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Ex ante impact assessment of breeding research under risk in agro-climatic zones of Iran

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Introduction: In recent years, agricultural research investment has declined in developing countries, for example, Iran, exposing it to significant financing challenges. In this situation, economic policymakers need documentary evidence of its benefits to be persuaded to fund it. Without this evidence, agricultural research will fail to receive sustainable funding support. This research was conducted to assess the economic return of crop breeding research in three agro-climatic zones in Iran that have been broadly divided into 10 different agro-ecological zones according to their similar climate conditions and types of crops grown. In addition to raising awareness, its results can convince the policymaking system to support agricultural research.

Methods: This research was conducted using the economic surplus analysis method under risk conditions in three agro-climatic zones of Iran.

Results and discussion: Based on the findings, most crop breeding research projects in the three studied zones yield an internal rate of return ranging from 17 to 81% despite the uncertainty and risk in agricultural research and activities. Therefore, using the developed varieties derived from these projects can play an essential role in increasing agricultural production and the supply of strategic agri-products. The evidence emphasizes the need to support and fund agricultural research, especially crop breeding research. However, the results show that returns on breeding research in the studied agro-climatic zones vary, partially due to climatic and weather conditions. For example, the expected average internal rate of return for irrigated wheat breeding research in the three zones is 70.4%, 71.8%, and 57%, respectively, implying that climate and weather conditions affect the economic return of agricultural research.

KEYWORDS
breeding research, ex ante impact assessment, agro-climatic zones, Iran, agriculture development

1 Introduction

Agricultural research investment can enhance production quality and quantity, contributing to food security, poverty alleviation, the conservation of essential resources, and the development of agricultural exports (Izadi et al., 2019). Sustainable economic growth cannot be achieved without research (Masters et al., 1996; Aazami et al., 2019; Osintseva and Ishutin, 2023; Jung, 2024). However, evidence suggests that, in recent years, public (governmental)-sector agricultural research systems, particularly in developing countries, have entered an era of resource scarcity and face significant financing challenges (Beintema et al., 2012; Pardey et al., 2013; Ivanova et al., 2023).

A comparison of research expenditures between developed and developing countries underscore this fact. During 1960–1962, 10 developed countries and some emerging economies accounted for 62% of the world's agricultural research and development expenditures; by 2007–2009, this figure had risen to 67%. Meanwhile, the bottom 100 countries' share declined from 17% in 1960–1962 to 13% in 2007–2009. This indicates the increasing concentration of agricultural research within a few developed countries and emerging economies in the world (Pardey et al., 2013; Ghadermarzi et al., 2020; Shakir, 2023). Comparing the share of agricultural research expenditures in government budgets shows that in developed countries, a larger share (2.7%—3%)[1] of the government budget was allocated to agricultural research in 2021. But in developing countries, this share was as low as 4%—6% in 2008.[2] Also, the agricultural research budget share in the Iranian government's public budget was 0.67% in 2021.[3]

In these conditions, documenting agricultural research returns is necessary to secure an appropriate level of public support. Without clear documentation and convincing returns, research will not gain sustainable support (Ataei et al., 2021). Therefore, with reductions in resources required for agricultural research, evaluating its impact is gaining growing significance. By assessing agricultural research returns, managers and researchers can justify and prioritize their activities to achieve the highest returns. Research impact assessment improves attitudes toward applying science to decision-making and resource allocation. In addition, raising awareness can secure political support (Mardia et al., 2001; Mohammed and Zaheer, 2023; Towoju and Petinrin, 2023).

The Agricultural Research, Education, and Extension Organization (AREEO) is Iran's state-run institution responsible for agricultural research in Iran, receiving more than 95% of the funding (Mehraby and Nickseir, 2009; Ataei and Zamani, 2015; Ataei et al., 2018). Like other developing countries, this organization is struggling with serious problems due to extensive research duties and funding constraints (Sharifzadeh and Abdullah Zadeh, 2011; Ghadermarzi et al., 2022; Minh et al., 2023). Evidence shows that in real terms, its annual budget increased by only 18.7% over 10 years, from 1989 to 1999. However, between 2000 and 2010, there was not only no further increase but also a 0.04% decline. Therefore, AREEO's research projects have been decreasing in recent years. For instance, the number of research projects undertaken by the Seed and Plant Improvement Institute, AREEO's most important research affiliate, declined from 2,563 in 2005 to 1,927 in 2011—a reduction of about 25%.

Another critical aspect of Iran's agricultural research, which distinguishes it from research sectors in other parts of the world, is its regional nature. That is, regions may have varying research needs due to differences in agricultural and climatic structures, as well as development levels. Among these factors, the most important component that makes a difference in the functionality and agricultural research results is climatic conditions, including their impact on production resources. Therefore, in assessing agricultural research's impact, zones must be planned separately.

1 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Government_budget_allocations_for_R%26D_(GBARD).

