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MICROECONOMIC DRIVERS OF SUSTAINABLE AGRICULTURAL CONSUMPTION: BREEDING INNOVATION, CONSUMER CHOICE, ENVIRONMENTAL EXTERNALITIES, AND WELFARE IMPLICATIONS

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SUMMARY

Crop breeding innovations with sustainable attributes are crucial for food systems of tomorrow; however, the economic worth of such innovations to producers and consumers has not received substantial assessment. This research aimed to fill up that gap by evaluating the effects of particular breeding-based parameters. Among these are climate resilience and nutrient-use efficiency (NUE) and other factors affecting consumer choice, willingness to pay (WTP), and welfare outcomes in food chains in Turkey and Eastern Europe. The study used the microeconomic model integrating farm-level production data with life-cycle assessment and a discrete-choice experiment (N = 472 consumers). The random-parameter logit model showed that breeding variables were the most influential determinants of market preferences, attributing 21%–35% variance in WTP and consumer welfare, which emerged considerably larger than sustainability labels (1%–3%) and income heterogeneity (4%–20%). Resistant cultivars considerably contributed to consumer welfare, and the producers were surplus by 15.8 index and 10.2 USD/ha, respectively. By providing evidence to breeders and policymakers, integrating climate resilience and NUE into germplasm, the congruent economic benefits reached their development across the entire value chain. This provided a scalable avenue for breeding programs to directly affect the sustainable agricultural consumption.

Keywords: Sustainable agricultural consumption, breeding innovations, agri-food systems, climate resilience, nutrient-use efficiency, discrete choice experiment, economic benefits

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Key findings: Sustainability factors based on breeding innovations were the most significant consumer choice determinants, which enhanced the consumer's willingness to pay and purchase likelihood. The disparity in income diminished the attained welfare of the lower-income consumers, showing distributional bottlenecks to adopting sustainable products.

INTRODUCTION

Agricultural consumption is one of the challenging issues that exist at the crossroads of food security, environmental factors management, and economic well-being. The agri-food chain will be able to deliver adequate, affordable, and nutritious food at the expense of mitigating the detrimental environmental externalities, i.e., greenhouse gas emissions (Behnassi *et al.,* 2024), nutrient runoff, and resource depletion. These develop varied societal costs, which market transactions did not account for (Pengue *et al*., 2018). In this context, sustainable consumption can internalize both environmental and social costs without interfering in economic efficiency and consumer welfare (Liu, 2024).

In food markets, the selection behavior of consumers is an attribute of the product, price, income, and information cue, which incurs the frequent modeling of a random utility framework (Mir-Artigues, 2022). Product differentiation through inherent quality values and extrinsic sustainability indicators like eco-labels aligns with private preferences to social goals (Donato, 2025). Agricultural innovation, such as climate-resilient and nutrient-use efficient crop cultivars, transforms production technologies and environmental footprints, influencing the cost of production and downstream consumer welfare (Nazir *et al.,* 2025). The development of genetic enhancement through traditional breeding and advanced molecular technology has the potential to increase the stability of yield, nutrient-use efficiency, stress tolerance, and quality of products. This can lead to a decrease in the intensity of inputs and the environmental load throughout production systems. Consumer benefits can also materialize from such improvements through lower prices, better nutritional qualities, and increased availability of sustainable food products in the market (Wang et al., 2022). Practical evidence showed consumers are willing to pay more for sustainability (reduced carbon footprints, eco-certification, and improved nutritional quality). Overall, the technological innovations in the production phase and consumer preference formation attained unanimous determination via sustainability (Wang *et al.,* 2022).

In Turkey and Eastern European nations, it is vital to note such a situation offers a specific context for this study because of the heterogeneous agri-food system and varied agricultural modernization rates exposed to the new sustainability consciousness of consumers (Bhagat *et al.,* 2024). The environmental factors' pressure and the market dynamics involved in these areas are unique, too, and that is why the study, based upon the breeding innovations and consumer behavior, is especially relevant to these areas (Campobasso *et al.,* 2025). To begin with, the majority of consumer studies assessed the informational interventions, such as eco-labels, without considering the production technologies that produce these qualities (Sigurdsson *et al.,* 2022).

