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Ancient marble wine-press from Croatia. Photo by Joadl, 2012 (Wikimedia Commons)

Cover Story

ὡς Διωνύσοι᾽ ἄνακτος καλὸν ἐξάρξαι μέλος
οἶδα διθύραμβον οἴνῳ συγκεραυνωθεὶς φρένας.

That I will lead the dance in Lord Dionysos' noble song
of the dithyramb I know, once my wits are thunderstruck with wine
Archilochos fr. 120 West (Ath. 14.628a)

With these words, the ancient Greek poet Archilochos of Paros (c.680 – 645 BCE), one of the Cycladic islands of Greece, describes the ritualistic choral song (dithyramb) for the wine god Dionysos. The reference to wine and its Ancient Greek god is by no means accidental; indeed, a robust wine culture is embedded in the island's history. Indications of wine-making and consumption date back to the Early Cycladic period (c.3200 – 2300 BCE), while Paros became a wine-export centre from the Classical period onwards (5th c. BCE), a reputation that endures until today.

In the 20th century, Paros saw a revival of its winemaking industry, with modern techniques enhancing the production of red and white wines from the famous grape varieties of Monemvasia and Mandilaria as well as the sweet, sun-dried wine of Malvasia. The six wineries of the island focus on sustainable and organic farming practices and are geared towards quality rather than quantity, with an annual production of more than 230,000 hectoliters of wine. The landscape is dotted with thousands of dry stone-walled terraces dedicated to wines (c. 485ha), an integral part of the scenery. Paros' wines enjoy a PDO (Protected Designation of Origin) status, celebrating the island's long tradition of viniculture. In Archilochos' words, it is not a surprise that one will naturally dance after tasting the Parian wine, a direct celebration of Paros' ancient heritage.

(Manolis Pagkalos, Associate Professor in the Humanities, Jiyang College, Zhejiang A&F University, PRC)

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About the Journal

Agricultural & Rural Studies (**A&R**, **ISSN 2959-9784**) is a quarterly journal to be an international, multi-/inter-disciplinary platform for communicating advances in fundamental and applied studies on contemporary agricultural, rural and farmers' issues and policies, as broadly defined by the disciplines of economics, sociology, human geography and cognate subjects.

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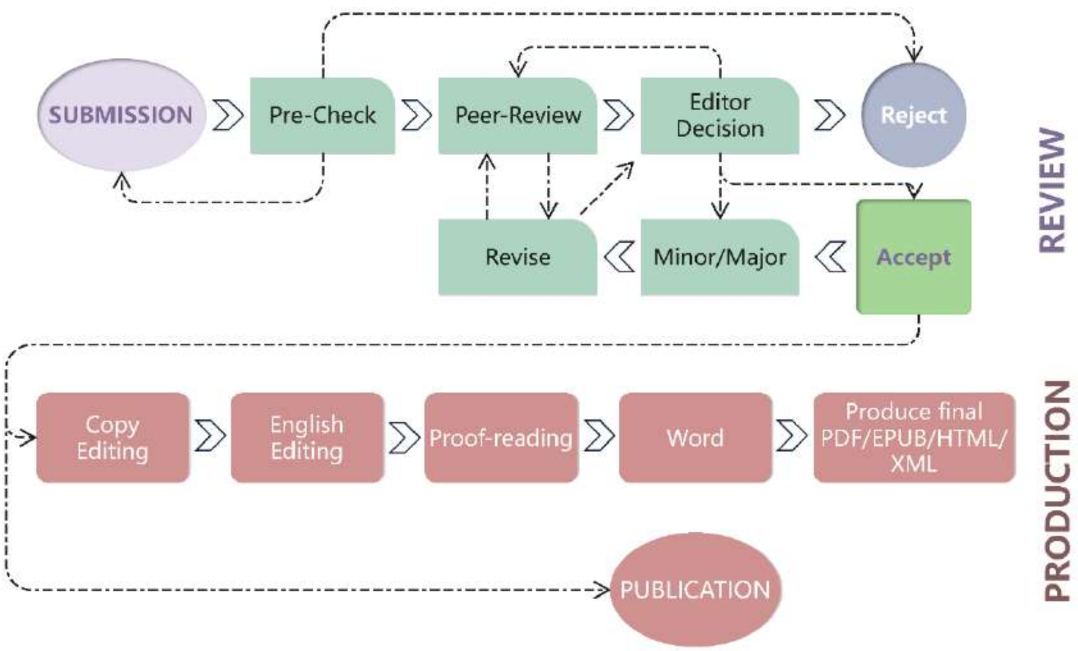

Agricultural & Rural Studies

Article

Quality and Safety of Extracted Humic Substances as Fundamental Factor of Natural Regulation for the Sustainable Development

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Abstract: Humic substances as natural biogeochemical macromolecules have been formed over tens of millions of years as a result of the processes of natural destruction of biological systems with a high degree of chemical diversity. The prospects and realities of today's use of humic substances by humans in agriculture, pharmaceuticals and medicine raise the issue of strict safety control of various drugs derived from these natural substances. These technologies for the extraction and purification of final humic preparations should be carried out in accordance with the balanced development of natural ecosystems and biosafety requirements. In this publication we raise the issue of creating a single standard for the quality and safety of purified humic substances on a global scale.

Keywords: humic substances; extraction; quality and safety

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1. Introduction

The global study of humic substances began more than two hundred years ago, in 1786, by F. Ahard, and by the mid-19th century, chemists like Berzelius and Sprengel had begun to study these complex molecules more thoroughly. Humic substances themselves are the "organic origin" (matter) of the aquatic and terrestrial environment. This is a complex dispersed-heterogeneous composition of various organic compounds that are produced by microorganisms as a result of fermentation of residues of organic substances in the medium: soil, bottom sediments of water bodies, or rock. At the same time, scientists classify humic substances (HS) as a supramolecular association of small heterogeneous molecules that are connected by weak intermolecular bonds. HS extracted from soil and water are the most common organic compounds that have arisen in the process of chemical-physical and microbial transformation of biological molecules. In terms of the volume of organic carbon on the planet, they account for about a quarter of the total and account for up to two-thirds of the dissociated organic carbon in water. This situation is considered by many scientists as determining for many ecological and microbiological processes in both soil and water systems (Makan, 2021). It is known that humic substances are complex organic compounds obtained as a result of humification of plant residues as a result of enzymatic transformation by their microorganisms under certain influences of abiotic factors. They are characterized by non-schiometric composition, branched structure, their structural elements are heterogeneous and have high polydisperse properties. They consist of humic, fulvic, and hymatomelanic acids each of which has unique properties. Humic acids are characterized by high molecular weight and insoluble in water at low pH while fulvic acids have a lower molecular weight and are soluble in water at any level of acidity, hymatomelanic acids are soluble in alkali and alcohol, but insoluble in acid. These compounds are enriched with many functional groups, such as phenols and carboxyl groups, which give them powerful anti-inflammatory, antioxidant, and antimicrobial properties (Figure 1; Chen et al., 2020; Cui et al., 2017).

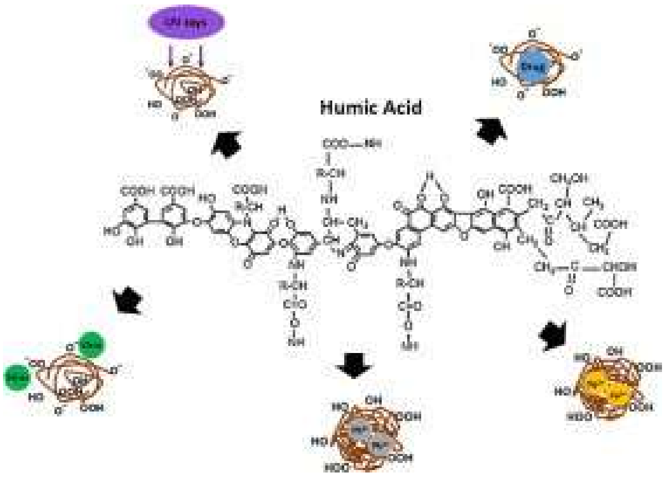

Figure 1. Humic acid composition of phenolic, carboxylic acid, quinone, enolic, and ether functional groups as many peptides and sugars (de Melo et al., 2016).

HS exist naturally in almost all highly viscous media: in soil, leonardite, brown coal, soil peat, river, lake, and other waters, etc. As a result of their decomposition and enzymatic transformation of animal and plant remains, their formation is explained by several theories. The presence of phenolic-carboxyl groups in their composition is determined by their many properties and, above all, water dissociation and, as a result, the absorption of various cations or mycotoxins. Polyelectrolyte properties determine the high efficiency of HS chelation. A number of scientists have shown the high efficacy of these substances in detoxification, antiviral, anti-inflammatory, and anti-cancer effects. It is shown that in nature scanty amounts of humic substances are contained in standing water, clays, and sandy soils. A little more of them are identified in medical mud, humus, and upper soil layers. The highest content in peat ranges from 10 to 40%, in lignite from about 10–30%, and in brown coals, an average of 40% of the volume. It has been shown that specific substances, called oxyhumolites, are formed from brown coal or lignites when exposed to air and water. They include the largest amount (50–80%) of humic substances (Vašková et al., 2023).

Humic acid (HA) is increasingly attracting attention and is becoming widely used in medical practice, health care, and beauty salons. The definition of "humic acid" is a complex mixture of many quantities of different acids naturally present in soils, rivers, and oceanic waters. Humic acids are almost completely degradable residues of organic life—proteins and amino acids of relict plant and animal organisms. Saprophytic bacteria and fungi enzymatically transform these remnants of flora and fauna in aerobic and anaerobic conditions. At the same time, ammonia is released and some of the protein hydrolysis products can become part of humic molecules. This is due to covalent binding to phenolic or quinone cyclic chains, which has already been noted by a number of research scientists (Stevenson, 1994). It is important to note the cation exchangeability of humic substances. It was also noted about the high water retention capacity. HA perfectly binds insoluble ions of various metals their oxides and hydroxides. Thus, bound ions perfectly make them more accessible to nutrition for plants, for example. This uniqueness of HA has been widely used in recent years in organic farming and serves as a good tool for improving product quality and safety and increasing the number of crops. Such results have been obtained by many scientists including in Nepal, for example. Thus, it is shown that HA significantly increases the production parameters and quantity and quality of agricultural products (Gairhe et al., 2021).

Due to the ever-growing global demand for food production, there is widespread overuse of chemical (mineral) fertilizers. This approach has led to global acidification and deterioration of soils across the planet. Scientists point to immediate action to restore the primacy of agrocenosis and soils. Increasingly it is necessary to use technologies using organic fertilizers such as manure or compost which contain vital substances and compounds for quality plant growth and restoration of soil fertility. The direct use of HS increases the supply of plants with the necessary nutrients. Due to the increased metabolism with such biotechnologies, there is an effect of increased absorption of atmospheric CO_2 due to an increase in the yield of the final biomass of plants and yield. There is a clear conclusion about the need for global promotion and application of HS starting with the cultivation of crops both outdoors and indoors including modern vertical greenhouses. This technology significantly reduces the concentration of CO_2 in the atmosphere and creates sustainable agricultural development (Tiwari et al., 2023).

2. Methodology

Humic acid is not a pure fertilizer and is an effective component to be used as a supplement to mineral or organic fertilizers adjusting their balance and useful properties. Agrotechnologists have proven that regular use of humic acid reduces the need for various fertilizers due to the ability of plants to assimilate them better. In some cases, fertilizer application can be completely excluded with a sufficient amount of organic material. It has been shown that using humic acids improve the soil structure by limiting excessive loss of various substances and water in sandy (light) soils and improving soil aeration and water retention too. This is a great benefit for the environment of the agricultural sector and for producers.

HA perfectly stimulates the activity of the overall growth of plants and microorganisms. It catalyzes many biological processes that contribute to the growth and spread of beneficial microflora of microbial origin in the soil. This clearly increases the natural resistance of plants to diseases and pests. There is an active growth of roots especially vertical roots which ensures better absorption of nutrients and process of transpiration of plants. HA plays a vital role in improving the quality of both yields and their appearance through increased synthesis of vitamins and transport of minerals in plants. This effect is directly related to the regulation of the beneficial bacterial community with plants responsible for the processes of speed and quality of plant growth (da Silva et al., 2021). HA reduces the amount of various soluble salts in soils thereby reducing their likely toxicity. Humic acid reduces the shrinkage of the roots that occurs due to the excessive concentration of salt in the soils after fertilization. By increasing the ability of soil colloids to group it improves the root system as a whole and plant development. Humic acid also chelates nutrients especially iron which as a result becomes more available to the plant. It was shown that it's possible to achieve an increase in yield of up to 70% with a parallel reduction of up to 30% in the use of fertilizers and pesticides while having a healthier growth of green mass for both ornamental crops and agricultural and forest park crops. It can be achieved with the regular use of high-quality humic preparations. Same time soil water retention increases significantly which leads to a significant reduction in water use. Thus, it should be noted that clarifying and encouraging farmers to use HS worldwide can also help reduce the concentration of CO_2 in the atmosphere and create a sustainable development of the ecosystem anywhere in the world (Tiwari et al., 2023).

It is already known that the excessive use of mineral fertilizers in agriculture in recent decades has had a detrimental effect on soil properties, especially in terms of reducing biodiversity, organic substances, and especially soil microbiological activity. Excessive use of fertilizers has also increased the risks of almost complete loss of nutrients due to soil leaching. The drainage of groundwater or surface runoff is also disrupted which poses a significant threat to the planet's environment on a national scale. In addition, high levels of fertilizer use can cause an imbalance in the availability of nutrients in the soil, which leads to low nutrient efficiency and metabolic changes. This is due to the fact that plants are not able to adequately absorb and use the absorbed nutrients for their intended purpose. Many effects in plants induced by HA depend on their molecular structure as evidenced by induced molecular structural modifications and their interactions with roots. Root exudates can change the molecular conformation and properties of HS (Nardi et al., 2024). It was also experimentally revealed that it is the physiologically active forms of humic acids that have trigger properties. Thus, physiological forms of humic acids contribute to the launch of a protein synthesis system that responds to adverse growth conditions. In addition, humic acid increases the photosynthetic activity of the plant and also increases the activity of the Rubisco enzyme. Humic substances have an anti-stress effect in conditions of non-living stress. These substances can also increase nutrient absorption and reduce the toxicity of some absorbed elements. Therefore, the use of humic substances when plants are exposed to salinity stress can lead to improved plant growth. In addition, humic acid affects the activity of plant enzymes (Hassan et al., 2023; Khalate et al., 2023).

Many scientists and biotechnology producers consider the process of extraction and purifying HS for further use in various areas—agriculture, animal husbandry, and for humans in various aspects. Based on the tasks set we propose to consider the basic existing principles of obtaining products for agricultural and human usage which could be officially recognized and validated today. It has been well known a number of methods for extracting humic substances, for example, from soil using soft alkaline extraction. All these methods are generally successful and give quite comparable results. However, the extraction method proposed by the International Society of Humic Substances (IHSS) is accepted worldwide as a method of extracting humic substances from soils (Aiken et al., 1985). Nowadays humic acid preparations are available from many manufacturers or specialized supplier companies in the world which are represented by many different types of products such as granules, powder, liquid, and flakes. This is determined depending on the technique of application to the soil, foliar application, seed treatment, drip irrigation, or application simultaneously with mineral fertilizers. It has been shown that the best economic results using HS can be obtained in light and sandy soils with poor humus as well as in reclamation fields. This is typical for almost all soils in dry and hot regions of the planet. As a result of the high rate of mineralization of organic substances that provide these soils with stable humic acids, this factor is indispensable for maintaining and improving soil fertility. The combined use of HS and mineral fertilizers alleviates the problems associated with continuous cropping systems. With HS the number of basic macronutrients (nitrogen, phosphorus, and potassium) and organic matter in the soil available to plants increases resulting in an increased uptake of macronutrients by plants. Various HS salts such as potassium and calcium humate are used as fertilizer additives to increase soil fertility. Increasing the level of natural HS such as potassium humate reduces the need for commercial fertilizers as it improves soil fertility (Karčauskienė et al., 2019; Niewes et al., 2023).

The HA production and purification process is based on the elimination of insoluble humic microparticles from products after alkaline extraction with subsequent deposition of soluble humates. To do this the following acid extraction procedure is performed. The resulting deposited elements (sediment) are cleaned to produce HA. It should be noted that fulvic acids (FA) are concentrated as soluble compounds in an acidic solution. The authors of the technologies proposed to separate humins from soluble alkaline extracts by filter pressing and subsequent centrifugation (Yan et al., 2021). Along with the quality of alkali purification of humates, it is necessary to determine the quality of separation of humins and inorganic impurities. It is this process that determines the qualitative properties of the obtained HA. Due to the wide use of HA in agriculture and especially in medicine such production requires high purity and quality of the product. This requires new and high-quality methods of separation and cleaning. Membrane filtration technology has been shown to be an effective way to reduce the ash content in the final product which allows it to be used for medical purposes. Membrane separation can also improve the water solubility of HA by changing their molecular distribution and removing various inorganic elements (Novák et al., 2001). Although membrane-based separation methods are quite effective and environmentally balanced technologies.