2 ASTI: Agricultural research intensities (AgR&D / AgGDP), proxy for government R&D share.

3 Anonymous (2021).

TABLE 1 List of the 10 agro-climatic zones of Iran.

Agro-ecological zone	Provinces
Central zone	Markazi, Qazvin, Qom, Semnan, Tehran
Caspian coastal plain zone	Gilan, Golestan, Mazandaran
North-Western zone	Ardabil, East Azarbaijan, Kordestan, West Azarbaijan, Zanjan
Central Zagros zone	Hamedan, Ilam, Kermanshah, Lorestan
Khuzestan zone	Khuzestan
Arid central zone	Esfahan, Yazd
Southern Zagros zone	Chaharmahal and Bakhtiyari, Fars, Kohkilooyeh, and Boyerahmad
Southern coastal plain zone	Bushehr, Hormozgan
Arid Southern zone	Jiroft, Kerman, Sistan, and Baluchestan
Khorasan zone	Khorasan

Reference: Booker and Hunting (1965).

Iran has been broadly divided into 10 different agroecological zones based on their similar climatic conditions and crops grown.

So to address the limited financial resources and carry out research projects in the agricultural sector, officials must persuade policymakers and economic planners (Ataei et al., 2025). In this context, research impact assessment helps AREEO managers provide documentary evidence of agricultural research returns to planners and policymakers. This study seeks to assess the impacts of crop breeding research under return uncertainty conditions across agro-climatic zones, including Southern Zagros, Khuzestan, and the Caspian coastal plain of Iran. Crop breeding research is particularly significant for AREEO, with more than half of its research devoted to cultivation subdivisions (Kamali and Najafi, 2002; Es'haghi et al., 2022). The findings can provide documented evidence of agricultural research's benefits and encourage planners and policymakers to offer necessary support and funding (Table 1).

2 Methodology

This article evaluated the potential returns of crop breeding research for wheat, barley, oilseeds, corn, potatoes, beans, rice, sugar, and cotton in three specified climates using the ex ante economic surplus method (ESM). The ESM is based on welfare theory in microeconomics. According to this method, applying research-derived knowledge or technology on farms leads to a rightward shift in the supply curve, increasing the welfare or economic surplus of producers and consumers. This shift's magnitude represents the social benefits of the research. Due to the diversity of the agro-climatic zones, a representative province was selected for each zone: Fars, Khuzestan, and Golestan. The evaluated crops play an important role in the agricultural economy of these zones and have been designated strategic crops in the comprehensive map of Iran's agricultural sector.

The welfare value or social benefits of given production and consumption levels can be measured using the concept of economic surplus. The ESM assesses the difference between two situations

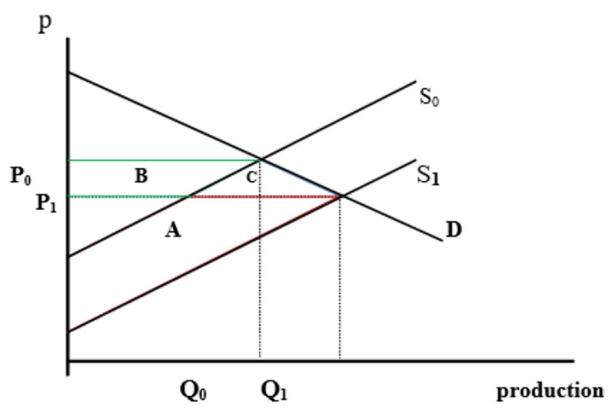

FIGURE 1
The effect of agricultural research on the economic surplus of producers (farmers) and consumers.

(one with research and one without research) through a single measure: welfare value or social benefits. Figure 1 shows the effects of successful research on the supply curve, price, quantity demanded, and economic surplus. When farmers adopt new technology, the product supply curve (S_0) shifts downward and to the right (S_1), moving in equilibrium to a lower price (P1), and a higher quantity produced (Q1). For producers, the economic impact of research is a reduction in production costs, which is shown in terms of economic surplus by area A (the area between the supply curves with and without research underprice P1). Research also lowers the prices producers receive, reducing their surplus by an amount equal to area B (the area between the two price lines, above supply without research). Hence, the net change in producer surplus is A–B. However, consumers always benefit from research because they gain what producers lose due to lower prices (area B) and the economic surplus of increased consumption (area C). As a result, the net consumer benefit equals the value of areas B+C. Thus, the total change in economic surplus or social benefits is equal to the sum of areas A and C. Although consumers gain area B, producers lose it. Area C represents the price-reduction benefit (from P_0 to P_1), while area A reflects the reduced-production-cost benefit (from one supply curve to another; Alston et al., 1998).