Second, the studies based on agricultural innovations focus highly on farm-level productivity and profitability, with less study on consumer choice and welfare. The side effects of breeding innovations on the value chain were not encountered (Chopin *et al.,* 2023). Third, despite recognition of environmental externalities, only limited past research incorporated the monetized effects of these externalities into a single welfare construct that included consumer surplus, producer surplus, and environmental costs (Ojha *et al.,* 2025). In light of the above discussion, few studies have been able to quantify the joint effects of breeding innovations, consumer preferences, and environmental factors externalities on welfare using an individual microeconomic model (Pashayev, 2025).

This research aimed to fill up the current gaps by constructing a comprehensive microeconomic model that integrates the breeding innovations, consumer decision, environmental externalities, and welfare outcomes. The study also estimated the comparative effects of breeding-based sustainability characters, label systems, and income heterogeneity on the willingness to pay, purchase probability, and welfare on the agri-food value chain. In particular, the study planned to a) demonstrate that breeding innovations, rather than labeling, determine consumer welfare, b) assess the differences in the impacts of carbon-based and conventional eco-labels, and c) assess whether innovation-based sustainability develops similar incentives for consumers and producers along the value chain.

MATERIALS AND METHODS

Research design

In this research, the use of a microeconomic mixed-method design proceeded. It combined the experimental choice model, observable farm-level data, and secondary environmental factors' impact data to analyze the drivers of sustainable agricultural consumption in Turkey and Eastern European countries. The primary objective was to measure the joint impact of breeding innovations, consumer tastes, and environmental factors' externalities on consumer welfare throughout the agri-food value chain. The model involved a) a discrete choice experiment (DCE) that embodies consumer preferences, b) farm-level production and cost data of conventional and improved crop cultivars, and c) the valuation of environmental externalities with the life-cycle emission coefficients. The presented research took place from 2023 to 2024 in accordance with international guidelines for reproducible economic research.

Population and sampling

The samples comprised consumers, consisting of adult food purchasers aged 18 and above. Employing stratified random sampling served to recruit participants to include income, education, gender, and urban-rural residence, with stratification weighted by the latest national census. The priori power analysis revealed that at least 420 respondents necessitated to identify the 5% difference in willingness to pay at alpha = 0.05 and 80% power in a multinomial logit model. The recruitment of 500 persons sought to address the unanswered cases, with 472 valid responses obtained after quality control.

The data collection depended on 120 conventional crop growers at the farm level with farmers cultivating both conventional and improved cultivars, typified by increased input-use efficiency. The selection of farms continued in two phases. The first phase was a cluster sample across three agro-ecological regions to achieve a heterogeneous production system; inclusion criteria were three years of continuous production records with a verifiable record of input and output. The second was excluding farms with more than 10% missing records.

Materials and instruments

The data comprising consumer preferences came from a structured questionnaire that used a DCE and encompassed the following attributes of breeding innovations (nutrient-use efficiency and drought tolerance), price, environmental footprint labeling, and certification. The Ngene software (Choice Metrics, v1.3), as used, helped develop a D-efficient fractional factorial design with reduced association of attributes.

Concerning farm production, the recording of data occurred on standardized sheets and incurred checking against logbooks. The research obtained data on environmental externalities (greenhouse gas emissions and nutrient runoff) from a peer-reviewed life cycle assessment database that conformed to ISO

14040/44. The entire statistical analysis continued in R (v4.3.1) using the mlogit and lme4 packages.

Procedure

The conduct of the consumer survey proceeded through face-to-face interviews with trained enumerators using a standardized protocol. The respondents practiced the choice examples before the experiment, and they were randomized into sets of choices. Data recorded at each farm included yield, input use, and costs. The status of breeding innovations reached confirmation by seed purchase records and varietal certification. Calculating the magnitude of environmental externalities used emission coefficients for the observed input rates, enabling the estimation of the cost per unit. All data entailed compilation under a high level of confidentiality and integrity.

Data quality control

The screening of internal consistency, dominance behavior, and temporal outliers used consumer responses, excluding the incomplete and poor-quality responses. The data from the different farms reached recording twice, with 15% of the records randomly selected for verification. The study provided yield and input-measuring instruments. The missing data sustained handling via multiple imputations under the missing-at-random assumption, and the use of sensitivity tests served to verify robustness.

Statistical analysis

Consumer choice data entailed modeling using random-parameter logit models that capture heterogeneity in preferences, and their estimation was via maximum simulated likelihood with 1000 Halton draws. Coefficients became perceptions as marginal willingness to pay. The linear mixed-effects random-intercepts models in agro-ecological areas evaluated productivity and cost differences among the conventional and improved cultivars. Placing environmental externalities into a partial welfare framework and monetizing them sought to quantify the net social welfare effects. All the tests were two-sided, with a significance level of $P < 0.05$, with the false discovery rate corrections applied when the number of tests was high. The model's assumptions, such as independence and error distribution, attained verification, with the standard errors and confidence intervals calculated.