It is noted that there is critically little research to optimize the operating parameters for membrane purification of a humic substance from an alkaline extract based on lignite. Scientists and technologists set a number of tasks to develop a perfect membrane system for the separation and purification of HA from humate retentates obtained as a result of the alkaline extraction process. It was noted that HA showed a certain dispersion between the original coals. While the final yield, molecular weight and amount of oxygen-containing HA groups increased in hydrogen peroxidized coals. It was also noted that the increase in the number of oxygen-containing functional groups depended on the quality of the original coals. The final HA yield depends on the quality of coal production and processing and not on the percentage. The final HA capacity from the original coal compared to the oxidized coal increases significantly from 17.47% to 40.03% (Sarlaki et al., 2019).

It is known that for the deposition of humic acids, they should be cleaned in an alkaline environment. The maximum HA capacity (90.2%) was obtained from the 0.250–0.180 mm size fraction of the coal sample at a reaction temperature and time of 190 °C and 7 h. Proximate analysis proved that the ash and sulfur of lignite can be removed by hydrothermal treatment. Elemental analysis showed that the O/C and H/C ratios were the highest for HA. For residual and raw coals indicates an increase in the content of oxygen and hydrogen in HA. Analytical studies have shown that hydrothermal extraction destroys the macromolecular structure of lignite and during the reaction organic substances are degraded and hydrolyzed (Cheng et al., 2019). Quite recently have shown several approaches to extract HA from lignite—physical, chemical alkaline and acidic as well as biological methods (Jaing et al., 2011).

HA extraction from Bulgarian lignite using NaOH dissolution and HCl sediment was also described. At the same time final product with 83% HA content was obtained at the output. Also, South Moravian lignite with the addition of NaOH (0.5 mol/l) and $Na_4P_2O_7$ (0.1 mol/l) solution with the subsequent addition of 0.5% HCl - HF solution (Stefanova et al., 2016). The method of extraction of HA by oxidation of H_2O_2/HNO_3 is also described (Cihlář et al., 2014). The production of water-soluble polycondensate which had similarities to humic acid, and which simulates the fundamental physico-chemical and spectroscopic properties of natural HA (Drosos et al., 2011) is described. It is also possible to extract HA dissolved in water as well as in a melanin-like polymer complex from wastewater using ammonium sulfate as a natural additive (Khemakhem et al., 2016).

3. Results and Discussion

Humic acids from young brown coals (leonardites) are about 55,000,000 years old from many sources located in Eastern and Western Europe, Asia, China, Canada, and the USA. It is a fossil with global reserves of trillions of tons the efficiency of which is extremely low when used in the energy sector. Leonardites have high humidity and a quite low combustion point and significant atmospheric emissions from their combustion from year to year reduce their global industrial consumption. At the same time, brown coal is a natural treasury containing almost all chemical elements including precious and rare earth metals, essential amino acids, and trace elements, without which no cell organism can develop. For many decades humanity has been in constant search for how to properly use this significant natural resource. There are several issues and obstacles along the way and the main ones are the cost of extracting elements useful for humanity and their subsequent purification of all foreign impurities such as accumulated radionuclides, heavy metals, chlorides, and other toxic and dangerous elements. For tens of millions of years, the formation of coal seams has simultaneously created an almost indestructible molecular bond of carbon with substances that are not always useful not for the environment neither for the soil nor for plants, and of course not for human consumption. Obviously, there have been many attempts to compile molecular formulas for humic substances in the history of science and technology. Nowadays there are dozens of such formulas and some of them only as flowcharts and others that more or less truly reflect the composition and properties of humic and fulvic acids.

Our innovative technology makes it possible to process natural brown coal, leonardite, etc. into high-purity organic biostimulants of the humic-fulvic type. At the end of process final products are free of heavy metals, radionuclides, toxic elements, and other impurities. The method we have taken as a technological basis allows us to clean highly viscous media at the stage of their extraction, during the processing taking place inside the mechano-chemical reactor invented. It carries out acidification processes with the formation of humic acid released from a liquid phase into a heavy phase of a coagulated pulp, carrying out mechanical phase separation processes in a centrifugal field, carrying out liquid-phase mechano-activation and the dispersion of reaction compositions via grinding, using residual "water" in recycling, and including the production of pure water-soluble humic acids and fuel briquettes, as well as allowing for the production of a wide range of vital and useful products (Figure 2).

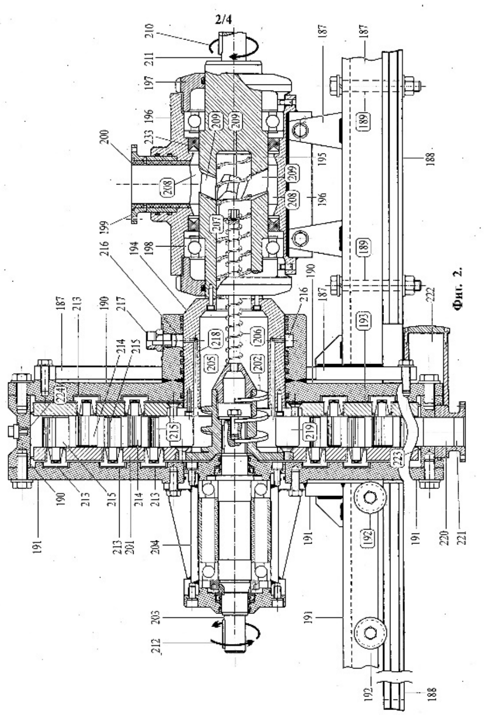

Figure 2. Scheme of the ProtoHumiX® mechanochemical reactor for processing highly viscous media according to Patent WO 2015163785 (Sevast'yanov et al., 2015) implemented in 42 countries.

The extracted substances are directly involved in the metabolic processes of plants, animals, and humans and thanks to their highest ecological purity they offer huge benefits for the health of species. Humic acids extracted from leonardites in accordance with our patented technology are 100% organic in nature, i.e. they have no analogues and cannot be laboratory synthesized as there are no exact molecular formulas for them. The main characteristics of the products that we receive when implementing our patented technology are as follows:

- the highest degree of purification (complete absence of harmful and potentially harmful impurities inherent in all extracts from highly viscosity media), which makes it possible to be used not only in the field of organic farming but also in animal husbandry, poultry, fishery, including for human use.
- the concentration of free active water-soluble humic acids (including fulvic, hymatomelan, and ulmic groups) is at the level of extract concentration (i.e., at a concentration of 10% humic

acids in a solution with about 10% free active water-soluble fractions); therefore, the effectiveness of ProtoHumiX® is many times more effective than any other extracts.

- the technology (unlike the existing ones) allows for the maximum possible extraction of humic acids from highly viscous raw materials.
- it allows to obtain an extract of the final product—the ProtoHumiX® humic acid complex—and the use of which does not prevent fine spraying (does not clog the nozzles of irrigation machines).
- ProtoHumiX® production is protected at the State level by patent protection in 42 countries worldwide both by technology (production method) and by technological equipment.
- Regardless of the territoriality of production, ProtoHumiX® is produced within the framework of a single technology and a single Pan-European (TM “Quinta Essentia”), Chinese, Kazakh, and other trademarks (Figure 3).

Figure 3. Dietary supplement “Quinta Essentia” TERRA for human consumption.

Over the past 7 years, international comprehensive and practical studies have been conducted in the field of impact and improving the efficiency of the use of humic substances in agriculture, animal husbandry, and human use. All products for agriculture and food additives for humans are certified in the European Union and are impressed with their functionality, quality, and safety. During 2023–2024 it has been shown that ProtoHumiX® in plant crop production accelerates seedling germination and contributes to the development of a powerful root system of Chrysanthemum plants. The cuttings (seedlings) were soaked for 60 minutes in water solution of ProtoHumix® and sprayed one time after rooting with a working solution of 0.2 g/l of water (without Cl). The second spraying of plants was carried out during the beginning of budding. Third spraying is carried out normally before flowers starting to bloom (Figure 4).

Figure 4. Chrysanthemum roots system development. 1: control plant; 2: ProtoHumix® treated. Picture on 52 days of cultivation.

Our investigations showed that humic substances can only be obtained by extraction from target-relevant sources and can be further purified to obtain a substance of pharmacological (reference) purity⩾95% (or not to be purified at all and can be used subsequently in various sectors of the farming, industrial sectors and human use; Tables 1, 2).

Table 1. Quality and safety indicators of ProtoHumiX®, solid.

№	Parameter	Result 1	Method 1	Permissible residual amounts, EU Directive 90/496/EEC, nutrition and health claims made on foods
0	Lignosulphonates, %	nil	ISO 19822:2018	-
1	Total content of organic acids, (humic, fulvic, ulmic, hymatomelanic), m/m %	58,0	calculation	-
2	Humic substance, m/m %	39,2	ISO 19822:2018	-
3	Ash free humic acids, (at low pH values), m/m %	28,9	ISO 19822:2018	-
4	The content of free water-soluble humic acids, (regardless of the pH value), m/m %	24,9	ISO 19822:2018	-
5	Content of ulmic acids, m/m %	2,0	Alcohol extraction Gravimetric	-
6	Content of hymatomelanic acids, m/m %	2,0	Alcohol extraction Gravimetric	-
7	Fulvic acid fraction, m/m %	43,6	ISO 19822:2018	-

Table 1. Cont.

№	Parameter	Result 1	Method 1	Permissible residual amounts, EU Directive 90/496/EEC, nutrition and health claims made on foods
8	Moisture contents (water-soluble), m/m %	8,4	ISO 19822:2018	-
9	The content of dry matter, m/m %	91,6	ISO 19822:2018	-
10	Total Mineral matter water-soluble, (ash), m/m %	33,6	ISO 19822:2018	-
11	pH	8,9	ASTM E70	-
12	Cadmium content as Cd, mg/kg	<0,1	AOAC 965.09	0,2
13	Lead content as Pb, mg/kg	0,2	AOAC 965.09	2,0
14	Mercury content as Hg, μg /kg	<20	AOAC 971.21	<100
15	Arsenic content as As, mg/kg	<0,5	AOAC 965.09	1,0
16	Specific effective activity, Cs^{137}, Bq/kg	<0,2	AOAC 973.67	$> 2 \times 10^{-10}$
17	Specific effective activity, Sr^{90}, Bq/kg	<0,5	AOAC 973.67	$> 2 \times 10^{-10}$
18	Effective specific activity of technogenic radionuclides, Bq/kg	<1	calculation	-
19	Specific effective activity, Ra^{226}, Bq/kg	7,8	AOAC 973.67	$> 2 \times 10^{-10}$
20	Specific effective activity, Th^{232}, Bq/kg	14,2	AOAC 973.67	$> 2 \times 10^{-10}$
21	Specific effective activity, K^{40}, Bq/kg	28	AOAC 973.67	$> 2 \times 10^{-10}$
22	Effective specific activity of natural radionuclides, Bq/kg	55,2	calculation	-
23	Hard particles content, %/mkm	<0,1/2	Membrane filtration	-
24	Chlorides as Cl, m/m %	0,01	GOST 10671.7	0,05

Table 2. Quality and safety indicators of ProtoHumiX®, liquid.

№	Parameter	Result 1	Method 1	Result 2	Method 2
0	Lignosulfonates	nil	ISO 19822:2018	-	-
1	Total content of organic acids, (humic, fulvic, ulmic, hymatomelanic), m/m %	15,5	calculation	11,3	Lamar method
2	Content of humic acids, m/m %	10,0	ISO 19822:2018	8,6	Lamar method
3	The content of “bound” humic acids, (at low pH values), m/m %	8,0	calculation	6,6	calculation
4	The content of free water-soluble humic acids, (regardless of the pH value), m/m %	8,0	ISO 19822:2018	6,6	Lamar method
5	Content of ulmic acids, m/m %	2,0	Alcohol extraction Gravimetric	2,0	Methanol extraction & Gravimetric
6	Content of hymatomelanic acids, m/m %	2,0	Alcohol extraction Gravimetric	2,0	Methanol extraction & Gravimetric
7	Fulvic acid content, m/m %	6,0	ISO 19822:2018	2,7	Lamar method
8	Moisture contents, m/m %	84,0	ISO 19822:2018	84,0	Lamar method
9	The content of “dry” substances in the product, minus moisture , (soluble substances and ash), m/m %	16,0	ISO 19822:2018	16,0	Lamar method
10	Mineral content, (ash), m/m %	4,2	ISO 19822:2018	4,2	Lamar method
11	pH	8,6	ASTM E70	8,6	Lamar method
12	Cadmium content as Cd, mg/kg	-	-	<0,1	AOAC 965.09
13	Lead content as Pb, mg/kg	-	-	0,14	AOAC 965.09
14	Mercury content as Hg, mg/kg	-	-	<0,02	AOAC 971.21
15	Arsenic content as As, mg/kg	-	-	<0,5	AOAC 965.09
16	Specific effective activity, Cs^{137}, Bq/kg	-	-	<0,2	AOAC 973.67
17	Specific effective activity, Sr^{90}, Bq/kg	-	-	<0,5	AOAC 973.67
18	Effective specific activity of technogenic radionuclides, Bq/kg	-	-	<1	calculation
19	Specific effective activity, Ra^{226}, Bq/kg	-	-	5,5	AOAC 973.67
20	Specific effective activity, Th^{232}, Bq/kg	-	-	8,6	AOAC 973.67
21	Specific effective activity, K^{40}, Bq/kg	-	-	12	AOAC 973.67
22	Effective specific activity of natural radionuclides, Bq/kg	-	-	17,7	calculation

Table 2. Cont.

№	Parameter	Result 1	Method 1	Result 2	Method 2
23	The content of solid, (ballast) particles in the product for seed soaking technologies, watering and spraying plants, %/mkm	-	-	<0,1/1	Membrane filtration
24	Chlorides as Cl, m/m %	-	-	0,01	GOST 10671.7

The purity has to be confirmed by spectrometric tests and this is the most important quality parameter for humic substances and must strictly comply with the quality and safety of the final products.

4. Conclusions

Based on absolute fundamental and practical conclusions, in our opinion, scientists and especially manufacturers of humic substances around the world should unambiguously understand the importance of this technology and using humic products in many aspects. In times of global warming, soil erosion, destructive wars in Europe, Africa, and the Middle East, pollution and removal of suitable land from agricultural circulation, and a constant increase in the world's population, we face a global responsibility to continue life and solve problems with providing people with sufficient quantity, quality, and safety of food.

Therefore, we bring to the general discussion the issues of quality and safety control in the receipt and implementation of the use of drugs obtained from humic substances - primarily humic and fulvic acids. It is their technological quality that should be strictly unified and comply with the adopted Pan-European standards governing the production of humic acid substances and bio-stimulators, in accordance with Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019, laying down rules on the making available on the market of EU fertilizing products, and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009, and repealing Regulation (EC) No2003/2003 (Regulation (EU) 2019/1009, 2019).

Systematization and strict control of quality and safety at the legislative level with many quantitative and qualitative indicators will prevent the negative consequences of the use of non-certified (not corresponding to quality parameters) products, the use of which in one hundred percent of cases has an extremely negative impact on ecosystems, soils, ground water first of all. Due to the not rarely uncontrolled use of humic substances (not purified from heavy metals and other xenobiotics, for example), we expose not only agroecosystems to all sorts of risks but also all subsequent tropical chains of planet Earth, from microorganisms, plants, and animals to the top of the food chain—humans!

Global legislative regulation of the production and use of high-quality and safe humic drugs for various purposes will allow the state levels of the countries of the world to solve important and urgent environmental problems in harmony with great economic benefits such as:

- increasing soil fertility and creation of artificial soils.
- detoxification (phytoremediation) of agrocenoses.
- increasing the qualitative and quantitative indicators of yield and the final cost of various crops and vegetables.
- reducing the nation's health spending.
- reduction of consumption and savings on the use of mineral fertilizers and pesticides.
- significant improvement in the environment of states and significant economic benefits.

We focus on the need for strict adherence to and continuous improvement of technologies for the production (extraction and purification) of high-quality final products of humic substances in accordance with the sustainable development of ecosystems and strict compliance with biosafety requirements. Due to the presence on the world market of a fairly large number of low-quality products called "humic acids," the latter can potentially damage the ecosystems of all living organisms including humans. Moreover, this kind of product discredits the technology itself and outstanding manufacturers on a global scale. We stress to focus on creating a single world standard for the quality and safety of extracted and purified humic substances with a view to their widespread use in many aspects of life on planet Earth.