There are several key points about the ESM. The impact of agricultural research is evaluated in two ways: ex ante and ex post. In an ex ante assessment, research is evaluated based on the anticipated costs and benefits before it is undertaken. This method is typically used to analyze projects that require economic justification by those who propose it. Additionally, financial suppliers rely on such assessments to ensure that investments will yield acceptable returns. Therefore, the ex ante ESM is employed to measure the potential benefits of research, guiding resource allocation, and prioritizing future research and research alternatives. Accordingly, this method is an integral part of agricultural research planning (Horstkotte-Wesseler et al., 2007). Based on the ex ante ESM, applying agricultural research–derived knowledge or technology shifts the supply curve to the right, enhancing the total economic surplus (ΔTS). Following the adoption of new technology resulting from a research project in an open economy, the change in economic surplus is calculated using Equation 1 (Alston et al., 1998):

$$\Delta TS_t = K_t P_w Q_0 \left[1 + 0.5 K_t \varepsilon\right] \tag{1}$$

in which ΔTS_t represents the total change in economic surplus or social benefits resulting from research and K_t is the shift parameter of the supply curve in year t, reflecting a relative shift in the measured price or production cost. In addition, P_w and Q are the global price and production before the research, respectively, and ε is the supply's price elasticity. The challenge of ex ante ESM lies in calculating the shift parameter, the most critical factor in determining the return on research. This parameter shows the net effect of increased productivity (through yield increments and reduced production costs) resulting from the research and is calculated using Equation 2 (Alston et al., 1998):

$$K_t = \left[\frac{E(YI)}{\varepsilon} - \frac{E(C)}{1 + E(YI)}\right] \Pr \times A_t \times (1 - \delta_t)^t \tag{2}$$

in which YI denotes the crop yield increment following the adoption of new technology (e.g., new seed or variety), ε represents the elasticity of supply, $E(C)$ is the relative change in production cost after adopting the new technology, Pr is the likelihood of yield increment in farmers' fields that have received the new technology, A_t represents the adoption rate, and $(1 - \delta_t)$ denotes the depreciation factor of research. In the economic surplus model, various factors, especially the adoption rate and the depreciation factor, are decisive in determining the shift of the supply curve (k parameter). Therefore, to justify using parameters such as the adoption rate and depreciation factor, this research has drawn on the perspectives of Alston et al. (1998) to explain the economic surplus model. In addition, some data (such as Pr and δj) in this study was inevitably based on the views and opinions of experts and agricultural extension agents. However, biases may have emerged in practice. To mitigate potential bias, the study incorporated the insights of experienced experts and extension agents.

To estimate the shift parameter in advance, the values of $E(YI)$, E, $E(C)$, Pr, t, and $(1 - \delta_t)$ must be properly estimated. The outcome of breeding research is new technology in the form of seeds (varieties) with higher yields (Farsi and Bagheri, 2006). However, the yield increment (YI) resulting from breeding research is uncertain and has a probability distribution. In other words, it is a random variable that can take on different values with varying probabilities. Therefore, the return on agricultural research should be assessed while considering the uncertainty and risks associated with yield increments. In this situation, this variable's possible values should be simulated using an appropriate method, and the impact should be evaluated by substituting these random values into YI in Equation 2. For crops, research gains are generally expressed in terms of increased yield or reduced cost. Calculating the yield increase due to research is the most common way to measure the effects of agricultural research. However, the amount of increase in crop yield resulting from a new technology is, by the nature of the research process, uncertain and random, and therefore has a probability distribution. In addition, other factors that affect farmers' decisions to

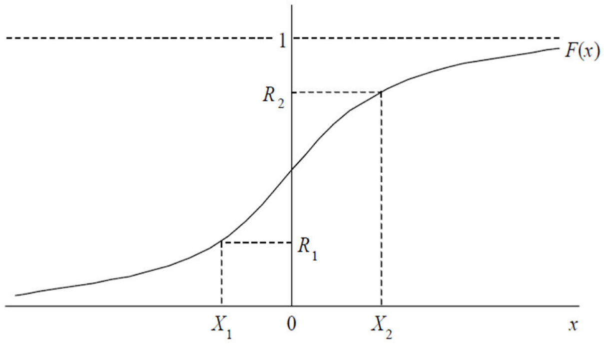

FIGURE 2
The random number simulation pattern with inverse transformation method.

adopt new technologies, such as extension system inefficiencies, market conditions, agricultural policies, and the effectiveness of agricultural infrastructure investment, cause research benefits to be stochastic in nature. It is evident that the stochastic nature of agricultural yield is affected by various factors, including farmers' management skills, government policies like investment in agricultural infrastructure, education, extension, and climate change.

The most common simulation technique is the Monte Carlo method, which is used in a wide range of disciplines, from nuclear physics to genetics and applied economics. To be the Monte Carlo method, it is sufficient that the methods used to produce random numbers (Banks and Carson, 2012). The most common technique for generating random numbers is the inverse transformation method (Figure 2).