RESULTS

Sample characteristics and descriptive statistics

The summary of sample characteristics and descriptive statistics of the consumer dataset is available in Table 1. The analytical samples comprised 3240 observations; the overall respondent age was 41.25 ± 9.77 years old; and the overall education level was 13.93/2.94 years old. The average willingness to pay (WTP) among all the respondents was 3.44 ± 0.69 USD/kg, with the lowest and highest WTPs at 1.12 and 5.51 USD/kg, respectively. The average purchasing power probability was 51.89 ± 6.30, and the consumer welfare index, summarized as the aggregate of the choice model utilities, was 135.67-14.78, revealing a wide range of welfare outcomes across the individuals.

Breeding type, label type, and income group descriptive outcomes

The descriptive statistics incurred disaggregation by breeding type, label type, and income group (Table 2). However, in all the income levels, the products derived from breeding-improved cultivars invariably had greater mean WTP and purchasing power probability and consumer welfare than the traditional and conventional cultivars.

With improved climate-resilient cultivars having a carbon label, the WTP was the highest between the consumers with high incomes (4.50 ± 0.40 USD/kg), and the lowest WTP was evident with the conventional eco labeled products among the low-income consumers (2.68 ± 0.45 USD/kg). There was a

Table 1. Sample characteristics and descriptive statistics (N = 3,240 observations from N = 472 respondents).

Variable	Mean	SD	Min	25th %ile	Median	75th %ile	Max
Age (years)	41.25	9.77	18	34.56	41.21	47.74	70
Education (years)	13.93	2.94	8	11.87	13.92	15.93	22
WTP (USD/kg)	3.44	0.69	1.12	2.98	3.46	3.91	5.51
Purchase probability (%)	51.89	6.30	23.89	47.65	51.97	56.19	73.31
Consumer Welfare Index (units)	135.67	14.78	89.34	125.85	135.89	145.58	197.45

Note: WTP = Willingness to Pay; Consumer Welfare Index = aggregate utility-based welfare composite derived from choice model; and SD = Standard Deviation.

Table 2. Primary outcomes by breeding type, label type, and income group (condensed means).

Breeding Type	Label Type	Income Group	WTP (USD/kg)	Purchase Prob. (%)	Consumer Welfare Index
Conventional	Carbon	High	3.60	51.43	135.39
Conventional	Carbon	Middle	3.23	50.00	132.07
Conventional	Carbon	Low	2.89	47.87	126.87
Conventional	Eco	High	3.37	50.67	132.03
Conventional	Eco	Middle	3.06	48.72	129.14
Conventional	Eco	Low	2.68	46.69	123.52
Climate-resilient	Carbon	High	4.50	58.57	151.05
Climate-resilient	Carbon	Middle	4.11	57.33	147.27
Climate-resilient	Carbon	Low	3.79	56.09	145.24
Climate-resilient	Eco	High	4.29	57.19	147.60
NUE	Carbon	High	4.21	56.26	144.52
NUE	Eco	High	4.02	55.08	142.58

monotonic enhancement in the average purchase probability due to breeding innovations and conventional and improved climate-resilient cultivars producing 46.69%–51.43% and 54.18%–58.57%, respectively. The consumer welfare index was comparable to the highest welfare experienced on improved climate-resilient and carbon-labeled products among the high-income consumers (151.05 ± 11.84). In all the combinations, the income group differences were systematic, where the high-income consumers had better welfare outcomes than the middle- and low-income groups.

Key variables' association

The WTP had a moderate positive relationship with purchase probability (r = 0.489) and consumer welfare index (r = 0.450) (Table 3). Consumer welfare also had a positive correlation with purchasing power probability (r = 0.353). Contrastingly, all the outcome variables showed weak correlations with age and education (r < 0.04). However, there was a nonsignificant linear relationship between sociodemographic variables and preferred outcomes and welfare in the sample group.