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Agricultural & Rural Studies

Article

Determinants of Information Needs on Climate-Smart Agriculture Among Male and Female Farmers Across Farming Systems and Agroecological Zones in Sierra Leone: Implications for Anticipatory Actions

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Abstract: This study explores the determinants of information needed on climate-smart agriculture among male and female farmers across farming systems and agroecological zones in Sierra Leone and the implications for anticipatory actions on the basis of espousing the differences in their susceptibilities and coping mechanisms in order to improve their resilience. Eight hundred and sixty-five households were randomly selected from a sampling frame of one million households generated through house listing in twenty-one villages in Sierra Leone. In addition to secondary weather data, primary data were collected with a structured questionnaire covering climate-smart agriculture practices and analyzed using frequencies, percentages, t-test, trend analysis, Probit regression, and relationship maps to enhance data visualization. The results show that a differential in information needs exists between male and female farmers with female farmers having the highest information need. The determinants of information need are agroecological zone, age, education, marital status, household size, number of children below 18 years, household status, length of stay, farming experience, farming system, adoption, and constraints were significant determinants. From the trend analysis, it was inferred that information needs unmet have a high propensity to transform into anticipatory actions of emergencies and humanitarian crises.

Keywords: information need; anticipatory actions; gender; climate-smart; farming systems; agroecological zones

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1. Introduction

Information is a vital tool for empowerment, making decisions for development, and ascertaining readiness and preparedness for incidences of risks. Agricultural production is enhanced through information by creating awareness, knowledge, and skill (Anmol et al., 2021), all activities across the value-chain for efficient management through changing scenes of operations. The utility of information is often correlated to its influence on profitability, thus limited access to information and technical knowledge constitutes a major barrier to the effective management of agricultural risks (Skaalsveen et al., 2020). Information is crucial to the effective management of agricultural risks (McKune et al., 2018), making adoption decisions (Mulwa et al., 2017), increased resilience (Blazquez-Soriano & Ramos-Sandoval, 2022), adaptation and mitigation Ponce (2020), improved capacity (Intergovernmental Panel on Climate Change [IPCC], 2019), decision-making (Antwi-Agyei et al., 2021).

Climate information services have been leading to an increase in adaptation strategies for climate change, specifically, weather variability (Djido et al., 2021), productivity enhancement, and livelihood protection (Alidu et al., 2022). The application and use of information in response to risks through anticipatory actions are changing the landscape of its utility, importance, and worthiness. Anticipatory actions help in the reduction, mitigation, and enhancement of impacts of disaster and post-disaster response, through the early warning systems (Wilkinson et al., 2020). Farmers are simultaneously exposed to multiple risks and thus need access to diverse information along the production cycles of their enterprises (Korell et al., 2020).

Information Needs Among Farmers

The diversity of farmers' information needs extends to the contents (Amah et al., 2021); typologies and message adequacy; alignment to users' needs (Kumar et al., 2020); and preferred sources and channels of information (Mottaleb et al., 2017). The majority of research on information needs focused on production and market risks (Komarek et al., 2020), to the neglect of the adequacy of measures required by end-users (Nwafor et al., 2020) specific information for different stages of the value chain (Diemer et al., 2021) and emerging needs (Chen & Lu, 2020). Farmers' vulnerability is related to agricultural risks, resilience capacity, and perceived consistency of meteorological data (Rapholo & Diko-Makia, 2020), and farmers' perceptions expressed as information need can serve as an important input into the adaptation and anticipatory planning for specific contexts (Ankrah et al., 2023). Several authors have affirmed that gender-gaps exist in relation to resources and opportunities and the gap gets widened due to the effects of climate change leading to differences in the climate information needs between men and women (Diiro et al., 2016), agro-advisory knowledge (Ngigi & Muange, 2022), adaptation strategies (Ouedraogo et al., 2018), and households' roles and responsibilities (Ngigi et al., 2016). Partey et al. (2020) reported the need for climate information services is gender-neutral, while Adzawla et al. (2020) indicated that although males had higher adaptive capacity than females; the livelihoods of females suffered more impacts than males in Ghana. This study explores the research question on what are there differential determinants of information needs of male and female farmers across farming systems and agroecological zones of Sierra Leone. In the context of Sierra Leone, there have not been any studies on information needs underlying the information-seeking behavior, and the choice of mode of access to the best of our knowledge. The concept of information need is operationalized in this study as a gap between what is and what ought to be to facilitate effective decision-making (Case & Given, 2016). This study focuses on Sierra Leone because it is one of the countries with the highest impacts of climate change (IPCC, 2019). The objective of this study is to analyse the determinants of information needs on climate-smart agriculture among male and female farmers across farming systems and agroecological zones in Sierra Leone and their implications for anticipatory actions.

2. Materials and Methods

The study was carried out in Sierra Leone which is bordered by Guinea, Liberia, and the Atlantic Ocean on the north, east, south, and west respectively (Sierra Leone Agricultural Research Institute [SLARI], 2011). Sierra Leone has four (4) agroecological zones (AEZs) and sixteen (16) districts (SLARI, 2017). The AEZs overlapped into 3–4 districts, so the AEZs are not mutually exclusive of the districts. Food production and other activities from agriculture form the most important contributor to the economy of Sierra Leone (Statistics Sierra Leone, 2017; Bryan et al., 2017). The study covered 7 districts including Kailahun, Bo, Bonthe, Moyamba, Kambia, Koinadugu, and, Western Rural District, across the five administrative provinces namely Eastern, Southern, Northern, North-Eastern, Western Areas of Sierra Leone.

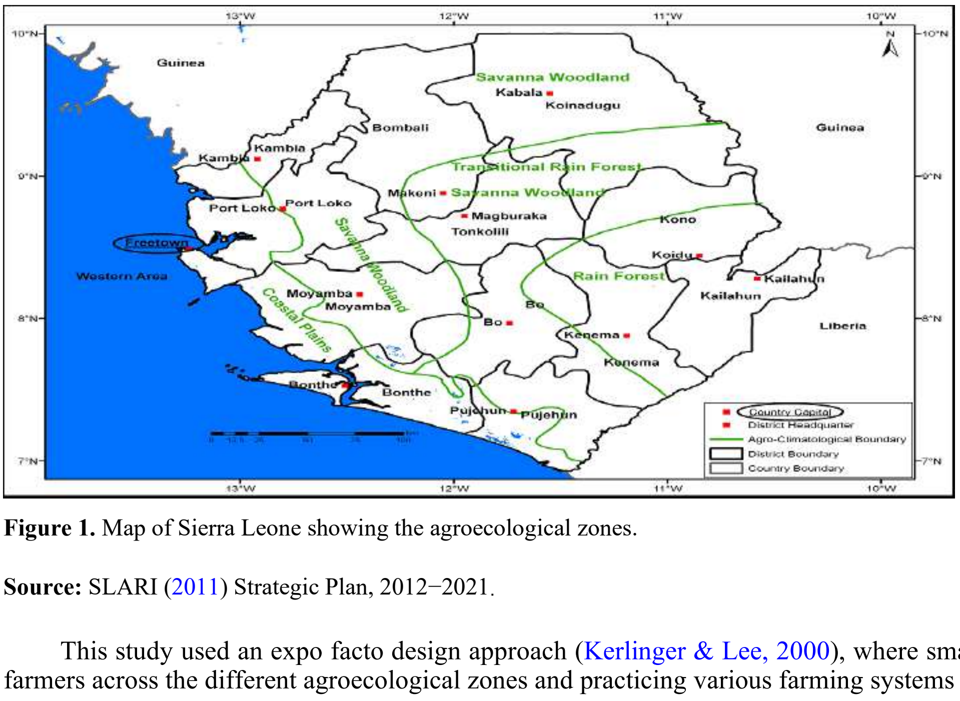

Figure 1. Map of Sierra Leone showing the agroecological zones.

Source: SLARI (2011) Strategic Plan, 2012−2021.

This study used an expo facto design approach (Kerlinger & Lee, 2000), where smallholder farmers across the different agroecological zones and practicing various farming systems in Sierra

Leone constituted the study population. From each of the agroecological zones, districts that are predominantly reflective of the zones were purposively selected. The selected districts are Kailahun, Bo, Bonthe, Moyamba, Kambia, Koinadugu, and Western Rural. Rao Soft sample size calculator was used to obtain sample size from each of the districts with 160, 110, 50, 110, 150, 130, 5, and 150 respectively from the districts. Data were collected through structured questionnaires earlier subjected to face validity of experts in agricultural extension and climate-smart agriculture and recorded a reliability coefficient of 0.87 using a split-half technique. The questionnaire assessed respondents' levels of information needs disaggregated by male and female. Data were analyzed as a reference group. Ethics approval was granted by the committee of the School of Agriculture, Njala University, Sierra Leone. Data were analyzed using percentages and probit regression.

For the probit models, farmers choose from two alternatives of needs or not as expressed by Nagler (1994). The model is appropriate since it can overcome heteroscedasticity and satisfies the assumption of cumulative normal probability distribution (Gujarati, 2004).
It is assumed that Y can be specified as follows:

$$Y = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_{ki} X_{ki} + U_1 \quad (1)$$

And that:

$$\begin{aligned} Yi &= 1 \; if \; Y > 0 \\ Yi &= 0 \end{aligned} \quad (2)$$

Otherwise, Where $X_1, X_2 \ldots X_n$ represents a vector of random variables, β represents a vector of unknown parameters and U represents random disturbance terms (Nagler, 1994). Table 1 presents the list and level of measurements of variables in the Probit model.

t-test analysis

t-test analysis is applied to assess statistical differences for the means of two groups thus comparing the mean score of socio-economic, information needs, and climate-smart agriculture practices of male and female farmers.

The equation used was as follows:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{S_1^2}{N_1}} + \sqrt{\frac{S_2^2}{N_2}}} \quad (3)$$

(Koutsoyiannis, 1977)

Where

X_1 = socio-economic, information needs, and climate-smart agriculture practices of male farmers
X_2 = socio-economic, information needs, and climate-smart agriculture practices of female farmers
S_1^2 = variance of X_1
S_2^2 = variance of X_2
N_1 = number of male farmers
N_2 = number of female farmers

Table 1. Description of variables in the study.

Variables	Description
Agroecological zone	Dummy =1 if rain forest, 0 otherwise
Age	Age in years
Education	Dummy =1 formal education, 0 otherwise
Marital Status	Dummy =1 if married, 0 otherwise
Household size	Number of persons (total)
Dependent Below18	Number of persons below 18 years
Household head status	Dummy =1 if male, 0 otherwise
Length of stay	Length of residence in years
Farming Experience	Farming experience in years
Farming System	Dummy =1 if crop-based, 0 otherwise
Adoption of climate-smart practice	Dummy =1 if yes, 0 otherwise
Constraints to adoption of climate-smart practice	Constraints score

3. Results

Figure 2 presents the results of the gender-disaggregated trends of rainfall, temperature, awareness, incidence, and information needs from the respondents. The trend patterns are very similar between the meteorological data and farmers' perceptions.

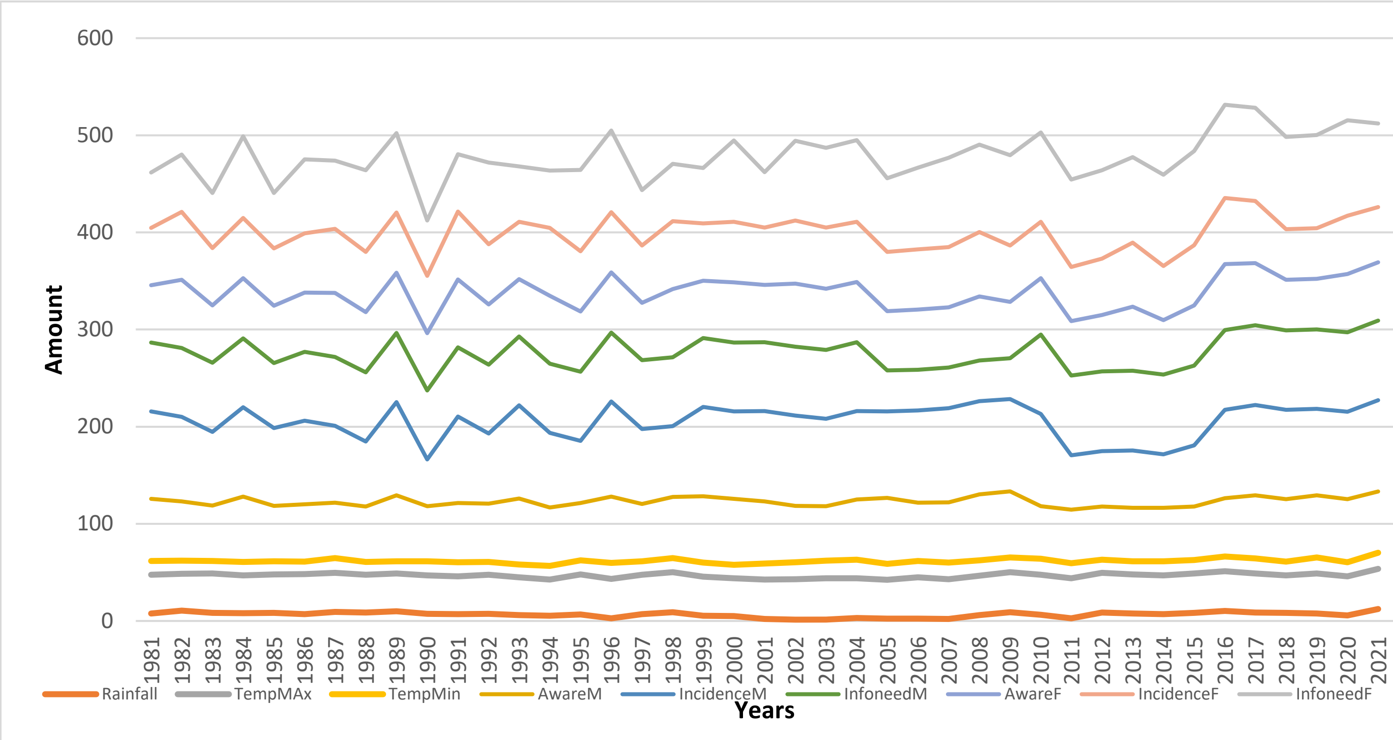

Figure 2. Trends of rainfall, temperature, awareness, incidence, and information need.

Table 2 presents the results on male and female farmers according to information needs on crop-smart practices and their determinants. Twelve crop-smart practices were listed and the results show that 67 % to 69 % of male farmers and 77 % to 79 % of female farmers have high information needs for all practices under crop-smart practices.

Table 2. Male and female farmers according to information needs on crop-smart practices and their determinants.

	Percentage distribution							Probit regression model of determinants		
	Male		Female		t-test			Male	Female	Pooled
Crop-smart practices	Yes	No	Yes	No	t	p	Parameters	Estimate (SE)	Estimate (SE)	Estimate (SE)
Intercropping	421(68.6)	18 (2.9)	197 (78.5)	4 (1.6)	−2.153	.032	AgroZones	.084 (.010) ***	.217 (.025) ***	.148(.016) ***
Crop rotations	418 (68.1)	21 (3.4)	196(78.1)	5(2.0)	−2.095	.037	Age	.014(.001) ***	.034(.002) ***	−.006(.002) ***
Improved crop varieties	420(68.4)	19(3.1)	196(78.1)	5 (2.0)	-2.198	.028	Education	.163(.011) ***	.015(.023)	−.267(.021) ***
Early maturing crop variety	418(68.1)	21(3.4)	191(76)	10(4)	−2.563	.011	Marital Status	.049(.039)	.073(.040)	.099(.050)
Contingency crop planning	419(68.2)	20(3.3)	191(76)	10(4)	−2.613	.009	HHsize	−.022(.004) ***	.050(.008) ***	−.029(.006) ***
Planting resistant crop varieties	415(67.6)	24(3.9)	190(76)	11(4.4)	−2.506	.013	Below18	.035(.008) ***	−.070(.017) ***	.109(.010) ***
Improved stor. and processing	420(68.4)	19(3.1)	194(77)	7(2.8)	−2.388	.017	HHstatus	.400(.054) ***	.318(.048) ***	−.638(.067) ***
Multiple planting dates	424(69.1)	15(2.4)	194(77)	7(2.8)	−2.593	.010	LoStay	.008(.001) ***	−.006(.001) ***	−.026(.001) ***
Crop diversity	419(68.2)	20(3.3)	196(78)	5(2)	−2.146	.032	Farming Exprienc	−.010(.001) ***	−.013(.003) ***	.030(.002) ***
Use of bio-pesticides/bio-enhancer	423(68.9)	16(2.6)	193(77)	8(3.2)	−2.634	.009	Farming System	−1.716(.088) ***	−4.447(.124) ***	−1.593(.082) ***
Mixed farming	417(67.9)	22(3.6)	193(77)	8(3.2)	−2.330	.020	Adoption	.274(.038) ***	.585(.079)	.035(.044)
Creating seed banks	425(69.2)	14(2.3)	194(77)	7(2.8)	−2.645	.008	Constraints	1.420(.130) ***	−1.795(.063) ***	1.375(.115) ***
							Intercept	−5.880 (.364) ***	1.782(.292) ***	−3.514(.349) ***
							Chi-Square	5.087E+15	2.897E+31	1.079E+18
							df	600	238	851
							p	0.00	0.00	0.00

Table 3 presents the results on the percentage distribution of male and female farmers and Probit regression model of determinants of water-smart practices information need. Twelve water-smart practices were listed and the results show that 4 % to 7 % of male farmers and 2.8 % to 5 % of female farmers have high information needs for all practices under crop smart practices.