According to Figure 1, *inverse transformation* refers to the inverse of the cumulative distribution function ($F(x)$ of a random variable). In this transformation, at every simulation of possible values (X) of a variable, a random number, U, is generated between zero and one from the uniform distribution function, U (0, 1). This value is then applied to the cumulative distribution function, $F(x)$, stimulated by the random number X using Equation 3.

$$X = F^{-1}(U) \tag{3}$$

To simulate the possible values of a random variable, the probability distribution and its parameters must be determined. Based on reviews by Alston et al. (1998) and Mutangadura (1997), the most appropriate probability distribution for the yield increment of new varieties resulting from crop breeding research is the triangular probability distribution, which describes the random nature of the yield increase and is highly flexible. It includes interpretation parameters calculated using the critical method (minimum, most likely, maximum, and expected mean). Therefore, it has gained acceptance and popularity among simulation modelers and risk analysts (Gierend, 1999). In this regard, Mutangadura (1997) have noted that the range of changes in agricultural yield increment follows a triangular probability distribution pattern. It is obvious that agricultural yield values on farms vary within a range (minimum, maximum, and expected mean). However, this behavioral pattern may also follow other probability distributions such as the normal distribution.

The method used in this study to simulate the possible values of relative yield increment data resulting from breeding research, reviewed products, the production nature of a random variable having a triangular probability distribution, and the determined cumulative distribution function. For this purpose, the possible values for YI were simulated and generated using inverse transformation from the cumulative distribution function. Then, these values in Equation 2 were replaced with YI to produce and simulate possible values of shift parameters in the supply curve. Next, possible values of the internal rate of return (IRR), efficiency index (EI), and net present value (NPV) of return corresponding to the possible values of YI were simulated by iterating the economic surplus method. In this study, the triangular probability distribution's parameters for yield increment of improved varieties included the minimum (YI_l), maximum (YI_h), and most likely yield increment (YI_m), which were derived from ongoing breeding research results and interviews with researchers conducting breeding research at agricultural research and natural resource centers in the mentioned provinces. The different stages of simulating possible values of yield increment for improved varieties (YI) with triangular probability distributions using the inverse transformation method are outlined as follows (Gierend, 1999):

$$F(YI) = \frac{(YI - YI_l)^2}{(YI_h - YI_l)(YI_m - YI_l)} \qquad \text{If } YI_l < YI < YI_m \tag{4}$$

$$F(YI) = 1 - \frac{(YI_h - YI)^2}{(YI_h - YI_l)(YI_h - YI_m)} \qquad \text{if } YI_m < YI < YI_h \tag{5}$$

in which $F(YI)$ is the cumulative probability distribution function and YI_h, YI_l, and YI_m denote the maximum, minimum, and mode of the yield increment variable resulting from improved varieties through breeding research, respectively. Before simulating the possible values of the YI variable using the inverse transformation of the cumulative probability distribution function, defining the critical value of U^* in two cases as follows is necessary: values less than and values greater than YI_m:

$$U^* = \frac{(YI_m - YI_l)}{(YI_h - YI_l)} \tag{6}$$

After determining the critical value U^* in the range of zero to one based on U from a uniform distribution, one of the following equations must be used for the inverse transformation of the cumulative probability distribution function and the simulation of the possible values of YI:

$$YI = YI_l + \sqrt{U(YI_h - YI_l)(YI_m - YI_l)} \quad \textit{if} \;\; U <= U^* \tag{7}$$

$$YI = YI_l + \sqrt{1 - U(YI_h - YI_l)(YI_h - YI_m)} \quad \textit{if} \;\; U^* < U <= 1 \tag{8}$$

With this method, we can produce and simulate possible values of yield increment (YI). To apply Equation 2, we also need data on the adoption rate (A_t), the probability of research success (Pr), the price elasticity of supply (ε), and research depreciation (1 – δ_t). The size of the supply curve shift depends on the new technology adoption rate among farmers. Because this analysis is an ex ante type, given that the research is of an ex ante nature, the values of the price elasticity of supply (ε) of agricultural products estimated in supply or acreage response research conducted in Iran were generalized to this research and used in Equation 2. We can use the adoption rate of varieties introduced in recent years and generalize it to the adoption rate of the varieties to be introduced. The yield of newly improved varieties is not entirely stable over time due to various reasons, including breaking their resistance to biotic and environmental stresses. So research returns across different years can be adjusted and reduced by applying a depreciation factor (1 – δ_t) in Equation 2. Based on researchers' and agricultural extension agents; experience, an annual decline of 1% ($1\% = \delta_t$) was assumed for varieties by the end of the 5-year adoption period. This study used the estimated supply elasticities of internal studies investigations, including both provincial and national estimates. After determining these parameters and inserting sequential simulated values of *YI* into Equation 2, we can also produce and simulate the corresponding shift parameter of the supply curve.