A high heterogeneity resulted in consumer preference concerning breeding attributes in the random-parameter logit model. Climate resilience was the strongest driver (β = +0.847, $P < 0.001$), with a WTP premium of +1.18 USD/kg (95% CI: 0.86–1.50). Nutrient-use efficiency also increased WTP by +0.75 USD/kg (95% CI: 0.44–1.07). The positive effect of carbon labeling was weak (+0.37 USD/kg), and eco-labeling had no significant effect (+0.064, p = 0.347). The fit of the model was satisfactory (McFadden pseudo-R^2 = 0.214; Table 4, Panel B).

Table 3. Random-Parameter Logit Model Estimates (N = 3,240 observations; N = 472 respondents).

Attribute	Mean (β)	Std. Dev. (σ)	z-value	p-value	WTP (USD/kg)	95% CI
Climate resilience	+0.847	0.312	6.84	<0.001	+1.18	[0.86, 1.50]
Nutrient-use efficiency	+0.541	0.287	4.73	<0.001	+0.75	[0.44, 1.07]
Carbon label	+0.263	0.198	3.31	<0.001	+0.37	[0.15, 0.58]
Eco-label	+0.064	0.171	0.94	0.347	+0.09	[-0.03, 0.21]
Price	−0.718	—	−9.12	<0.001	—	—
Log-likelihood	−3,847.2					
McFadden pseudo-R²	0.214					
AIC	7,710.4					

Correlation matrix of continuous variables

Variable	Age (years)	Education (years)	WTP (USD/kg)	Purchase Prob. (%)	Consumer Welfare Index
Age	1				
Education	0.001	1			
WTP	-0.027	-0.018	1		
Purchase probability	-0.035	0.001	0.489	1	
Welfare	-0.014	-0.027	0.450	0.353	1

Table 4. Multivariable linear regression for consumer welfare index.

Predictor	β	SE	*P*-value	95% CI
Climate-resilient (vs. conventional)	15.82	0.64	<0.001	14.55–17.08
NUE (vs. conventional)	10.46	0.64	<0.001	9.20–11.72
Eco label (vs. carbon)	-3.68	0.53	<0.001	-4.72 to -2.65
Low income (vs. high)	-7.44	0.64	<0.001	-8.70 to -6.17
Middle income (vs. high)	-3.38	0.64	<0.001	-4.64 to -2.12
Age	-0.01	0.03	0.774	NS
Education	-0.11	0.09	0.233	NS

Breeding and label type and income effect on willingness to pay

A three-way factorial analysis of variance of WTP appears in Table 5x. The significant main effects reached recording for breeding type (F [22142] = 889.34, $P < 0.001$, 0.352), label type (F [12142] = 136.89, $P < 0.001$, 0.027), and income group (F [22142] = 492.78, $P < 0.001$, 0.195). The breeding type explained nearly 35.2% of the overall variance in WTP, being identified as the robust determinant. The accounted factors were income group at 19.5 and label type at 2.7.

The two- and three-way interactions were nonsignificant ($P > 0.05$), enunciating that the effects of breeding innovations, labeling, and income on WTP were additive rather than interactive. These additive patterns also revealed visual confirmation in Figure 1, in which the parallel mean differences in each label type occurred across each type of breeding category.

Influences on reported purchase probability

The analysis of variance of purchasing power probability occurs in Table 5x. Again, the significant main effects were evident with the breeding type (F [22142] = 394.34, $P < 0.001$, $\eta 2 = 0.253$), label type (F [12142] = 42.91, $P < 0.001$, $\eta 2 = 0.014$), and income group (F [22142] = 66.47, $P < 0.001$, $\eta 2 = 0.04$). Breeding type attributed 25.3% of variance in purchase probability, while the income group and label type explained 4.3% and 1.4% of variance, respectively. No significant interaction effects arose, unlike with WTP ($P > 0.30$). However, there was a gradual increase in purchasing power probabilities associated with breeding innovations, with a little visual

Table 5. Summary of three-way ANOVA results for primary outcomes.