Table 3. Percentage distribution of male and female farmers and Probit regression model of determinants of water-smart practices information need.

Percentage distribution							Probit regression model of determinants			
	Male		**Female**		**t-test**			**Male**	**Female**	**Pooled**
Water-smart practices	Yes	No	Yes	No	t	p	Parameters	Estimate (SE)	Estimate (SE)	Estimate (SE)
Water harvesting	40(6.5)	459(74.8)	12(4.8)	201(80.1)	−1.592	.112	Agroecological zone	.088 (.014) ***	.204(.023) ***	.137(.012) ***
Mulching	32(5.2)	455(74.1)	9(3.6)	200(80)	−1.646	.100	Age	.025(.001) ***	.024(.003) ***	.017(.001) ***
Cover cropping	33(5.4)	454(73.9)	7(2.8)	202(81)	−1.814	.070	Education	−.102(.018) ***	−.070(.027) ***	−.105(.015) ***
Drip/Farrow−bed irrigation	39(6.4)	448(73.0)	14(5.6)	195(77.7)	−1.494	.136	Marital Status	.337(.058) **	.101(.049) **	.226(.038) ***
Drainage management	42(6.8)	445(72.5)	13(5.2)	196(78)	−1.648	.100	HHsize	−.055(.006) ***	.076(.007) ***	−.007(.004) *
Land leveling	30(4.9)	457(74.4)	8(3.2)	201(80)	−1.659	.098	Below18	.111(.010) ***	−.005(.017)	.060(.008) ***
Conservation agriculture	30(4.9)	457(74.4)	8(3.2)	201(80)	−1.659	.098	HHstatus	−.863(.172) ***	−.040(.052)	−.651(.060) ***
Contour planting	31(5)	456(74.3)	12(4.8)	197(79)	−1.409	.160	LoStay	.003(.001) ***	.013(.002) ***	.005(.001) ***
Terraces and bunds	32(5.2)	457(74.4)	12(4.8)	197(79)	−1.327	.185	Farming Experience	−.006(.002) ***	−.012(.003) ***	−.019(.001) ***
Planting pits	30(4.9)	459(74.8)	11(4.4)	198(79)	−1.340	.181	Farming System	−2.129(.051) ***	−2.281(.098) ***	−2.176(.045) ***
Water storage	26(4.2)	475(77.4)	12(4.8)	201(80)	−1.072	.284	adoption	.103(.039) ***	.688(.057) ***	.208(.031) ***
Dam, pits, ridges	25(4.1)	464(75.6)	11(4.4)	198(79)	−1.199	.231	Constraints	.170(.045) ***	.090(.059)	.179(.037) ***
							Intercept	−2.297(.273)	−4.210(.296) ***	−2.177(.167) ***
							Chi-Square	9.045E+14	6.947E+15	2.346E+15
							df	600	238	851
							p	0.00	0.00	0.00

The results of the distribution of male and female farmers according to information needs on nutrient-smart practices and their determinants are presented in Table 4. Eleven nutrient-smart practices were listed and the results show that 4.4 % to 65 % of male farmers and 4 % to 67% of female farmers have high information needs for all practices under crop smart practices.

Table 4. Distribution of male and female farmers according to information needs on Nutrient-smart practices and their determinants.

	Percentage distribution						Probit regression model of determinants			
	Male		Female		t-test			Male	Female	Pooled
Nutrient-smart practices	Yes	No	Yes	No	t	p	Parameters	Estimate (SE)	Estimate (SE)	Estimate (SE)
Boundary trees and hedgerows	30(4.9)	398(64.8)	8(4.4)	167(67)	−.430	.667	Agroecological zone	.043(.015)***	.159(.028)***	.088(.010)***
Green manuring	55(9)	363(59.1)	25(10)	133(53)	1.615	.107	Age	.013(.002)***	.005(.003)*	.022(.001)***
Integrated soil fertility mangt	42(6.8)	386(62.9)	12(4.8)	166(66)	−.660	.510	Education	−.300(.023)***	−.081(.027)***	−.124(.013)***
Organic fertilizers	40(6.5)	388(63.2)	15(6)	163(65)	−.436	.663	Marital Status	.289(.064)***	.044(.048)	.611(.028)***
Green manuring	33(5.4)	395(64.3)	13(5.2)	165(66)	−.385	.700	HHsize	−.057(.006)***	.032(.009)***	.024(.003)***
Nitrogen-fixing trees on farms	35(5.7)	393(64.0)	13(5.2)	165(65.7)	−.433	.665	Below18	.141(.010)***	−.022(.019)	−.037(.007)***
Multipurpose trees	38(6.2)	390(63.5)	12(4.8)	166(66)	−.564	.573	HHstatus	−.652(.171)***	−.099(.050)**	−.788(.062)***
Imp. fallow fertilizer/shrubs	28(4.6)	400(65.1)	11(4.4)	167(66.5)	−.382	.703	LoStay	−.008(.001)***	.008(002)***	.009(.001)***
Woodlots	27(4.4)	391(63.7)	12(4.8)	146(58)	1.501	.134	Farming Experience	.010(.002)***	−.011(.003)***	−.025(.001)***
Fruit orchards	29(4.7)	389(63.4)	10(4)	148(59)	1.341	.181	Farming System	−2.430(.052)***	−3.034(.111)***	−2.327(.046)***
Organic agriculture/farming	398(64.8)	30(4.9)	169(67.3)	9(3.6)	.023	.981	adoption	.096(.041)**	.294(.053)***	.084(.024)***
							Constraints	−.092(.041)**	.189(.055)***	.279(.027)***
							Intercept	−.638(.265)**	−1.187(.251)***	−2.471(.140)***
							Chi-Square	7.79E+16	8.573E+18	4.597E+16
							df	600	238	851
							p	0.00	0.00	0.00

In Table 5, the results of the percentage distribution of male and female farmers and the Probit regression model of determinants of energy/carbon-smart practices on information needs are presented. Nine crop-smart practices were listed, and the results show that 6 % to 10% of male farmers and 2.8 % to 5.6 % of female farmers have high information needs for all practices under energy/carbon smart practices.

Table 5. Percentage distribution of male and female farmers and Probit regression model of determinants of energy/carbon-smart practices information need.

	Percentage distribution						**Probit regression model of determinants**			
	Male		**Female**		**t-test**			**Male**	**Female**	**Pooled**
Energy/carbon-smart practices	Yes	No	Yes	No	t	P	Parameters	Estimate (SE)	Estimate (SE)	Estimate (SE)
Biogas	46(7.5)	418(68.1)	13(5.2)	144(57)	3.413	<,001	Agroecological zone	−.009(.012)	.274(.023)***	.149 (.009)***
Agroforestry	58(9.4)	406(66.1)	14(5.6)	143(57)	3.194	.002	Age	.018(.001)***	.015(.002)***	.011(.001)***
Integrated pest management (IPM)	18(2.9)	469(76.4)	1(0.4)	187(74.5)	.985	.325	Education	.014(.014)	−.023(.025)	−.001(.010)
Biochar	62(10.1)	402(65.5)	14(5.6)	143(57)	3.101	.002	Marital Status	−.104(.046)**	.148(.045)***	−.121(.030)***
Solar powered farm implements	46(7.5)	418(68.1)	13(5.2)	144(57)	3.413	<,001	HHsize	−.019(.005)***	.046(.008)***	.051(.002)***
Improved stoves	45(7.3)	419(68.2)	14(5.6)	143(57.0)	3.497	<,001	Below18	.004(.010)	−.038(.016)**	−.036(.005)***
Reduced tillage	42(6.8)	422(68.7)	13(5.2)	144(57)	3.507	<,001	HHstatus	.314(.069)***	.179(.048)***	.180(.028)***
Carbon trading	42(6.8)	422(68.7)	13(5.2)	144(57)	3.507	<,001	LoStay	.008(.001)***	.009(.002)***	.011(.001)***
Use of renewable energy sources	37(6)	577(94)	7(2.8)	244(97.2)	−2.284	.023	Farming Experience	−.018(.002)***	−.015(.003)***	−.020(.001)***
							Farming System	−1.507(.052)***	−3.852(.113)***	−1.921(.045)***
							adoption	.461(.056)***	.015(.056)	.003(.029)
							Constraints	0	0	0
							Intercept	−2.980(.191)***	−.921(.296)***	−1.883(.120)***
							Chi-Square	4.515E+9	7.922E+16	9.983E+11
							df	600	238	851
							p	0.00	0.00	0.00

The results on weather-smart agriculture are presented in Table 6, which shows the distribution of male and female farmers according to information needs on weather-smart practices and their determinants. Ten weather-smart practices were listed, and the results show that 5.2 % to 5.9 % of male farmers and 2.4 % to 2.8 % of female farmers have high information needs for all practices under weather-smart practices.

Table 6. Distribution of male and female farmers according to information needs on weather-smart practices and their determinants.

	Percentage distribution						Probit regression model of determinants			
	Male		Female		t-test			Male	Female	Pooled
Weather-smart practices	Yes	No	Yes	No	t	p	Parameters	Estimate (SE)	Estimate (SE)	Estimate (SE)
Weather forecasting	33(5.4)	581(94.6)	7(2.8)	244(97.2)	−1.869	.062	Agroecological zone	−.162(.014) ***	.627 (.027) ***	.020(.014)
Farm Insurance	36(5.9)	578(94.1)	7(2.8)	244(97.2)	−2.182	.029	Age	.036(.001) ***	.060(.003) ***	.028(.001) ***
Agro-weather advisory services	36(5.9)	578(94.1)	7(2.8)	244(97.2)	−2.182	.029	Education	−.173(.017) ***	−.090(.030) ***	−.292(.020) ***
Climate housing	34(5.5)	580(94.5)	7(2.8)	244(97.2)	−1.975	.049	Marital Status	.138(.052) ***	.603(.050) ***	.503(.035) ***
Climate data, maps and atlas	33(5.4)	581(94.6)	7(2.8)	244(97.2)	−1.869	.062	HHsize	−.116(.006) ***	.060(.009) ***	−.015(.005) ***
Early weather warning systems	36(5.9)	578(94.1)	7(2.8)	244(97.2)	−2.182	.029	Below18	.211(.010) ***	−.083(.019) ***	.041(.010) ***
Agro-ecological maps	32(5.2)	582(94.8)	7(2.8)	244(97.2)	−1.762	.079	HHstatus	−.519(.163) ***	.526(.053) ***	−.638(.064) ***
Agrometeorological Bulletins	33(5.4)	581(94.6)	6(2.4)	245(97.6)	−2.247	.025	LoStay	.016(.001) ***	−.001(.002)	.004(.001) ***
Seasonal climate forecasting	32(5.2)	582(94.8)	7(2.8)	244(97.2)	−1.762	.079	Farming Experience	−.018(.002) ***	−.045(.003) ***	−.017(.002) ***
Agrometeorological advisories services	425(69.2)	14(2.3)	194(77)	7(2.8)	−2.645	.008	Farming System	−.504(.034) ***	−.867(.070) ***	−.409(.032) ***
							adoption	−.563(.035) ***	.418(.057) ***	−.337(.034) ***
							Constraints	.184(.038) ***	.087(.054)	.096(.036) ***
							Intercept	−2.913(.241) ***	−8.392(.285) ***	−3.606(.165) ***
							Chi-Square	2.001E+11	4.152E+11	3.171E+7
							df	600	238	851
							p	0.00	0.00	0.00

Figure 3 shows the results of the relationship map exploring data visualization to describe the interactions among gender and information needed for crop-smart, nutrient-smart, energy/carbon-smart water-smart, and weather-smart. The total scores on the information need score rating scale were obtained for each of the climate-smart practices as well as the information needed. The total scores were further categorized into high and low, using the mean scores, and the relationship map was plotted. In the map, based on the interpretation of data visualization, the thickness of the lines, and the size of the circles represent the magnitude of the relationship and the number of respondents in each linkage, such that the thicker the lines and bigger the circles the higher the proportion of respondents that have indicated the magnitude of the effects. Similarly, color codes for the different variables enhance the readability and the manifestations of features associated with such variables. Berry (2018) reveals that relationship mapping shows patterns and the likelihood of their occurrence for exploring new patterns and hypothesis exploration without implying causation. International Business Machines (2021) stated that relationship maps show through visual representation the relationships, influence, and connections among variables using the nodes, and links to show strength of influence between nodes.

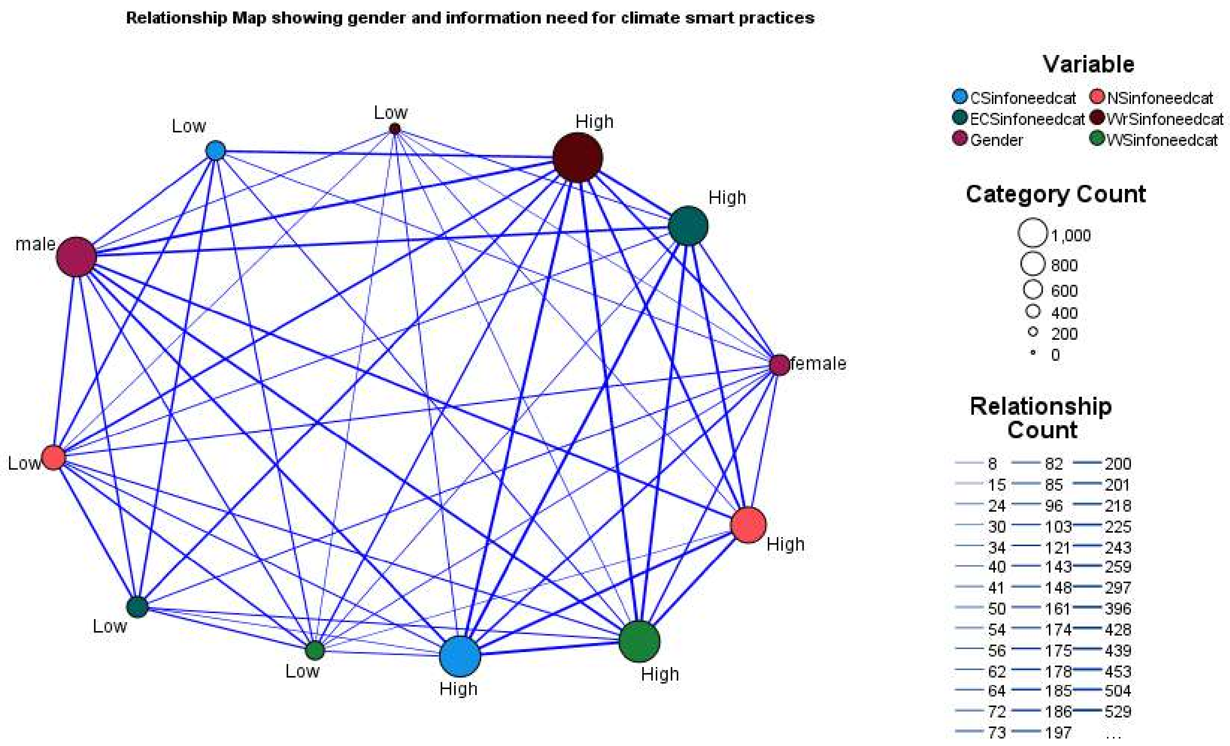

Figure 3. Relationship map showing gender and information needs for climate-smart practices.

4. Discussions

In Figure 2, the perceptions of awareness, incidence, and information need were more pronounced between 2011 and 2017 than what the patterns from meteorological data revealed. This may be due to the fact that the intensity of the consequences of the climatic variability was so strong among farmers. Simelton et al. (2013) reported that farmers observed high variability in the inter-yearly timing of rain onsets, dry days, volume of rainfall, and rainfall cessation to be different from recorded meteorological data. The meteorological data similarly proved otherwise, although farmers reported decreasing rainfall, sunshine, maximum, and minimum temperature from 2009 to 2018 in southern Ghana. Hubertus et al. (2023) found that farmers' perception of increasing unreliability of short and long rainfall seasons, delayed beginning, and earlier stoppage, high rainfall intensity, and unstable pattern of rainfall and droughts, partially disagree with meteorological data. According to Balasha et al. (2023), farmers' perceptions and local historical climate data were consistent; while Nduwayezu et al. (2023) found that the perception of farmers from different elevations matched the Weather data in terms of increasing rainfall and decreasing temperature. The trend of these findings affirms the report of Omasaki and Mokoro (2023) that farmers with limited information on climate variations have high information needs, and a high propensity to perceive changes in weather patterns.