To calculate the total economic surplus change of research activity, the annual expenditure on research, price, amount of product to research, and discount rate (the minimum acceptable rate of return on investment or minimum IRR) must be provided along with shift parameters. In this article, the discount rate or minimum acceptable rate of return on investment, and the long-term interest rates for agricultural credit in Iran's banking system were considered to be 17% of 2014. However, lower rates of public sector investments in research are also acceptable. Because the economic surplus model is considered in terms of the open economy, the global price and the quantity of products can be used for research.

Research expenditure data are one of the most challenging aspects of research impact assessments. In this study, the annual expenditure per breeding research includes its research and extension costs. After preparing the data, Equation 1 can be used to produce and simulate possible values of total economic surplus (ΔTS_t) corresponding to potential values of *YI*. After calculating the annual cost (C_t) and simulating possible changes in total economic surplus for each breeding research activity over a time horizon of 20–25 years, we can measure their possible returns. A relevant criterion for determining whether investment in research is acceptable includes the IRR and EI of that research. IRR is the return rate at which the net present value is equal to zero. The research's EI is the net return per unit of expenditure spent on it. The EI represents the net benefits per unit of research expenditure. From Equation 9, the IRR can be calculated in any of the possible values of ΔTS_t:

$$\sum_{i=1}^{t} \frac{(\Delta TS_t - C_t)}{(1 - IRR)^t} = 0 \tag{9}$$

in which ΔTS_t is the change in economic surplus or total return, C_t is the total annual expenditure on research, and *IRR* is the IRR of research. For investment in agricultural research to be considered economically viable, the IRR must be higher than the discount rate that is an acceptable minimum rate of return on investment (the opportunity cost of capital). The possible values for each research project's EI are calculated using Equation 10:

$$EI = \frac{NPV}{\sum_{t=1}^{t} \frac{C_t}{(1+IRR)^t}} \tag{10}$$

A research project is economically justified if its IRR is greater than the discount rate. In Equation 10, *NPV* is the net present value of benefits, *C* is the present value of expenditure, and *EI* is the EI. The EI represents the net benefits per unit of research expenditure.

In practice, other methods, such as the econometric method (production function) and the cost-benefit method, are also used to assess the benefits of agricultural research. The econometric approach uses the production function, cost function, or factor productivity analysis to estimate changes in the marginal productivity of research expenditures over an extended period. When estimating the production function, the stock of technical knowledge (investment in research and extension) serves as an explanatory variable. The coefficients derived from this function are then used to determine the rate of return on research. This approach requires times-series data spanning at least 30 years, which can be challenging to collect in developing countries. The cost-benefit method is a simplified version of economic surplus analysis. In this method, annual benefit and cost streams of research options over a planning horizon are determined and discounted to estimate their benefit-cost ratio, NPV of benefits, or IRR. One advantage of the cost-benefit method is that it does not require price elasticity data, as it assumes that the supply and demand functions are either vertical or horizontal, so the supply and demand elasticities are symmetric (opposite), demand is infinitely elastic, and supply is absolutely inelastic or vice versa (Alston et al., 2000).

3 Results and discussion

This study simulated 100 possible values of the yield increment (*YI*) variable of improved varieties resulting from the examined breeding research projects using the plug-racial @RISK application in an Excel spreadsheet using the Monte Carlo method. *IRR*, *NPV*, and *EI* were then calculated under 100 risky situations for each variable. Tables 2–4 present the minimum, maximum, and expected values of *IRR* and *EI*, respectively. These results show the random nature of agricultural research returns. Of course, this uncertainty is amplified in farmers' situations due to factors such as climate change, different management levels, insufficient extensional activities, market price fluctuations, inadequate supply of inputs, a lack of infrastructure facilities, and marketing shortcomings. So inferring the return certainty of agricultural research is not reasonable. These findings show the random nature and potential return of agricultural research. For example, according to Table 2, in Golestan Province, located in the Caspian zone, potato breeding research projects are expected to have an

TABLE 2 Internal rate of return (IRR) and efficiency index (EI) of crop breeding research in the zone of Caspian coastal plain (Golestan Province).

Breeding research	IRR (percentage)			EI (rials)		
	Minimum	Maximum	Expected mean	Minimum	Maximum	Expected mean
Irrigated wheat	61	76	70.4	11	25	18.9
Rice	57.2	71	64	6.68	13.6	9.7
Rain-fed wheat	36.9	69.2	56.1	2.38	23	10.6
Rain-fed barley	42	55	49.6	4.2	14.6	10.17
Soybean	42	51	48	9.36	26.9	16.8
Irrigated canola	35.6	46.8	40.61	0.72	9.2	5.38
Potatoes	14.3	51.2	39.6	−0.59	8.6	3.94
Irrigated barley	33.6	43	37.9	2.16	4.95	3.29
Rain-fed canola	28.8	40.5	34.6	1.52	5.3	3.04
Cotton	22.7	41.2	23.8	0.73	8.9	4.2
Rain-fed sunflower	20.6	30.5	27.04	0.42	2.7	1.67
Corn	0.09	18.6	16	−0.54	0.17	−0.08
Durum wheat	0	24.7	14.6	−1.45	0.62	−0.25
Rain-fed chickpea	0	10	5.7	−1.1	−0.4	−0.7

IRR that varies from 14.3 to 51.2% and an EI that varies from −0.59 to 8.6 rials. The random nature of the return on the breeding research of other crops can also be seen. This suggests the need to acknowledge inherent risks associated with research and agricultural activities and implement strategies for risk reduction.

