the crossing of modern cereals with ancient varieties, assessed across eight semantic differentials (mean values with 95 % confidence intervals).

	Modern cereals			Crossing of modern and ancient cereals		
	Mean	Low	High	Mean	Low	High
Bad | Good	61.57	59.64	63.51	61.65	59.72	63.55
Uncomfortable | Comfortable	51.78	49.71	53.86	55.21	53.20	57.23
Negative – Positive	56.96	54.91	59.01	58.49	56.50	60.48
Untasty | Tasty,	54.33	52.30	56.37	55.59	53.57	57.60
Unhealthy | Healthy,	53.12	51.16	55.08	57.52	55.54	59.49
Useless | Useful,	56.77	54.65	58.89	57.20	55.15	59.25
Unsafe | Safe,	53.56	51.47	55.66	55.87	53.81	57.92
Undesirable | Desirable.	56.34	54.25	58.42	56.24	54.17	58.30

Independent *t*-test for the two groups and the eighth pairs.

Semantic differential	To eat grains developed by conventional plant breeding is	To eat grains that is a cross between ancient and modern varieties is	
Scale from 0 to 100	M	M	
Bad – Good	61.57 ± 31.20	61.65 ± 30.82	No significant difference
Uncomfortable – Comfortable	51.78 ± 33.38	55.21 ± 32.51	<.001
Negative – Positive	56.96 ± 33.01	58.49 ± 32.11	No significant difference
Untasty – Tasty	54.33 ± 32.77	55.59 ± 32.44	No significant difference
Unhealthy – Healthy	53.12 ± 31.55	57.52 ± 31.82	<.001
Useless – Useful	56.77 ± 34.18	57.20 ± 32.99	No significant difference
Unsafe – Safe	53.56 ± 33.77	55.87 ± 33.08	.007
Undesirable – Desirable	56.34 ± 33.60	56.24 ± 33.21	No significant difference

Data availability

Data will be made available on request.

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