Outcome	Factor	F-value	*P*-value	η² (Eta-squared, Effect Size)
WTP	Breeding type	889.34	<0.001	0.352
	Label type	136.89	<0.001	0.027
	Income group	492.78	<0.001	0.195
Purchase probability	Breeding type	394.34	<0.001	0.253
	Label type	42.91	<0.001	0.014
	Income group	66.47	<0.001	0.043
Welfare index	Breeding type	310.89	<0.001	0.211
	Label type	49.33	<0.001	0.017
	Income group	66.81	<0.001	0.045

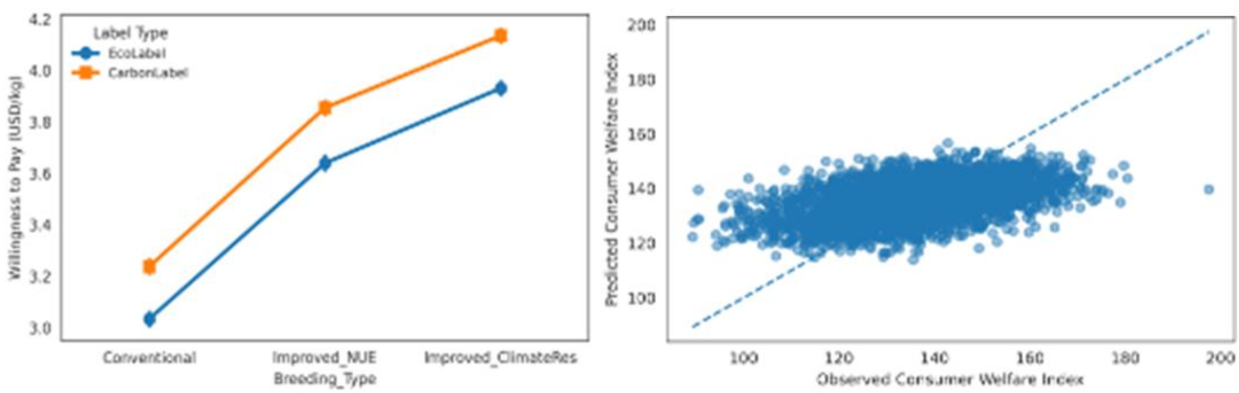

Figure 1. a) Breeding innovation and labeling are additive with respect to the consumer's willingness to pay, and b) Predictive and model fit accuracy of consumer welfare framework.

differentiation observed among the label types within each breeding group, consistent with the nonsignificant interaction effects (Figure 2).

Consumer welfare index implications

The findings of the three-way analysis of variance of the consumer welfare index occur in Table 5x. The main effects appeared to be nonsignificant for breeding type (F [22142] = 310.89, *P* < 0.001, η2 = 0.211), label type (F [12142] = 49.33, *P* < 0.001, η2 = 0.017), and income group (F [22142] = 66.81, *P* < 0.001, η2 = 0.045).

Breeding type accounted for 21.1% of the total variance in consumer welfare, while income group and label type accounted for 4.5% and 1.7%, respectively. Overall, the interaction effects emerged as nonsignificant (*P* > 0.45), which validates the cumulative and independent welfare effects across the factors.

The comparative significance of the drivers shows an outline in Figure 3, which identified the breeding innovations and income as the most influential drivers of welfare heterogeneity.

Consumer welfare multivariable regression analysis

The multivariable linear regression model revealed that improved climate-resilient cultivars significantly increased the consumer welfare index by 15.82 points (*P* < 0.001, 95% CI [14.55, 17.08]), and improved nutrient-use-efficient cultivars increased it by 10.46 points (*P* < 0.001, 95% CI [9.20, 11.72]) compared with conventional cultivars. However, eco-labeling reduced welfare relative to carbon-labeling (β = -3.68, *P* < 0.001). Consumers in low- and middle-income groups showed lower welfare than those in the high-income group,

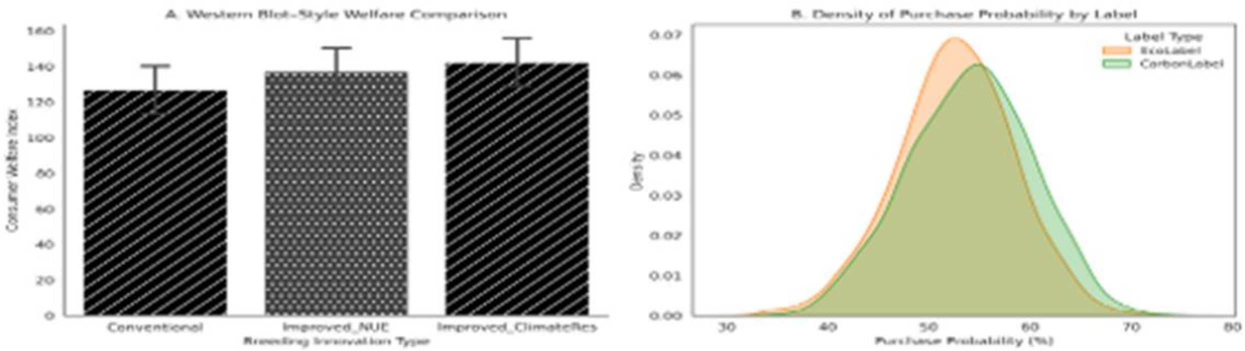

Figure 2. Findings on the effect of breeding innovation and sustainability labels on stated purchase probability: A discrete choice experiment results.