According to Table 2, the highest and lowest return (IRR and EI) belong to irrigated wheat and rain-fed chickpea breeding research projects, respectively. The expected values for the IRR and EI of wheat crop breeding research projects are 70.4% and 18.9 rials, while they are 5.7% and −1.1 rials for breeding research of rain-fed chickpeas, respectively. These results show a significant return of all crop breeding research projects in this zone except for rain-fed chickpeas. The EI of irrigated wheat breeding research in this area suggests that 1-rial investment in research and extension of this strategic crop will create an economic return of ∼18.9 rials. Thus, we can see that despite the uncertainty and risk return of research and agricultural activities, applying new and improved varieties resulting from the crop breeding research of this crop increases farmers' and consumers' production and return considerably. In this zone, the breeding research projects on other crops have acceptable benefits, except for chickpeas. So farmers and consumers benefit from applying research results.

The return of breeding research of different crops varies with factors such as the adoption rate of findings (modified varieties), the probability of research success, the price elasticity of crop supply, farmers' agricultural knowledge and skills, and yield increments. The results attest to the positive benefits of this research and imply the need for investment and financing.

The results in Table 3 show the random nature of return on crop breeding research in Fars Province located in the Southern Zagros zone. The maximum and minimum IRRs are related to wheat and soybean breeding research projects, respectively. However, the expected return of all crop breeding research projects in this zone is >17%, except for soybeans, which exceeds the acceptable minimum rate of investment return and ensures economic and social returns. The highest and lowest expected IRR values in breeding research of irrigated wheat and soybeans are 71.8% and 13%, respectively. The expected value of EI is 30 and −0.15 rials. Explaining that the rial is the official currency of Iran is necessary. So each rial invested in breeding research of irrigated wheat will create 30 rials of net return. In contrast, investing the same amount in soybean breeding research will provide 0.15 rials of economic losses. The return of other breeding research in this zone is within the mentioned rates. Table 3 shows that investing in breeding research is economically justifiable, and using advanced varieties resulting from this research, despite return uncertainty, will entail acceptable returns and enhance society's welfare. The evidence supports the positive economic and social benefits of breeding research in this zone and endorses the need for investment and financing.

As with Golestan Province, the difference in the efficiency of breeding research of different crops in this province may be affected by the acceptance rate of the findings (modified varieties), the probability of research success, the price elasticity of product supply, farmers' knowledge and skills, and yield variations.

Table 4 presents the results of the return assessment of crop breeding research, with a focus on IRR and EI, in Khuzestan Province located in the Khuzestan zone. Although uncertainty and the random nature of the breeding research returns are considerable in this zone, these results confirm that, except for the date, the research on breeding other crops has economic justification, and their investment return exceeds the acceptable minimum rate of return. The evidence implies positive economic and social benefits of this research, so these projects deserve investment and financing.

TABLE 3 Internal rate of return (IRR) and efficiency index (EI) of crop breeding research in the zone of the Southern Zagros (Fars Province).

Breeding research	IRR (percentage)			EI (rials)		
	Minimum	Maximum	Expected mean	Minimum	Maximum	Expected mean
Irrigated wheat	50	81	71.8	8	47.6	30
Irrigated barley	44	58	50	4	10.2	6.8
Rain-fed wheat	29.5	54.2	34.8	1.3	9.9	4.9
Durum wheat	0	51	44.4	−3	14.3	8.8
Rice	33	43	40	2.5	14.3	10.9
Irrigated bean	35	46	40	5	17	10
Rain-fed chickpea	18	44	38	0.12	14	7.8
Corn	31	42	37	3.3	10.6	6.8
Irrigated canola	26	27	34	1.5	6.1	4.4
Cotton	32	39	35	3.3	6.7	4.4
Sugar	30	40	34	2.4	8.1	4.2
Almond	0	24.5	31.56	−4.2	12.6	6.2
Sesame	25.7	34.1	30.6	1.8	5	3.4
Orange	18.7	26.7	22	0.3	2.7	1.1
Irrigated sunflower	0	24	20.6	−1.2	0.28	0.15
Soybean	0	21	13	−2.2	−0.28	−0.15

Rice breeding research in this agro-climatic zone has the highest expected IRR, which is equal to 57%. Similarly, the EI is the highest. Regarding the EI of rice breeding research, a 1-rial investment in research and extension of this crop is expected to create a net return of 28.9 rials. Based on the results, the return on investment in date breeding research is less than the acceptable minimum rate of return. In fact, date breeding research, which has a costly process, is considered a long-term project compared to other crops. In addition, applying the research findings of horticultural crop breeding requires changing composition gardens' fertile trees, which is not easy, and for the date, the adoption rate of breeding research findings will not be significant in the short term. Most research on horticultural crops, including date, is of a reformed agriculture type, focusing on production management in gardens. Alston et al. (2000) also showed that the research benefit of perennial horticultural crops is less than the rate of return on farm crops.