The results in Table 2 may be attributed to the fact that a high proportion of male and female farmers engage in crop production activities and may not be aware of crop-smart practices. Bai et al. (2022) reported that smallholder crop farmers in Sierra Leone required information on suitable crop varieties, pest and disease management, soil conservation, and water management. Kansiime et al. (2021) reported that men and young people meet their information needs by exploring a diversity of information sources than women and elderly people. Similarly, the results of the t-test show significant differences between male and female farmers across the 12 practices. According to Gebre et al. (2019) and Oduniyi and Tekana (2021), male and female farmers experience different levels of access to inputs and information acquisition. Nadeeshani Silva (2022) noted that information availability is ranked as an important factor than cultural proximity for information access among farmers in Sri Lanka. The determinants of information needs on crop-smart techniques among male and female farmers, as well as the pooled data are agroecological zone, age, education, household size, number of children below 18 years, household status, length of stay, farming experience, farming system, adoption, and constraints. Marital status was not significant either for male or female farmers as well as the pooled data. Kosoe and Ahmed (2022) reported factors influencing information needs to include gender, education level, Mamun et al. (2021) indicated agroecological zones, land tenure systems, religion; Myeni and Moeletsi (2020) noted marital status, access to credit, access to extension services, and Kassa and Abdi (2022) stated education, household size, income, climate change perception, and farmland size.

The findings in Table 3 may be attributed to the fact that a high proportion of male and female farmers do not engage in water-smart activities and may not be aware of water-smart practices. Smallholder farmers in Sierra Leone require information for climate-resilient production systems (Bai et al., 2022); targeting information to various gender and age categories (Kansiime et al., 2021). The t-test results show that significant differences between male and female farmers were recorded for 3 techniques namely cover cropping, land leveling, and conservation, while no significant differences were recorded for other techniques. Nadeeshani Silva (2022) found that agricultural instructors and neighbors are the most trusted and reliable sources of information among farmers; and a negative but significant relationship between gender and information needs (Addison et al., 2018; Namonje-Kapembwa & Chapoto, 2016). The results of the probit regression analysis on the determinants of information needs on water-smart techniques among male and female farmers, as well as the pooled data show that agroecological zone, age, education, marital status, household size, number of children below 18 years, household status, length of stay, farming experience, farming system, adoption and constraints were significant determinants. Information needs have been reported to be influenced by climate and ecological settings, access to extension services, farming systems, market, knowledge, awareness, and skills, (Nyang'au et al., 2021; Dhehibi et al., 2022).

The findings in Table 4 may be attributed to the fact that organic farming is the most popular technique among all the nutrient-smart practices. Several reports suggest that meeting the information needs and removing information mismatches enhance higher adaptation (Djido et al., 2021; Yegbemey et al., 2021; Kumar et al., 2020). Similarly, the results of the t-test show no significant differences between male and female farmers across the eleven practices. Freeman and Qin (2020) noted that low acquisition of agricultural information leads to poor adoption of improved inputs and technologies. The determinants of information needs on nutrient-smart techniques among male and female farmers, as well as the pooled data, are agroecological zone, education, household size, length of stay, and farming experience. According to Serote et al. (2023), information need is influenced by contact with extension and advisory services; agricultural information access (Kelil et al., 2020), information awareness and understanding (Elia, 2017), information source (Colussi et al., 2022), farming systems and household size (Akano et al., 2023).

The findings in Table 5, energy-smart is one of the categories of climate-smart agriculture that reduces greenhouse gas emissions; soil carbon sequestration; and crop resilience (Taneja et al., 2014). Similarly, the results of the t-test show significant differences between male and female farmers across the nine practices except for integrated pest management. Zhang et al. (2016) stated that differences exist between male and female farmers in relation to agricultural information. The determinant of information needs on energy/carbon-smart techniques among male and female farmers, as well as the pooled data are agroecological zone, age, education, household size, number of children below 18 years, household status, length of stay, farming experience, farming system, adoption, and constraints. Khatri-Chhetri et al. (2017) found that factors influencing information needs include technologies and their cost of implementation. Omodara et al. (2023) and (Musafiri et al., 2020) reported similar findings in Nigeria and Zimbabwe respectively.

In Table 6, the results may be attributed to the fact that there is a high level of awareness of the roles weather information plays in helping farmers adapt to climate change a high proportion of male and female farmers engage in crop production activities and may not be aware of crop-smart practices. The depiction of climate change as an existential threat to livelihoods has stressed the need for adequate information and timely training on climate change (Olorunfemi et al., 2020). Similarly, the results of the t-test show significant differences between male and female farmers across the 10 practices although mostly at a 10% significance level. Ajadi et al. (2015) and Dhehibi et al. (2022) found that culture manifests through gender in terms of access to information and decision-making. The determinants of information needed on crop-smart techniques among male and female farmers, as well as the pooled data are agroecological zone, age, education, household size, number of children below years, household status, length of stay, farming experience, farming system, adoption and constraints. The correlates of information needs are social networks and information, finance and extension services, inputs and market linkages (International Fund for Agricultural Development, 2018), information, extension services, and market opportunities (Kargbo et al., 2023); weather information, extension services, credit, social networks, and community-based organizations (Muyanga et al., 2022; Nhemachena et al., 2020), access to, land tenure security, access to finance, household size, and education level (Haregewoin et al., 2020) access to credit, market information, and technical assistance, access to inputs, credit, and extension services, (International Fund for Agricultural Development, 2018) and access to training and technical assistance (Iiyama et al., 2014).

Figure 3 shows that most thick lines are linked to male farmers, while most thin lines are linked to female farmers. This implies that more female farmers have higher information needs than their male counterparts on crop-smart, nutrient-smart, energy/carbon-smart, water-smart, and weather-smart. Haque et al. (2023) and Ge et al. (2023) noted that socioeconomic characteristics and, access to agricultural extension influence gender and climate change perception. The results show that weather information need has the highest number of thick lines connected to other variables. This may be associated with the fact that weather information is believed to have overarching effects and impacts on adaptation. Matere et al. (2023) found that farmers accessed weather forecasts and agrometeorological advisories. Similarly, high information needs are depicted by big circles are much bigger than the low information needs that were represented by small circles.

Implications for Anticipatory Actions

The effects of the cumulative duration, magnitude, frequency, and severity of climate-related hazards have manifested in different forms of disasters and poor progress toward the achievement of sustainable development goals. The novelty of this study is the extrapolation of the links between information needs and anticipatory actions. There is therefore a need for a comprehensive, systemic perspective on risks and underlying causes (United Nations Office for Disaster Risk Reduction, 2022). Information need is a precursor to anticipatory actions and disaster risks due to the fact that risk assessments for complex risks often rely on information in various forms and formats on the hazard, exposure, and vulnerability. The information needs would serve as inputs into data for risk identification and analysis (Zebisch et al., 2021), which will enhance anticipatory adaptation to potential risks (Association of Southeast Asian Nations, 2022) in terms of information, planning, and priority setting (Blazquez-Soriano & Ramos-Sandoval, 2022) and thus the capacity for anticipatory actions are situated within the adaptation-mitigation continuum (de la Poterie et al., 2023). The anticipatory action continuum consists of early warning and action space, forecast-based financing-early action gaps, and livelihood protection. The gaps in effective recognition of information needs often transform into a disaster that requires anticipatory actions. Across the landscape of development activities, anticipatory actions have activated reactive programming where adaptation actions are responsive rather than proactive programming that builds on preparedness to potential shocks (Levine et al., 2020). The usefulness of risk assessment depends on the determination of information needs and its correlates to prevent climate-related hazards and ensure that future development pathways do not create new risks.

5. Conclusions

The findings from this paper have added to the literature through large-scale evidence of the Determinants of information need on climate-smart agriculture among male and female farmers across farming systems and agroecological zones in Sierra Leone: Implications for anticipatory actions. Male and female farmers' information need was specifically compared on indicators of crop, water, nutrient, energy/carbon, and weather-smart agricultural practices. A differential exists in information needs exists between male and female farmers with female farmers having the highest information need. The determinants of information need are agroecological zone, age, education, marital status, household size, number of children below 18 years, household status, length of stay, farming experience, farming system, adoption, and constraints were significant determinants. It can be inferred from the findings that information need is a precursor to anticipatory actions and disaster risks due to the fact that risk assessments for complex risks often rely on information in various forms and formats on the hazard, exposure, and vulnerability. The usefulness of risk assessment depends on the determination of information needs and its correlates to prevent climate-related hazards and ensure that future development pathways do not create new risks. The trend patterns are very similar between the meteorological data and farmers' perceptions. It is therefore conditional that unmet information needs have a high propensity to transform into anticipatory actions for emergencies and humanitarian crises.

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Agricultural & Rural Studies

Article

Assessing the Impact of SNAP-Ed: A Comprehensive Evaluation Framework for Healthy Living Promotion in the United States

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Abstract: The Supplemental Nutrition Assistance Program Education (SNAP-Ed) plays a crucial role in promoting healthy food choices and physically active lifestyles among low-income populations. This article proposes a comprehensive evaluation framework for SNAP-Ed initiatives to assess the program's reach, implementation, outcomes, and cost-effectiveness. The framework incorporates key components such as needs assessment, process evaluation, outcome evaluation, and economic evaluation. By integrating various data sources and methods, the proposed framework enables a holistic understanding of the program's strengths, challenges, and opportunities for improvement. It emphasizes the importance of rigorous evaluation methods to measure the impact of SNAP-Ed interventions on nutrition knowledge, attitudes, behaviors, and overall health outcomes. The framework aims to provide a structured approach for SNAP-Ed Implementing Agencies to demonstrate the program's effectiveness and guide decision-making for continuous improvement.

Keywords: SNAP-Ed; evaluation framework; nutrition education; outcome assessment; program improvement

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1. Introduction

Food security is an essential condition in defining the health of a population and the prosperity of a country (George, 2009; Lor & George, 2014; Singhania et al., 2022). In this regard, the Supplemental Nutrition Assistance Program Education (SNAP-Ed) is an important milestone in the United States. It is also an essential component of the broader Supplemental Nutrition Assistance Program (SNAP) in the United States, which was meant to ensure healthy eating and living for everyone. SNAP-Ed aims to provide nutrition education to individuals and families eligible for SNAP benefits, assisting them in making healthier food choices within a limited budget and promoting physically active lifestyles in alignment with the Dietary Guidelines for Americans (Burke et al., 2022). Research has shown that SNAP-Ed interventions have led to positive outcomes such as increased fruit and vegetable consumption, improved food security, better dietary outcomes, and enhanced nutrition-related behaviors among low-income populations (Young et al., 2013; Rivera et al., 2016; Caldwell et al., 2021; Ryan-Ibarra et al., 2020).

SNAP-Ed is implemented through various channels, including schools, farmers markets, and community organizations, with the objective of reaching SNAP-eligible households and participants (Wall et al., 2011; Scherr et al., 2021). The program underscores the significance of education in advocating for healthier food choices, efficient food resource management, and overall dietary enhancement (Adedokun et al., 2020). By offering nutrition and physical activity education, SNAP-Ed aims to empower individuals to make well-informed decisions regarding their food purchases and consumption habits (Scherr et al., 2021).

Studies have indicated that SNAP-Ed interventions can result in notable enhancements in food security, particularly among households with children (Rivera et al., 2016; Eicher-Miller et al., 2020). Furthermore, SNAP-Ed programs have been associated with improved cardiovascular fitness in school-aged children, highlighting the positive influence of nutrition education on physical health outcomes (Thompson et al., 2020). Despite the advantages of SNAP-Ed, challenges persist in delivering direct nutrition education programs, especially in rural areas where obstacles like limited transportation and food supply can impede implementation (Haynes-Maslow et al., 2019). It is important to develop strategies to overcome these barriers to ensure the effective dissemination of nutrition education to all eligible individuals and families (Haynes-Maslow et al., 2019).

2. The SNAP-Ed Program: History and Prospects

The SNAP-Ed program has a history dating back to the 1960s when the Food Stamp Program, now known as SNAP, was first introduced. Pilot nutrition education initiatives were launched in the late 1970s and early 1980s, leading to the formal establishment of SNAP-Ed in 1992 under the Food and Nutrition Service (FNS) of the United States Department of Agriculture (USDA) (Calancie et al., 2015). Initially focused on providing nutrition education, SNAP-Ed has expanded to include obesity prevention and the promotion of physical activity, aligning with public health goals to combat chronic diseases like obesity (Buscemi et al., 2019). The Healthy, Hunger-Free Kids Act of 2010 played a crucial role in reauthorizing SNAP-Ed and providing additional funding to support its efforts in fostering healthy eating habits and active lifestyles among low-income populations (Linder, 1999).

SNAP-Ed has emphasized evidence-based approaches to ensure the effectiveness of its interventions, aligning its programming with best practices in nutrition education and behavior change (Grimsey & Lewis, 2007). The program has also broadened its reach through public-private partnerships and collaborations with various stakeholders, including community organizations and healthcare providers, to enhance the impact of its initiatives (Kraak et al., 2011). Today, SNAP-Ed operates nationwide, offering nutrition education and obesity prevention services through various channels such as classroom-based programs, community events, social marketing campaigns, and policy, systems, and environmental change initiatives (Burke et al., 2019). By utilizing these multifaceted strategies and partnerships, SNAP-Ed continues to play a vital role in promoting healthy behaviors and reducing the risk of chronic diseases among low-income individuals and families across the United States.

The SNAP-Ed program faces several challenges and opportunities that will shape its future. One significant challenge is the difficulty in data collection due to the program's tailored interventions at the community level, making it challenging to gather uniform data for national effectiveness assessment (Lohse & Wamboldt, 2013). Also, the broad focus of recent programs, targeting various levels of influence within communities, lacks sufficient peer-reviewed studies evaluating their impact (Scherr et al., 2021).

To address these challenges, the USDA's Food and Nutrition Service launched the National Program Evaluation and Reporting System (N-PEARS) to enhance data collection and evaluation (Lohse & Wamboldt, 2013). Moreover, the SNAP-Ed Behavior Outcome Measurement Toolkit was introduced to support individuals in making healthy choices, aligning with the SNAP-Ed Evaluation Framework (Sadeghzadeh et al., 2022). The FY 2024 SNAP-Ed Plan Guidance provides states with policy direction for operating the SNAP Nutrition Education and Obesity Prevention Grant Program (Sanjeevi, 2024).

These initiatives offer prospects for the SNAP-Ed program by improving data collection, enhancing intervention effectiveness, and providing policy guidance. The future of SNAP-Ed will be influenced by these efforts, ensuring that the program effectively meets the needs of SNAP-eligible individuals. Continuous monitoring and evaluation will be crucial to adapting strategies and ensuring positive outcomes for the program's participants.

3. Objectives of the Study

(1) To highlight the value of a robust evaluation framework for assessing the reach, implementation, outcomes, and cost-effectiveness of SNAP-Ed initiatives.

(2) To provide a structured approach to measure the impact of the program and guide decision-making for State agencies and Implementation partners.

(3) To address the challenges in implementing a comprehensive evaluation framework, including resource requirements and scalability issues.

To ensure the successful implementation of the SNAP-Ed nutritional education program, a robust evaluation framework is essential (Rivera et al., 2016). Effective program evaluation plays a critical role in assessing the reach, implementation, outcomes, and cost-effectiveness of SNAP-Ed initiatives (Bleich et al., 2020). A comprehensive evaluation framework provides a structured approach to measure the impact of the program and guide decision-making for State agencies and Implementation partners (Kaiser et al., 2015). However, challenges exist in implementing such a comprehensive evaluation framework, including resource requirements and scalability issues (Sanjeevi, 2024). Typical frameworks' focus on short-term outcomes may limit its ability to capture the long-term impact of SNAP-Ed interventions on participants' health and well-being (Haynes-Maslow et al., 2018). Addressing these concerns is crucial to enhance the robustness and effectiveness of the evaluation process and ensure that SNAP-Ed initiatives are evaluated comprehensively and accurately (Leung & Wolfson, 2019).

The proposed evaluation framework emphasizes the importance of rigorous evaluation methods to assess the effectiveness of SNAP-Ed interventions (Young et al., 2013). By incorporating key evaluation components such as needs assessment, process evaluation, outcome evaluation, and economic evaluation, the framework aims to provide a comprehensive understanding of the program's impact (Thompson et al., 2020). This structured approach enables SNAP-Ed Implementing Agencies to measure key outcomes and demonstrate the program's reach and effectiveness at various levels (Sadeghzadeh et al., 2022). By integrating various data sources and methods, the proposed framework enables a holistic understanding of the program's strengths, challenges, and opportunities for improvement. It incorporates a needs assessment, program design and implementation, process evaluation, outcome evaluation, economic evaluation, and a continuous improvement cycle. This approach ensures that the SNAP-Ed program is tailored to the specific needs of the target population and delivers measurable positive impacts on nutrition knowledge, attitudes, behaviors, and overall health outcomes.

4. Towards a Comprehensive SNAP-Ed Program Evaluation Framework

The evaluation component gets activated during the later stages of the SNAP-Ed project plan. However, it is critically important for the evaluation framework to be ready during the project planning itself and definitely before the project implementation begins.

The following are the key components that we propose to include in our evaluation framework:

4.1. Needs Assessment

Conduct the survey to gather information on dietary habits, nutrition knowledge, barriers, and preferences of the target population.

Analyze existing data sources (e.g., state health statistics, food insecurity rates) to identify high-need areas or populations.

Conduct focus groups or interviews with stakeholders (community leaders, healthcare providers, educators) to understand local contexts and challenges.

4.2. Program Design and Implementation

Develop program goals, objectives, and measurable outcomes based on the needs assessment findings.