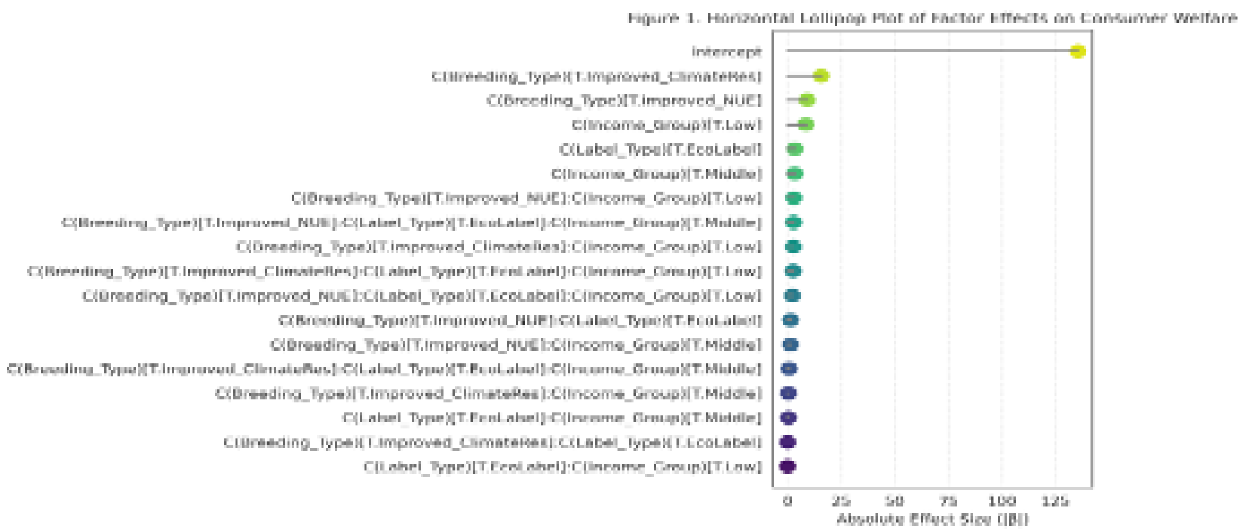

Figure 3. Determinants of consumer welfare and heterogeneity in preference in sustainable agricultural consumption.

with decreases of 7.44 and 3.38 points, respectively. Age and education were not statistically significant predictors ($P > 0.20$). The model showed a high level of agreement between observed and predicted welfare values, with only limited unexplained variation (Table 4).

Linear mixed-effects models revealed that better cultivars produced higher yields and were more cost-efficient than traditional cultivars. The better NUE cultivars cut down on input expenses by 23.2 USD/ha and yielded 0.47 t/ha. Climate-resilient cultivars' yield gain increased most with the highest yield gain (+0.69 t/ha) and lowest costs (-15.8 USD/ha). The differences between the types of cultivars were significant for yield ($P < 0.01$; Table 6), input cost, and net profit.

Producer surplus effects

The better cultivars enhanced producer surplus among all income groups. Improved NUE (+10.2 USD/ha) and climate-resilient cultivars (+11.4 USD/ha) benefited middle-income farmers the most. There were widespread economic benefits, with low-income farmers receiving +6.5 to +7.8 USD/ha (Table 6a).

Table 6. Linear mixed-effects model: Yield and cost differences by cultivar type (N = 120 farms).