Based on the results, the range of returns of breeding research varies across the zones, which is partially associated with their different agro-climate conditions. For example, the expected average IRR of irrigated wheat breeding research is 70.4%, 71.8%, and 55% in the Khuzestan zone (Khuzestan Province), Southern Zagros (Fars Province), and Caspian coastal plain (Golestan Province), respectively. The average expected return from breeding research in the Khuzestan zone (Khuzestan Province), which has a tropical and humid climate, is lower than that in other zones. In addition, the IRR of rain-fed wheat breeding research is 10.6%, 4.9%, and 7.9% in the Khuzestan zone (Khuzestan Province), Southern Zagros (Fars Province), and Caspian coastal plain (Golestan Province), respectively, indicating the lower return of breeding research on this crop in the Southern Zagros zone (Fars Province), which has a relatively warm, dry climate. These results clearly show the effect of climate on the return of crop breeding research.

Although the results show the effect of differences in agro-climatic zones on the return of agricultural research, in practice, the AREEO's structure has followed Iran's provincial-based divisions and, regardless of necessity and more based on political interests, included the expansion of research institutes and centers in all provinces—just for political purposes—unnecessarily increasing the organization's research commitments and mission and complicating their adaptation to regional problems and challenges. Therefore, this organization currently has numerous research centers, including 32 provincial agricultural and natural resources research centers, 25 single-crop and thematic research institutes, and more than 300 research stations.

The findings support the returns of crop breeding research in the three studied zones and therefore the need to finance them. These results emphasize the positive and acceptable returns on investment in agricultural research. Because the studied breeding research projects have focused on crops considered strategic in the agricultural sector and for the national economy, the supply of financial needs will enhance the productivity of production factors, thereby increasing production and domestic supply. Therefore, special attention to agricultural research, especially breeding research, contributes to developing agriculture, as well as the national economy.

TABLE 4 Internal rate of return (IRR) and efficiency index (EI) of breeding research in the Khuzestan zone (Khuzestan Province).

Breeding research	IRR (percentage)			EI (rials)		
	Minimum	Maximum	Expected mean	Minimum	Maximum	Expected mean
Rice	44	65	57	9.3	46.3	28.9
Irrigated wheat	43	63.4	55	3.4	15.5	8.2
Rain-fed wheat	47.8	57.4	52.3	5.8	10.7	7.8
Irrigated barley	42.3	55.9	52.3	6.9	10.6	8.4
Sesame	45.8	54.7	50.7	12.4	23.4	16.7
Corn	42.3	52.3	47.6	8.4	26.5	17.6
Irrigated been	31.3	51.1	45.1	3	23.6	14
Durum wheat	0	40.1	37.7	−0.64	4.6	2.7
Rain-fed barley	30.1	43.3	37.5	1.4	4.8	3
Potatoes	17.8	49.4	30.1	0.4	5.5	2.5
Irrigated canola	15.9	32.5	23.8	−0.09	2.5	0.7
Soybean	13.6	21.8	18.2	−0.28	0.61	0.13
Date	0	24.8	13.4	−2.4	2.5	−0.1

The finding is relatively consistent with Alston et al.'s (2000) meta-analysis on agricultural research and ex ante assessment of the potential return for animal disease control research in Indonesia (Patrick and Vere, 1994), research on beans in Brazil (Pachico et al., 1987), bio-technological changes of perennial crops (Gotsch and Herrmann, 2000), breeding research in the Philippines (Yorobe, 2006), breeding research on mango (Bayer et al., 2008), breeding research on coffee (Benin and You, 2007), and breeding research on mango in Thailand (Napasintuwong and Traxler, 2009), which have emphasized agricultural research's considerable return.

As the results showed, the economic effects of the studied breeding research varied across the studied climatic-agricultural zones. Therefore, this issue should be considered in the research planning of the agricultural sector. Currently, it is widely accepted that the average global temperature will increase by 1°C−2°C during this century. Climate change, which leads to undesirable changes in temperature, rainfall, and sea level, will disrupt food, water, and livelihood security systems in different regions of the world. Therefore, predictive research is urgently needed to investigate the impact of adverse weather. Crop breeding research should change its emphasis from per crop to per day productivity. Drought and flood codes should be developed and implemented. Climate risk management research and training centers should be established in all climatic agricultural zones (Karimi and Ataei, 2024). Therefore, agricultural research should be tailored to the need for climate-resilient agricultural systems. Climate literacy should be expanded, and a cadre of social climate risk managers should be formed in villages. The climate change disaster should be turned into an opportunity to develop and expand climate-resilient agricultural techniques and systems (Swaminathan and Kesavan, 2012; Aliabadi et al., 2022; Ataei et al., 2024).