Design educational curricula, materials, and delivery methods tailored to the target audience's preferences and needs.

Train educators and facilitators to ensure consistent and effective program delivery.

Document program implementation processes, including reach, dosage, and fidelity measures.

4.3. Process Evaluation

Conduct observations of educational sessions to assess delivery quality, participant engagement, and fidelity to the curriculum.

Administer participant satisfaction surveys to gather feedback on the program's relevance, clarity, and applicability.

Track participation rates, attendance, and completion rates to evaluate program reach and retention.

4.4. Outcome Evaluation

Develop pre- and post-program assessments to measure changes in participants' knowledge, attitudes, skills, and behaviors related to nutrition and healthy eating.

Conduct follow-up surveys or interviews to assess long-term impacts on dietary habits, food resource management, and overall well-being.

Analyze changes in relevant health indicators (e.g., obesity rates, food insecurity) at the community or state level, if feasible.

4.5. Economic Evaluation

Collect data on program costs, including personnel, materials, facilities, and administrative expenses.

Estimate the potential cost savings or economic benefits associated with improved health outcomes and reduced healthcare costs.

Conduct cost-effectiveness or cost-benefit analyses to evaluate the program's return on investment.

4.6. Reporting and Continuous Improvement

Compile evaluation findings and present them in a clear and accessible format (e.g., annual reports, dashboards, presentations).

Share evaluation results with stakeholders, including funders, policymakers, and the community.

Use evaluation data to identify areas for program improvement, modify curricula or delivery methods, and inform future program planning and budgeting.

5. The Evaluation Workflow

The flowchart presents the proposed SNAP-Ed evaluation framework as a sequential process, guiding the program's evaluation from start to finish. It begins with a needs assessment, which informs the program design and planning phase. Once the program is designed, it enters the implementation stage, followed by a process evaluation to assess the quality and fidelity of the implementation. The next step is an outcome evaluation, measuring changes in participants' knowledge, behaviors, and health indicators. An economic evaluation is then conducted to analyze the program's costs and potential cost savings or benefits. Finally, the evaluation findings are reported, and a continuous improvement cycle is initiated, allowing for adjustments and refinements to the program based on the evaluation results.

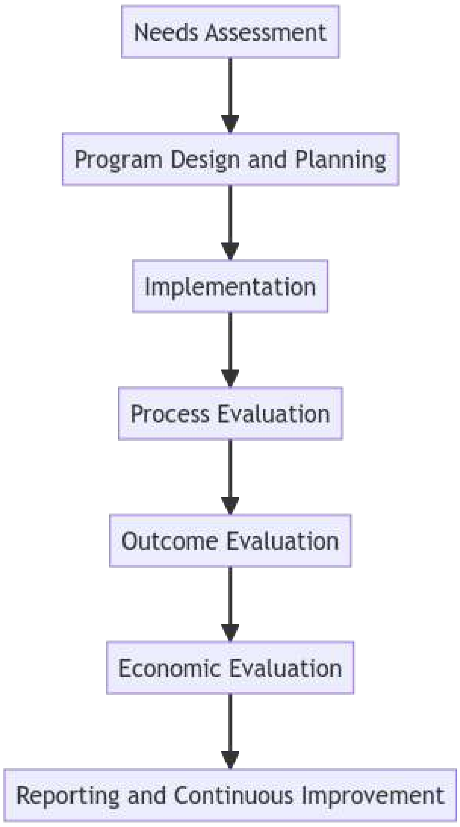

Figure 1. Evaluation Framework: A Flowchart.

The flowchart provides a clear, step-by-step representation of the evaluation process, ensuring a comprehensive and systematic approach to assessing the SNAP-Ed program's effectiveness.

6. Depicting the Evaluation Framework as A Logic Model

The logic model diagram is an attempt to provide a visual representation of the SNAP-Ed evaluation framework, illustrating the logical relationships between the program's inputs, activities, outputs, and intended impacts. It begins with the necessary inputs, such as funding, personnel, partners, and existing data sources. These inputs fuel the activities, which include conducting a needs assessment through surveys, data analysis, and focus groups, as well as designing the program's curricula, materials, and training. The outputs encompass the delivery of educational sessions and the observed changes in participants' knowledge, attitudes, skills, behaviors, and health outcomes. The logic model culminates in the desired long-term impacts, including improved nutrition and healthy eating, reduced nutrition-related health issues, and potential cost savings in healthcare.

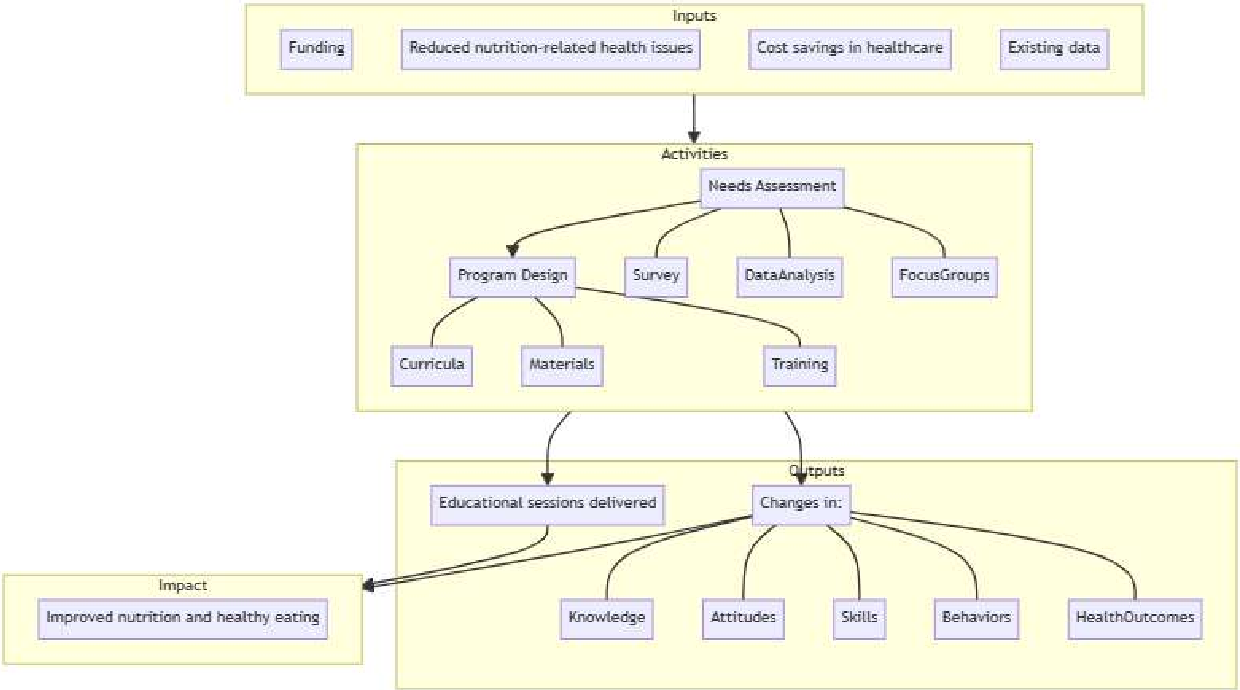

Figure 2. The evaluation framework as a logic diagram.

The logic model diagram (Figure 2) complements the evaluation framework flowchart (Figure 1) by providing a visual representation of the SNAP-Ed program's theory of change and the logical relationships between its inputs, activities, outputs, and intended impacts. While the flowchart in Figure 1 focuses on the sequential steps and processes involved in the evaluation, the logic model in Figure 2 emphasizes the causal links and assumptions that connect the program's inputs to its intended outcomes. The logic model begins with the necessary inputs, such as funding, personnel, partners, and existing data sources. These inputs fuel the activities, which include conducting a needs assessment through surveys, data analysis, and focus groups, as well as designing the program's curricula, materials, and training. The outputs encompass the delivery of educational sessions and the observed changes in participants' knowledge, attitudes, skills, behaviors, and health outcomes. The logic model culminates in the desired long-term impacts, including improved nutrition and healthy eating, reduced nutrition-related health issues, and potential cost savings in healthcare. By presenting the evaluation framework through these two complementary lenses, the manuscript offers a completer and more coherent picture of the proposed approach, addressing both the "how" (the evaluation process) and the "why" (the logic and theory behind the program and its evaluation).

7. Discussion

Ensuring that individuals have consistent access to adequate and nutritious food is one of the fundamental expectations from developed societies (Kreider et al., 2012; Mabli & Ohls, 2015). Food security sustains communities and societies and is an integral element of collective wellbeing, particularly in rural areas (Okech et al., 2012; Ratcliffe et al., 2008). As we have mentioned earlier in the paper, the SNAP federal food assistance program plays a pivotal role in alleviating food-related hardships. SNAP participation is associated with an increase in household food security, thereby improving the health and well-being of families. Despite the positive impact of SNAP on food security, there have been challenges in assessing its effectiveness, particularly in promoting food security and addressing health issues. Proper measurement of food security is crucial for targeting food aid, monitoring global food systems, evaluating nutrition programs, and informing policy decisions (Jones et al., 2013).

SNAP-Ed has been highlighted as a successful intervention in enhancing food security among households with children (Rivera et al., 2016). SNAP-Ed's efficacy in improving food security has been observed across urban and rural settings, emphasizing its role in enhancing food security regardless of environmental factors. SNAP-Ed improves food security independently of food assistance and program characteristics, underscoring its importance in promoting food security (Eicher-Miller et al., 2020). SNAP also contributes to enhancing the food security of recipients, emphasizing the program's role in ensuring consistent access to adequate food (Nord, 2012). However, short-term participation in SNAP has shown few changes in food security and dietary intake among low-income individuals, highlighting the need for continuous support and education programs like SNAP-Ed (Leung et al., 2014).

As mentioned elsewhere in this paper, there have been concerns and criticisms about the currently employed evaluation approaches and frameworks. One key concern is the need for consistency in measurement tools and outcomes across evaluations. Studies evaluating the effectiveness of SNAP-Ed interventions have been characterized by inconsistency in measurement tools and outcomes, which can hinder the ability to compare results and draw meaningful conclusions (Rivera et al., 2019). Another criticism relates to the potential limitations of the framework in capturing the full spectrum of program outcomes. The framework primarily focuses on key SNAP-Ed outcomes, but there may be other important metrics or unintended consequences of the program that are not adequately captured or evaluated (Sadeghzadeh et al., 2022). Likewise, the reliance on self-reported data in evaluations poses a risk of response biases, which can impact the validity and reliability of the findings (Hofer et al., 2021). It is essential to consider the potential for bias when interpreting evaluation results and to explore alternative data collection methods to enhance the robustness of the evaluation process.

The available frameworks face challenges in terms of resource requirements and scalability, too. Implementing a comprehensive evaluation framework like SNAP-Ed across different regions and populations may demand significant resources, expertise, and funding, which could limit its widespread adoption and effectiveness (Haynes-Maslow et al., 2019). Moreover, the framework's emphasis on short-term outcomes, such as changes in knowledge and behaviors, may not fully capture the long-term impact of SNAP-Ed interventions on participants' health and well-being. Evaluating long-term health outcomes and sustainability beyond the duration of the program is crucial for understanding the lasting effects of SNAP-Ed initiatives (Caldwell et al., 2021).

In the light of the above, the evaluation framework presented in this paper offers a comprehensive and multi-dimensional approach to assessing the effectiveness and impact of the SNAP-Ed nutritional education program. By incorporating various data sources and evaluation methods, this framework addresses the diverse aspects of program implementation, outcomes, and cost-effectiveness, providing a holistic understanding of the program's strengths and areas for improvement. A key strength of our proposed framework is its emphasis on a thorough needs assessment, which lays the foundation for designing and tailoring the program to the specific needs and preferences of the target population.

The inclusion of the survey instrument, complemented by data analysis and focus groups, ensures that the program is relevant, culturally appropriate, and addresses the real-world challenges and barriers faced by participants. This comprehensive need assessment aligns with the recommendation of the U.S. Department of Agriculture's SNAP-Ed Guidance, which emphasizes the importance of understanding the unique circumstances and contexts of the communities served. The proposed framework also recognizes the importance of process evaluation, which is often overlooked in program evaluations. By conducting observations, participant satisfaction surveys, and tracking implementation metrics, this framework enables the identification of potential issues or deviations from the intended program delivery. This information can be used to make real-time adjustments and ensure fidelity to the program's design, ultimately improving the quality and effectiveness of the educational interventions.

The outcome evaluation component, which measures changes in knowledge, attitudes, skills, behaviors, and health outcomes, provides valuable data to demonstrate the program's impact and justify continued funding and support. The proposed use of pre- and post-program assessments, as well as follow-up surveys or interviews, allows for the evaluation of both short-term and long-term effects, providing a comprehensive understanding of the program's impact on participants' lives. The economic evaluation component of the framework addresses a critical aspect of program sustainability and resource allocation. By estimating the potential cost savings and economic benefits associated with improved health outcomes, this evaluation can inform policymakers and funders about the program's return on investment and its broader societal impacts. This information can be instrumental in securing continued funding and support for the SNAP-Ed program. The emphasis on reporting and continuous improvement ensures that the evaluation findings are effectively communicated to stakeholders and used to inform program refinements and future planning. This iterative process fosters a culture of data-driven decision-making and ongoing program optimization, ensuring that the SNAP-Ed program remains responsive to evolving needs and maximizes its impact on the communities it serves.

While the proposed evaluation framework is reasonably comprehensive, we must acknowledge potential limitations and challenges. Implementing such a multi-faceted evaluation may require significant resources, including personnel, expertise, and funding. In addition, the collection of long-term outcome data and community-level health indicators may be challenging due to factors such as participant attrition, data availability, and the influence of external variables.

However, these challenges can be mitigated through careful planning, resource allocation, and the use of appropriate statistical methods and data analysis techniques.

8. Conclusion

The SNAP-Ed program serves as a pivotal instrument in fostering healthier dietary choices and active lifestyles among economically disadvantaged groups. The comprehensive evaluation framework proposed in this paper offers a robust tool for assessing the program's reach, implementation, outcomes, and cost-effectiveness. By amalgamating various data sources and methodologies, this framework provides a holistic view of the program's strengths and areas for enhancement. It underscores the necessity of stringent evaluation techniques to quantify the impact of SNAP-Ed interventions on nutrition knowledge, attitudes, behaviors, and overall health outcomes.

Our SNAP-Ed evaluation framework offers a robust and systematic approach to assessing the program's effectiveness and impact. By combining a variety of evaluation methods, including surveys, focus groups, process monitoring, outcome assessments, and cost-benefit analyses, this framework provides a comprehensive understanding of the program's successes, challenges, and areas for improvement. The data gathered through this evaluation process will not only demonstrate the program's impact and justify funding requests but also inform continuous program refinement and optimization. The evaluation framework ensures that the SNAP-Ed nutritional education program remains responsive to the evolving needs of the community, maximizes its reach and effectiveness, and contributes to lasting positive changes in nutrition and health outcomes for its participants. The framework is designed to equip SNAP-Ed Implementing Agencies with a structured approach to validate the program's efficacy and inform decisions for ongoing refinement.

This research underscores the potential of such a comprehensive evaluation framework in enhancing the effectiveness of SNAP-Ed and similar initiatives, ultimately contributing to improved health outcomes among low-income populations. Future research should focus on applying this framework in diverse settings and exploring its adaptability to other public health programs.

Limitations and Potential Research Directions

The proposed SNAP-Ed evaluation framework has several limitations. First, implementing a comprehensive evaluation requires significant resources, which may limit its widespread adoption and scalability. Second, collecting long-term outcome data and isolating the program's impact from confounding factors can be challenging. Third, reliance on self-reported data may introduce response biases, affecting the validity and reliability of findings. Fourth, the framework may not fully capture all relevant metrics or unintended consequences of the program. Lastly, the framework's effectiveness may vary across different contexts and populations, requiring adaptations to ensure cultural appropriateness and feasibility. Despite these limitations, the proposed framework offers a valuable starting point for assessing SNAP-Ed's impact. Future research should focus on refining the framework, addressing resource constraints, and testing its applicability in diverse settings. Collaborative efforts among stakeholders can help enhance the framework's robustness and practicality.

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Agricultural & Rural Studies

Article

Socioeconomic and Environmental Prospects of the Food Industry

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Abstract: Food production systems and consumption patterns are significant contributors to the social, economic, and environmental impacts of the industry, which swap with changing population demographics. The life cycle assessment approach has been increasingly utilized to evaluate the agricultural and food processing systems to ensure reliable and evidence-based support for decision-making for both industry stakeholders and policymakers. This study discusses the key social, economic, and environmental impacts of various food processing sectors, especially greenhouse gas (GHG) emissions, land, water, and energy use. Impacts vary widely depending on the types of foods, their sources, and supply chains. The animal (excluding poultry) slaughtering, rendering, and processing category has the highest contributions in both socioeconomic and environmental impacts out of all food and beverage processing industries. The food industry touches transdisciplinary policy domains and is recognized as dynamic and complex. It is thus important to adopt an integrated approach involving stakeholders from all policy domains associated with food supply chains to ensure the sustainability of the food industry. A broader sustainability check must be adopted for any strategic change in the food industry to reduce the risks to its sustainability and avoid rebound effects on society.