Parameter	Conventional	Improved NUE	Improved Climate-Res	F-value	p-value
Yield (t/ha), Mean ± SE	3.42±0.18	3.89±0.16	4.11±0.19	14.73	<0.001
Input cost (USD/ha)	187.4±12.3	164.2±11.8	171.6±13.1	8.42	<0.001
Net profit (USD/ha)	241.3±19.4	258.7±18.2	264.9±20.1	6.31	0.002
Random intercept variance (σ²)	0.043				

Producer Surplus Gains by Cultivar Type and Income Group (USD/ha, bootstrapped 95% CI)

Cultivar	Low-income farms	Middle-income farms	High-income farms
Conventional (baseline)	0	0	0
Improved NUE	+6.5 [4.2, 8.8]	+10.2 [7.9, 12.5]	+8.7 [6.1, 11.3]
Improved Climate-Res	+7.8 [5.3, 10.2]	+11.4 [9.0, 13.8]	+9.9 [7.4, 12.4]

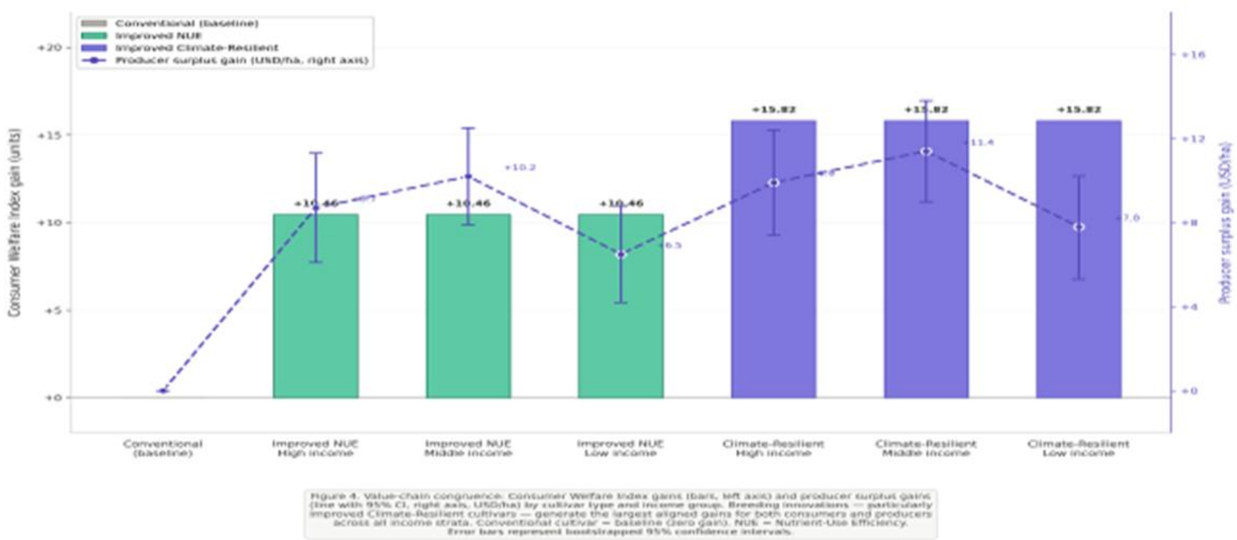

Figure 4. Value-chain congruence: Consumer Welfare Index gains and producer surplus gains (USD/ha) by cultivar type across income groups.

Combined welfare pathways

The microeconomic implications of the relationship between breeding innovations, labeling, consumer preferences, and welfare results were noticeable as the indirect impact of breeding and labeling on welfare occurs through willingness to pay and purchasing power probability. Meanwhile, income level has a positive and a negative impact on welfare.

Consumer welfare and producer surplus were greatest with climate-resilient cultivars (+15.82 units; +11.4 USD/ha) and then improved with NUE cultivars (+10.46 units; +10.2 USD/ha). Labeling had a small consumer and insignificant producer effects. These results suggest that the designed breeding innovations were consistent in the value chain (Figure 4).

DISCUSSION

This research comprised an investigative study of the interplay among breeding innovations, sustainability labeling, and income heterogeneity in influencing consumer choice and purchasing power and welfare provision in a sustainable agricultural market (Cook *et al.*, 2023). The results showed breeding innovations have a robust effect on willingness to pay (WTP), purchasing power probability (Gorton *et al*., 2023), and the consumer welfare index, whereas effects of labeling and income were secondary but also significant (Van-Riemsdijk *et al.,* 2023). The results supported that breeding innovations applied to intrinsic product attributes have a more robust effect on consumer welfare than informational cues, and the interaction effects between the two factors were nonsignificant (Taufik *et al.,* 2022; Panahov and Shafizada, 2022).

In all the analytical models, breeding innovations had the greatest explanatory capacity on consumer outcomes. The three-way analysis of variance revealed the breeding type accounted for only 35.2%, 25.3%, and 21.1% of the variance in WTP, purchasing power probability, and consumer welfare, respectively. Moreover, it showed significant and durable effects that were much higher than those for labeling and income groups (Liu *et al.,* 2023). These results were consistent with the existing findings, which exhibited technological advancements directly enhancing the product performance elicit stronger consumer reactions than symbolic sustainability communication (Kapoor *et al.,* 2023).