4 Conclusion

This study evaluated the economic return of crop breeding research in Golestan, Fars, and Khuzestan Provinces, representing three agri-climatic zones, using the ex ante economic surplus method. The findings show that despite the uncertainty and risk inherent in the research and agricultural activities, the examined breeding research increases factor productivity and crop supply, thereby improving farmers' and consumers' welfare. In addition, the results should persuade policymakers and economic planners to sustainably finance agricultural research. Based on the findings, it is recommended that provincial and national agricultural research resource provisions be expanded, especially for breeding research in the studied zones. It is clear that supportive policies for the introduction and development of varieties with higher yields, in addition to increasing the total social welfare, can also provide a significant amount of foreign exchange savings. Considering breeding research returns for society, a part of the resources must be dedicated to preserving and increasing production capacity to improve other technologies in agricultural research to alleviate national credit constraints and challenges for agricultural research. On the whole, special attention must be paid to the AREEO, and the appropriate infrastructure must inevitably be provided to carry out full-fledged research activities to ensure the development process of the agricultural sector and the national economy. Due to the uncertainty of agricultural research returns, scientific solutions for managing and reducing uncertainty in agricultural operations may have links to achieving maximum benefits. In this regard, presenting and deepening education and advocacy and facilitating the dissemination and adoption of technologies resulting from research, sufficient and timely provision of inputs, infrastructure facilities, and agricultural marketing system reform can be decisive in maximizing the return on investment in agricultural research and development.

Considering that the type of agro-climatic zone affects the return of agricultural research and that the provinces located in each zone have similar agro-climatic characteristics, the AREEO is recommended so that the provincial agricultural research centers located in each zone are merged to reduce the number of research projects and allocate limited resources more optimally.

Furthermore, the differences between the IRRs of crop breeding research among zones can be partially ascribed to the zones' agro-climatic conditions. As can be seen, the IRR of most rain-fed crops in the Southern Zagros zone, which is a dry, hot zone, is lower than that of rain-fed crops in the other two zones. It is obvious that drought and heat will affect the efficiency of field crops.

In addition, based on the results, breeding research returns in the studied zones are different. Currently, it is widely accepted that the average global temperature will increase by 1°C−2°C during this century. Climate change, which leads to undesirable changes in temperature, rainfall, and sea level, will disrupt food, water, and livelihood security systems in different regions of the world. Therefore, predictive research is urgently needed to investigate the impact of adverse weather. Crop breeding research should change its emphasis from per crop to per day productivity. Drought and flood codes should be developed and implemented. Climate risk management research and training centers should be established in all climatic agricultural zones (Karimi and Ataei, 2023; Ataei et al., 2023). Therefore, agricultural research should be tailored to the need for climate-resilient agricultural systems. Climate literacy should be expanded, and a cadre of social climate risk managers should be formed in villages. The climate change disaster should be turned into an opportunity to develop and expand climate-resilient agricultural techniques and systems (Swaminathan and Kesavan, 2012; Ataei et al., 2022; Khoshnodifar et al., 2023).

As the results showed, a factor affecting the return of crop breeding research is the rate of adoption of its impacts by stakeholders, especially farmers, the increase in crop production due to research, and the amount of production before research in the studied zones. Based on the available statistical data, the cultivation and production levels of crops such as rain-fed chickpea, soybean, and sunflower in the Southern Zagros and Khuzestan zones, as well as in the Caspian coastal zone, the cultivation and production levels of rain-fed sunflower, corn, durum wheat, and rain-fed chickpea is not significant compared to other crops. Therefore, if the yield increment is significant due to the new varieties developed, the adoption rate and, consequently, the return of breeding research on these crops will be small, given the low cultivation and production levels of these crops.

The agricultural research returns are also associated with risk and uncertainty because the conditions of farmers' fields are different from those of research fields. For example, the amount of increase in crop yield through research cannot be achieved exactly in farmers' conditions. Also, the adoption rate of research impacts can cause a risk to the return on research. Therefore, the factors that influence creating risk and uncertainty in farmers' conditions should be reduced with different solutions. For this purpose, farmers' management skills can be increased through education and promotion. In addition, the introduction of drought-tolerant varieties and pests and diseases should be given more attention. Also, by facilitating private-sector investment in agricultural research, the degree of dependence of agricultural research on public funds can be reduced.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

NA: Conceptualization, Data curation, Investigation, Supervision, Writing – original draft. HA: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – review & editing.

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