Keywords: food processing industry; resources use; greenhouse gas emissions; social, economic, and environmental impacts; sustainability

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1. Introduction

Global greenhouse gas (GHG) emissions have increased remarkably due to human activities in different sectors. The world emits 50 billion tonnes of GHG each year (Ritchie, 2020). The food industry is one of the largest industrial sectors and thus, consumes a large number of resources, and emits a considerable amount of GHG, causing severe climate abnormalities. The food sector emits one-third of global anthropogenic GHGs (Crippa et al., 2021). Food production necessitates the utilization of diverse resources, with water and energy being crucial inputs throughout various stages of the food supply chain. These stages encompass activities such as crop and livestock production, food processing, manufacturing, as well as storage and distribution (Salmoral & Yan, 2018). One-fourth of the world's workforce is engaged in agriculture (Roser, 2023). The food demand and production processes are constantly changing with small and medium-scale industries decreasing in different jurisdictions. For example, small and medium-scale farms are decreasing in Canada while large-scale farms are increasing (Statistics Canada, 2017a; Statistics Canada, 2022a). The global food demand will continue to increase due to the increasing world population which is projected to be 9.8 billion in 2050 (Department of Economic and Social Affairs, n.d.). Hence, it is crucial to expand our understanding of the long-term social, economic, and environmental impacts of food production and research sustainable approaches to mitigate these impacts.

Currently, there is a growing body of literature that focuses on food systems and explores the connections between food and various dimensions of contemporary life. A wide range of indicators exist that encompass the economic, social, and environmental dimensions of the entire food system, including aspects such as sourcing raw materials, production, processing, packaging, distribution, and end-of-life considerations (Kucukvar et al., 2014). These indicators play a crucial role in achieving and improving the sustainability of food systems. Numerous studies have been conducted with a specific focus on environmental indicators within various food systems (Kucukvar et al., 2014; Egilmez et al., 2014) because of the growing concerns about the environmental sustainability of the food industry and the awareness of consumers. It is important to acknowledge that in addition to environmental indicators, the analysis of food system sustainability should also consider social and economic factors. However, societal, and economic prospects of the food industry along with environmental sustainability studies are scarce while the food demand and production are constantly changing in different jurisdictions with changing population demographics. This study provides a general overview of the current state of the Canadian food and beverage processing industry, discussing key social, economic, and environmental metrics of sustainability, and concluding with a summary of the most influential food and beverage processing sectors, having the highest contribution to the overall impacts of the food industry.

2. Methodology

This paper relied on a content evaluation where a comprehensive literature search was carried out using the Google Scholar web search engine, placing specific attention to more recent publications to gather the most up-to-date information to answer the research questions: environmental, economic, and societal prospects of the food industry. Social sustainability or impact, economic sustainability or impact, environmental sustainability or impact, food industry, consumption pattern, and life cycle impact assessment were used to find and collect relevant information that is compiled in this study. The literature collection process resulted in the identification of 87 articles (papers, reports, news, websites, etc.) related to this study. The articles were then read by the authorship team providing the environmental, economic, and societal insights of the food industry, and 75 articles were used in this study.

Environmental sustainability, based on natural sciences, primarily focuses on evaluating the overall effects of human activities on ecosystems. The most widely employed method for assessing these effects is the life cycle assessment (LCA). The LCA entails measuring and describing the inflow of resources (such as energy, land, and water) into the production system, as well as the emissions and impacts generated by the system. It is crucial to include the environmental impacts caused by these emissions across different spatial scales, while also considering the availability of resources at local, regional, and global levels. When conducting LCAs for environmental sustainability, it is important to base the scope on the function of production rather than organizational boundaries. Therefore, all inputs and outputs related to the production system should be taken into account, irrespective of economic ownership (Notarnicola et al., 2017). In this review, the literature on environmental sustainability was selected to include topics such as land and energy use, greenhouse gas emissions, eutrophication, pollution, food waste, and other environmental hazards.

Regarding economic sustainability, this aspect of sustainable development encompasses aspects such as job creation and income generation, aimed at supporting the population's financial well-being. However, the scientific community lacks a definitive consensus on the most effective methods for measuring economic sustainability. From a sustainability accounting perspective, the Global Reporting Initiative (GRI) reporting standards offer guidance on the factors to consider, including economic indicators like costs, revenues, profits, and investments (GRI, 2023). Essentially, the economic dimension of sustainable development emphasizes the growth of the economic system and the preservation of capital invested in businesses. A noteworthy differentiation can be made between weak and strong sustainability, which concerns natural and economic capital. Weak sustainability revolves around maintaining the combined sum of these two forms of capital, while strong sustainability focuses on preserving each type separately (Ayres et al., 2001). From an economic perspective, sustainability can also concentrate on the responsible utilization of natural resources within a defined economic system. This implies that sustainability is achieved when economic activities do not deplete natural resources. The economic concept of negative externalities proves useful in comprehending and accounting for all costs associated with production, including not only costs incurred by producers but also societal costs (Van den Bergh, 2010). In this review, we selected the literature which took into consideration economic indicators such as tax payments, profits, economic efficiency, costs, and investments in sustainability initiatives.

Social sustainability is a dimension of sustainability that has received less attention and lacks a precise definition (Vallance et al., 2011). It can be described as the capacity of a community to establish systems and frameworks that fulfill the needs of its members while ensuring the ability of future generations to maintain a thriving community (Davidson, 2009). However, there is no universally accepted definition of social sustainability, and it has been defined in various ways, often in relation to the other two dimensions of sustainability. One overarching definition proposes that social sustainability is the attainment of a life-enhancing state within communities, facilitated by a process that strives for such a condition (Hajirasouli & Kumarasuriyar, 2016). In this review, the concept of social sustainability discusses several indicators, including gender equality, health and safety rights, skill development, labor rights, and community resilience.

3. Food Processing Industry in Canada

Food and beverage processors engage in the conversion of raw food materials or substances into either finished product, ready for immediate consumption or use, or semi-finished products that serve as raw materials for subsequent manufacturing processes (Agriculture and Agri-Food

Canada [AAFC], 2023a). In Canada, food and beverage processing industry plays a significant role in revenue generation. In 2019, the food and beverage processing industry accounted for 17% of the manufacturing sales, which represented 2% of the gross domestic product (GDP). The food and beverage industry is the second largest manufacturing industry in Canada, employing 290,000 people (AAFC, 2021).

Despite the size of the food processing industry in Canada, Canada still depends largely on the import of certain food from other countries. For instance, over 75% of the fresh vegetable demand in Canada is met through imports (International Trade Administration, 2022). Since the food is being transported over a longer distance to get to the consumers, this tends to increase its carbon footprint and contribute to food waste due to its limited shelf-life. Meat product manufacturing is the largest sector within the Canadian food and beverage processing industry, responsible for 25% of all manufacturing sales and generating $30 billion in 2019 (AAFC, 2021). It is the major food-producing sector in Quebec, Ontario, Manitoba, and Alberta. Dairy product manufacturing is the second largest sector within the industry generating $14.8 billion in sales in 2019 (AAFC, 2021).

3.1. Domestic Market and International Trade

The prosperity of the Canadian agricultural sector is greatly reliant on its ability to export agricultural products to other nations, and Canada is recognized as one of the world's major food exporters. In 2022, the total value of agriculture and food product exports from Canada, encompassing raw agricultural materials, fish and seafood, and processed foods, reached nearly $92.8 billion (AAFC, 2023a). Canada holds the fifth position globally as an exporter of agri-food and seafood, following the EU-27 block of countries, the United States, Brazil, and China. Canada exports to nearly 200 countries, based on 2022 data (AAFC, 2023a). Although Canada became the fifth food exporter on the earth, its agri-food and seafood imports reached $44.5 billion in the first 10 months of 2020 (AAFC, 2020). Additionally, it's worth to note that around 75% of the food supply in Canada comes from packaged and processed food items (L'AbbeLab, n.d.).

The United States stands as Canada's primary trading partner, responsible for approximately 60% of all agri-food and seafood exports and over half of the imports. Since 2012, China has consistently been Canada's second-largest export market for agri-food and seafood, with exports to China increasing by 75.8% during this period (AAFC, 2023a). While international markets are significant, the domestic market plays a critical role in the sector's performance. In 2022, Canadian households spent a total of $189.7 billion on food, beverages, tobacco, and cannabis products, positioning this expenditure category as the third-largest household expense, following transportation and shelter (AAFC, 2023a).

3.2. Sustainable Development of the Canadian Agri-Food System

Canada possesses several pivotal strengths that position it as a potential global leader in food production and processing: abundant land and water resources; access to international markets; capabilities to invest in research and development; high food quality and safety standards recognized globally; and strong commitment to environmental stewardship. The agriculture and agri-food sector in Canada exhibit substantial economic growth potential. Canada adopted a departmental sustainable strategy (AAFC no. 13134E) to ensure sustainable food (AAFC, 2022). Leveraging these key advantages can propel Canada to become a leader in sustainable food production and processing. Canada's strong reputation for environmental stewardship can drive higher demand and prices for local agricultural products. Capitalizing on these key opportunities is crucial to ensure that the sector remains competitive, sustainable, resilient, and prosperous well into the future. (AAFC, 2023a).

Food demand in Canada is increasing with changing population demographics. Canadian farmers and processors are assumed to be capable of meeting steadily increasing food demand; however, policy issues and policy controversies are prevailing with the increasing complexity of society. Food policy is considered to be a dynamic system (Kappelman & Sinha, 2021) where various stakeholders are engaged. It is not only dynamic but also multidimensional and highly complex, reaching several policy domains involving economic, environmental, societal, and cultural spheres (Barling et al., 2002). Canada has developed agricultural and food safety policies, and only later in 2017 the government has launched a multisectoral consultation for developing comprehensive food policy, extending beyond these two areas (Bancerz, 2018). Consequently, an integrated, and multidisciplinary approach is needed to improve the sustainability of food industries.

4. Impact Assessment of Food Industry

4.1. Social Sustainability

Key social indicators commonly mentioned in the literature in relation to the well-being of the food processing industry workers are quality of life, compensation of employees, labour rights, and worker's health and safety (Food and Agriculture Organization of the United Nations [FAO], 2014). The social and economic well-being of food industry workers are interconnected. One-fourth of the world's workforce is engaged in agriculture (Roser, 2023).

In 2022, Canada's agri-food system employed 2.3 million people, providing 1 in 9 jobs in Canada, along with $143.8 billion (around 7.0%) contribution to gross domestic product (GDP) (AAFC, 2023a). In the food and accommodation service industry, evening work is the most common, employing 21.8% of workers while regular evening hours workers are high among students, aged 15 to 24 of both the male and female groups (Statistics Canada, 2023). In April 2022, 918,000 people, aged 15 to 69, worked in a regular evening shift and were mostly part-time workers while only 3.3% of evening shift workers are full-time employees, and a similar trend was also found in the case of night-shift (Statistics Canada, 2023). In the United States, the food consumption categories have maintained a stable share in terms of income and employment, due to consistent demand, which can be translated to Canada, given the similarities in the economy (Kucukvar et al., 2019). Canada had 280,043 farms in 1991 which reached to 189,874 in 2021 while the average farm size changed from 598 acres to 809 acres (Statistics Canada, 2022a). The number of farm employees also changed from 327 to 257 thousand from 2008 to 2022 (Statista, 2023) while there were 293,925 farm operators in 2011 (Statistics Canada, 2017b) and 262,455 in 2021 (Statistics Canada, 2022b).

The U.S. food industry employed 22.1 million people in 2022 (U.S. Department of Agriculture [USDA], 2022). The shiftwork is prevalent in the food industry, nearly half of the workers were employed part-time in 2012 (Kucukvar et al., 2019). Most injuries that occur in the food industry are non-fatal and often arise from falls, slips, burnings, and lacerations. Young workers, who lack safety training and experience, tend to have higher rates of workplace injuries. Furthermore, a significant number of workers in this industry reported not receiving payment during their recovery period. A survey conducted among over 600 workers in the U.S. food industry revealed that only 21% of them received compensation during sick days. The authors noted that tobacco product manufacturing, breweries, and animal (excluding poultry) slaughtering, rendering, and processing accounted for 44% of the total tax revenue collected by the U.S. government (Kucukvar et al., 2019). When it comes to the compensation of employees and gender representation in the food industry, the major three categories were bread and bakery product manufacturing, animal (excluding poultry) slaughtering, rendering, and processing, and soft drink and ice manufacturing. These indicators contributed around 30 to 35 percent of the overall numbers. Injuries associated with animal (excluding poultry) slaughtering, rendering, and processing, as well as bread and bakery product manufacturing, and soft drink and ice manufacturing, accounted for 37% of the total injuries within the food industry.

4.2. Economic Sustainability

The primary economic indicators discussed in the literature for the food industry are internal and international investments, Gross Operating Surplus (GOS), Gross Domestic Product (GDP), imports, local economy and regional workforce (FAO, 2014). Canadian raw agricultural materials, fish and seafood, and processed foods exports reached $92.8 billion in 2022 (AAFC, 2023a) while agri-food and seafood imports were $44.5 billion in the first 10 months of 2020 (AAFC, 2020). In the first half of 2023, food and beverage sales increased by 8.4% and 7.3%, respectively compared to that of 2022 (Crosbie, 2023). The growth of the food and beverage industry is projected to rise to 11.6% by 2025 (BDC, 2022).

The U.S. agriculture, food, and related industries generated about US$1.264 trillion in 2021 (USDA, 2022). The food and beverage industry shared US$680.2 billion in 2022, an increase in compound annual growth rate (CAGR) of 3.6% compared to 2017 and it is expected to increase by 5% and reach US$869.1 billion by 2027 (AAFC, 2023b). Similarly, other food services such as chained food service franchises, the limited-service restaurants such as the eat-in channel are also expected to grow (AAFC, 2023b). Kucukvar et al. (2019) revealed that 34% of the GOS impact can be attributed to animal (excluding poultry) slaughtering, rendering, and processing, tobacco product manufacturing, and soft drink and ice manufacturing (Kucukvar et al., 2019). Moreover, in terms of the total investment indicator, the top three contributors were animal (excluding poultry) slaughtering, rendering, and processing, soft drink and ice manufacturing, and poultry processing, collectively accounting for 31% of the overall investment in the food sectors. Similarly, the aforementioned categories were identified as major contributors to the total intermediate value, representing 33% of the overall intermediate value for all food consumption categories.

4.3. Environmental Sustainability

The food industry is one of the largest industrial sectors and thus consumes large amounts of resources which emit GHGs and affect the environment. Every stage of the life cycle of food such as production, processing, manufacturing, packaging, distribution, storage and management of waste. Globally, food transport contributes 19% to total food system emissions (Li et al., 2022). Often, various impact categories of food industries are discussed; however, this study discusses the carbon footprint, energy consumption, water footprint, and land use.

4.3.1. Energy Consumption

Globally, 30% of the total energy is used in the food industry (UN-Water, n.d.). This is due to the dependency of the food industry on fossil fuel sources such as petroleum and natural gas. It was estimated that the food sector consumes 200 exajoule of energy annually, with 45% of the energy consumption used in the processing and distribution stages (Sims, 2011; FAO, 2017). Energy data reveals that instant coffee, milk powder, French fries, crisps, and bread rank among the food products with the highest energy requirements for production (Ladha-Sabur et al., 2019). The manufacturing processes for these items involve significant thermal energy consumption. It is thus crucial to explore alternate renewable energy sources to help mitigate GHG emissions and resource depletion.

In the meat and dairy processing sectors, energy and water usage have seen an increase due to elevated hygienic standards and more extensive cleaning requirements. Furthermore, meat products are often processed excessively to enhance consumer convenience, resulting in higher energy usage during manufacturing. In the United Kingdom (UK), more than 98% of all food is transported by road, with travel distances showing a recent upward trend. Tertiary distribution, which employs rigid vehicles, proves to be the most energy-intensive transportation method, while primary distribution at ambient temperature is the least energy-intensive. Refrigerated transportation, which demands more energy compared to stationary refrigeration systems, has also experienced an upswing in recent years (Ladha-Sabur et al. 2019). The authors noted that potato-based products had the highest energy consumption compared to other food categories (Figure 1) (Ladha-Sabur et al., 2019). It is worthy to note that energy consumption not only depends on the types of food but also contains different amounts of energy and food components (Roy et al., 2005, 2012a, 2022; Mekonnen et al., 2019). The energy consumption in the food sector can be reduced by adopting alternative food baskets as well as the processing intensity.