According to breeding innovations' characteristics theory, the utility-generating qualities of agricultural products incurred direct alteration from breeding innovations that enhanced the marginal utility and welfare in climate-resilient and nutrient-use-efficient cultivars. Compared with conventional crop cultivars, improved climate-resilient and improved nutrient-use efficient cultivars enhanced the consumer welfare by 15.8 and 10.5 index points, respectively (Karri and Nalluri, 2024). This emphasized the economic relevance of embedded sustainability attributes to consumers. Compared with labeling, these effects were consistent across the income groups, revealing that these robust effects were applicable in the market (Krsnik and Erjavec, 2024).

There was a steady relationship between carbon labeling and high WTP, purchase probability, and consumer welfare; however, the explanatory power was somewhat lower than that of breeding innovations (Krsnik and Erjavec, 2024). Carbon labels provided quantitative and outcome-based information, whereas eco-labels were binary, normative, and thus allowed continuous comparisons of the products. Previous research exhibited that numerical indicators decreased the uncertainty, increased credibility, and reduced mental effort in decision-making (Meinert and Krämer, 2022). In line with these past findings, carbon labeling enhanced willingness to pay, purchase intention, and consumer welfare relative to eco-labeling; however, the type of labeling accounted for only a minor proportion (1/3) of the labeling effect. This implies that as much as quantitative labels were more comprehensible and believable than general certifications, the overall impact was minimal (Wijewardena and Bhowmik, 2025).

In this presented study, the interaction effects were nonsignificant, unlike in past studies revealing synergistic effects of product innovation and labeling (Nabeshima *et al.*, 2024). The evidence showed consumers seem to combine breeding innovations and labeling in an additive, not a multiplicative, manner, focusing on intrinsic product characteristics when exposed to several sustainability cues (Mohamed *et al.,* 2025).

Income highly moderated welfare. Such systematic low values of the consumer welfare index were evident among low- and middle-income consumers compared with high-income consumers, and the estimated variations were 7.4 and 3.4 points, respectively (Mahdzan *et al.,* 2023). The results were consistent with the microeconomic theory, and the budget constraints limited the transformation of pro-sustainability preferences into realized welfare, even when desirable preferences exist (Bédu *et al.,* 2023). The welfare formation was therefore a preference-mediated model that was in line with the random utility theory, where variation in the indirect utility determines welfare outcomes (Rietveld, 2023).

By using improved crop cultivars, the producer surplus rose along with the consumer surplus. The biggest income increase had nutrient-use-efficient cultivars controlling it, especially among middle-income farmers, who received a positive income increase (+10.2 USD/ha). The same pattern was visible for low-income farmers. These results aligned with agronomic-economic findings that input-efficient technologies enable profitability maximization in the face of resource heterogeneity. The simultaneous increases in consumer welfare and producer surplus imply that breeding innovations align incentives across the agri-food value chain, reducing trade-offs between sustainability and economic viability (Mehrabi *et al.,* 2022).

The results highlighted breeding innovations as the main sustainability driver, and labeling was the secondary. Investments in innovation pipelines, seed dissemination, and adoption incentives to climate-resilient and input-efficient cultivars will lead to greater welfare gains. In practice, the combination of discrete choice models with welfare and producer surplus was recognizably a sound approach for assessing sustainability interventions.

Limitations include potential bias in reported preferences, measurement of short-term welfare, and context-specific environmental information. The research results were valuable as argue for the prevalence of breeding innovation in consumer welfare, elucidated the information advantage of carbon labels over eco-labels, and revealed innovation-based sustainability provides congruent incentives along the value chain.

CONCLUSIONS

This research used the microeconomic welfare model to determine the impact of breeding innovations, sustainability labeling, and income disparity on sustainable food decision-making. The results revealed breeding innovations have a significant positive impact on willingness to pay, purchase likelihood, and consumer welfare, accounting for 35% of the outcome variation. Significant but less prominent effects were notable in labeling and income, with the carbon labels found more effective than eco-labels. Sustainability generated through technology creates greater welfare benefits than that from information-based interventions. The observed behavior and dynamic welfare requires combining in future research to support the effective breeding and sustainability policies.

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