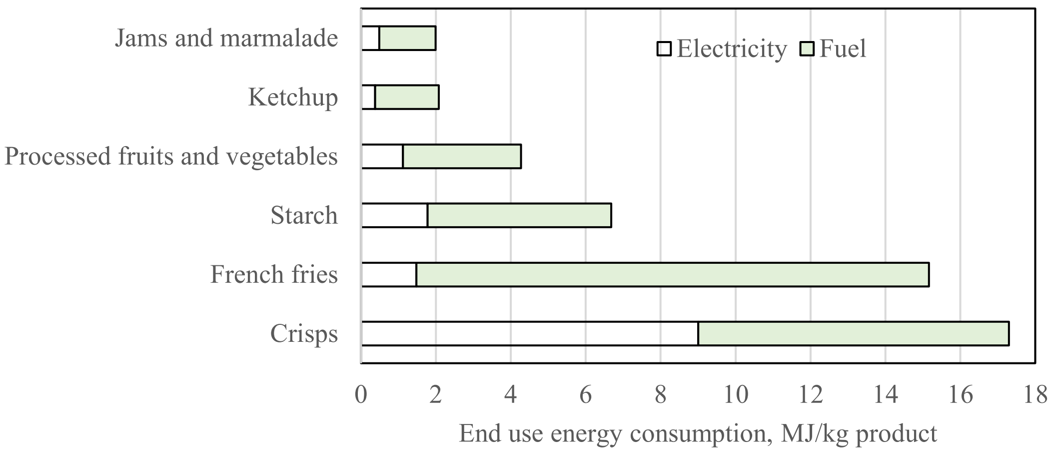

Figure 1. Energy consumption in fruits and vegetable processing. Adapted from “Mapping energy consumption in food manufacturing” by Ladha-Sabur et al., 2019, Trends in Food Science & Technology. Copyright 2019 by Elsevier Ltd.

In Canada, 92% of imported fruits and vegetables are transported more than 1,500 km, and 22% beyond 7,000 km (Kissinger, 2012). The first category of transport mostly includes truck shipments from the US, which contributed about 57% of all US - Canada trade in 2012 (Food Policy for Canada, n.d.). Road transport is the biggest contributor to total transport emissions; however, emissions per tonne-km for air freight and sea freight are the highest and the least, respectively (Food Policy for Canada, n.d.). Consequently, the improvement of local food supply as well as the selection of suitable transport methods would be helpful in reducing energy consumption in food transportation and improving the sustainability of the food sector.

Within the food industry, dairy processing is recognized as one of the sectors with the highest energy needs (Briam et al., 2015). Figure 2 demonstrates the energy consumption of different dairy products, with milk powder and whey powder having the highest energy consumption. This is likely due to the difference in their processing intensity (Adapted from Ladha-Sabur et al., 2019). When it comes to meat processing, in Ontario, sheep meat production process consumed 18.6–92.4 MJ/kg live weight (Bhatt & Abbassi, 2022). The United Nations also reported that meat production is more energy-intensive compared to other food categories (Climate Action, n.d.). Additionally, the study conducted by Tseng et al. (2019) concluded that there is higher energy usage and GHG emissions from the food industry compared to other industrial sectors and a recommendation was given to apply artificial intelligence and the concept of circular economy to help combat the challenges.

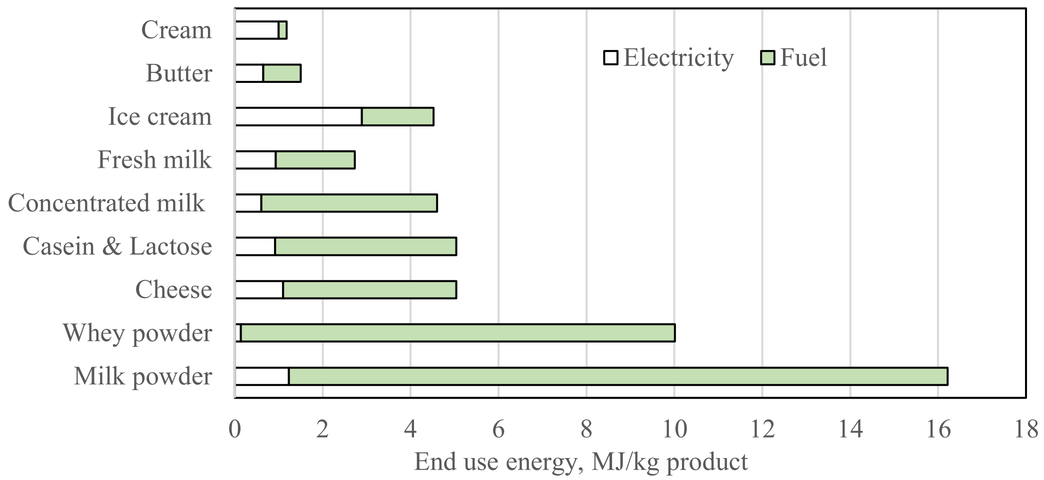

Figure 2. Energy consumption in dairy products processing. Adapted from "Mapping energy consumption in food manufacturing" by Ladha-Sabur et al., 2019, Trends in Food Science & Technology. Copyright 2019 by Elsevier Ltd.

4.3.2. Greenhouse Gas Emissions

Similar to energy consumption, GHG emissions also depend on the types of food, food production and processing, and distribution methods as well as sources of food (Blonk, 2017; Roy et al., 2022). For example, the environmental impacts of animal-based food are higher than plant-based food (Berardy et al., 2019; Heusala et al., 2020). The life cycle carbon footprint of oat- and faba protein is 50% and 80–90% lower than the dairy protein (Heusala et al., 2020). Figure 3 represents GHG emissions from protein which confirms that emissions depend on both the sources and types of food products (Adapted from Roy et al., 2022). Conversely, figure 4 represents GHG emissions from different food products (Adapted from Climate Action, n.d.). Meat has the highest emissions compared with other food categories, and nuts exhibit the lowest. However, this order of emissions magnitude may change if it is expressed in terms of food components such as protein or calories because these products contain different amounts of food components (Roy et al., 2022; Asadollahzadeh et al., 2018; Lee et al., 2020).

GHG emissions for grain crops also vary widely depending on the location of cultivation, type of crops, and methods of cultivation. For example, GHG emissions from rice production for conventional and organic cultivation in Malaysia were 0.46 and 0.14 kg-CO2 eq./kg rice, respectively (Harun et al., 2021) while in Bangladesh (Jimmy et al., 2017), Thailand (Thanawong et al., 2014) and Japan (Hokazono & Hayashi, 2012) it was 3.15, 2.97–5.55, and 1.46 kg-CO2 eq./kg, respectively. In Ontario, sheep production emits 8.4–18.6 kg CO2 eq./kg live weight (Bhatt & Abbassi, 2022). Similarly, emissions from meat production also vary widely. In Ontario, sheep production emits 8.4–18.6 kg CO2 eq./kg live weight (Bhatt & Abbassi, 2022) while in Japan, beef, pork, and chicken emitted about 34.3, 5.6, and 4.6 kg CO2 eq/kg-meat, respectively (Ogino et al., 2007; Roy et al., 2012a).

Emissions from a food basket (837436 kcal over a year; based on the Canadian food pyramid) in Ontario also widely varied depending on the dietary choices. For example, No Pork, Omnivorous, No red meat, and No beef dietary patterns emitted 3160, 2282, 1234, and 290 kg-CO2 eq., respectively, while Vegan and Vegetarian dietary patterns emitted 955 and 1015 kg-CO2 eq., respectively (Veeramani et al., 2017). The authors also noted that emissions from Omnivorous and Vegetarian dietary patterns widely vary among different jurisdictions. In addition, the projected population growth means there is a need to develop policies and techniques in the food production, distribution, and disposal of food to help combat the significant contribution to the carbon footprint.

Consequently, dietary patterns and recommended food pyramid for a healthy diet can play a crucial role in mitigating GHG emissions in different jurisdictions.

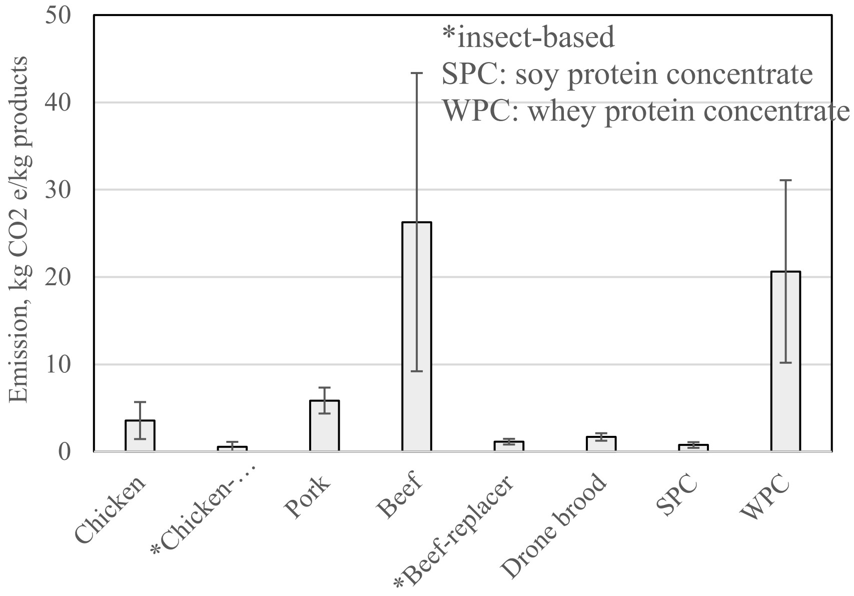

Figure 3. Emission of meat and meat substitute. Adapted from "Environmental Aspects of Plant Protein Foods" by Roy et al., 2022, Springer Cham. Copyright 2022 by Springer Nature.

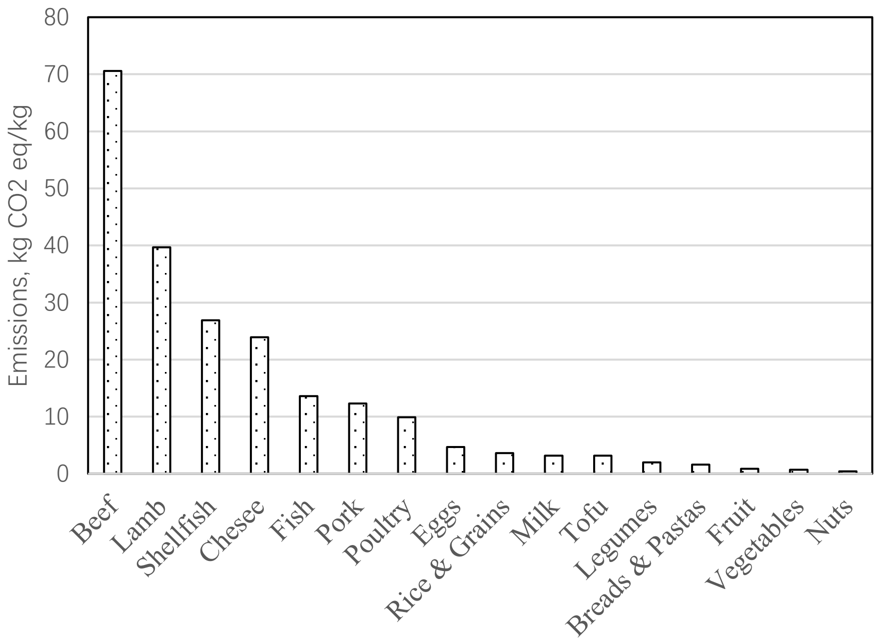

Figure 4. Kilograms of greenhouse gas emissions per kilogram of food. Adapted from "Food and Climate Change: Healthy diets for a healthier planet" by Climate Action. Copyright by United Nations.

4.3.3. Water Use

The food industry is largely dependent on the use of large amounts of fresh water. Water footprint represents the total amount of water that is used in the food industry. Agriculture accounts for the largest share of freshwater consumption globally and is a leading cause of freshwater eutrophication. The food industry also generates a lot of wastewaters that ends up polluting water sources, if not properly managed. To put this in perspective, 70% of the world's freshwater is used in food production and approximately, 78% of the world's eutrophication is caused by food production (Ritchie et al., 2022). The water footprint also widely varies depending on the sources of food, types of food, and their processing intensity. For example, for soy protein isolate, water use was noted to be 38.95 m3/kg protein-isolate (Berardy et al., 2015) while it was 0.64 m3/kg for milk and 16.67 m3/kg for beef (Mekonnen et al., 2019).

Water footprint for different crop production also widely varies depending on the locations, cultivation methods, and types of crops (Kalvani et al., 2019; Harun et al., 2021; Yu et al., 2022). In the Teheran province of Iran, the water footprint for pistachio, cotton, walnut, almond, and wheat was 11.11 m3/kg, 4.70 m3/kg, 3.93 m3/kg, 3.22 m3/kg, and 1.82 m3/kg, respectively (Kalvani et al., 2019) while it was noted to be about 0.8 m3/kg for maize, 1.4 m3/kg rice, 1.9 m3/kg wheat, respectively, in China (Yu et al., 2022) and 0.06–0.27 m3/kg for sheep production in Ontario (Bhatt & Abbassi, 2022). In Malaysia, a cradle-to-gate analysis of conventional and organic rice cultivation revealed that the water footprint was 0.098 m3/kg and 0.029 m3/kg for conventional and organic rice cultivation, respectively (Harun et al., 2021). It is also noted that water is required for food production or cultivation; however, less than 50% of the water applied through irrigation is used by crops (Sims, 2011). Different studies have shown that animal food products consume more water compared to crops' equivalent nutritional value. An example of this is the water consumption in beef production which is 20 times more than for cereals and starch roots (Vanham et al., 2013).

4.3.4. Land Use

Agriculture remains a significant source of livelihood for 40% of the global population and contributes around 30% to the GDP of low-income countries. Moreover, it plays a crucial role in providing sustenance, fiber, biofuels, and various other products to support the current global population (Ramankutty et al., 2018). Similar to GHG emissions, land use also widely varies depending on the sources, categories, and processing intensity of food. For example, land use for plant-based proteins was 1.7–13.3 m2/kg of protein (Smetana et al., 2019; Heusala et al., 2020). Conversely, animal-based proteins required 4.95–210.0 m2/kg of protein (Gésan-Guiziou et al., 2019; Thrane et al., 2017; Ulmer et al., 2020). Land use was the highest for beef-based protein followed by chicken, and pork (Thrane et al., 2017; Ulmer et al., 2020). Per capita, cultivable land is decreasing with the increasing population growth and industrial development. Globally, per capita cropland decreased from 0.45 ha in 1961 to 0.21 ha in 2016 (FAO, 2020). Agricultural land decreased by 30% since 1990 and reached 0.6 ha/capita in 2019 (FAO, 2021). Deforestation and removal of other natural vegetation contribute to climate change and the loss of biodiversity. Striking a balance between the environmental impact of agriculture and the imperative to sustainably feed current and future populations poses a substantial challenge. Thus, efforts are needed to ensure the efficient use of the available land to improve the sustainability of food systems.

5. Discussion

The growing concerns about climate change and the sustainability of existing food systems, the food industry is facing increasing pressure for sustainability and the health and safety of consumers. Although food consumption patterns are dependent on accessibility, availability, health concerns, and cultural and regional preferences, food demand is rapidly changing with international trade and changing population demographics in different jurisdictions. International trade enables year-round supplies of a variety of food which benefits consumers; however, imported food often exhibits a greater food carbon footprint as well as it is prone to food safety and quality because imported foods need to go through strict quarantine activities which also results in the shorter shelf-life due to long distance transportation leading to higher food loss, especially in the case of fresh fruits and vegetables. Canada loses or wastes 58% of all food supply annually (Nikkel et al., 2019) which affects the environmental sustainability of her food industry. Although food miles are often recognized as one of the environmental inefficiencies, it would not be the only determinant since agricultural production widely varies in different jurisdictions on the earth.

The food industry is recognized as a dynamic and multidimensional system, that touches several policy domains (economic, environmental, societal, and cultural spheres) (Barling et al., 2002; Kappelman & Sinha, 2021). Thus, the sustainability of the food industry also depends on multiple policy domains such as agriculture, food supply and demand, food pyramid, food self-sufficiency, food consumption patterns, etc. An empirical analysis of social, economic, and environmental impacts of food consumption categories (29 consumption categories were considered for evaluating direct and indirect impacts) in the USA revealed that supply chains are responsible for 80% of socioeconomic and environmental impacts such as gross operating surplus and imports, where animal slaughtering, rendering and processing emerged as the most dominant sector (Kucukvar et al., 2019).

Figure 5 shows the environmental, economic, and social heat map of different food consumption categories (Adapted from Kucukvar et al., 2019). The heat map analysis shows that the top three food consumption categories were animal slaughtering, rendering and processing (except poultry), soft drink and ice manufacturing, and bread and bakery product manufacturing. Animal slaughtering, rendering and processing, bread and bakery product manufacturing, and soft drink and ice manufacturing contributed 37% injuries of in overall food categories while animal slaughtering, rendering, and processing category contributed 30% GHGs all over the food consumption categories. This study revealed several weaknesses associated with the top three food consumption categories. In order to promote sustainable development and continuous improvement, it is recommended to establish and adopt policy implications. Policymakers should prioritize measures aimed at reducing injury rates in the animal and soft drink manufacturing and processing industries. Implementing rigorous safety and health regulations and standards, both locally and internationally, can effectively reduce human health impacts. Additionally, the state standards should enforce the use of the latest available technologies that prioritize maximum energy efficiency.

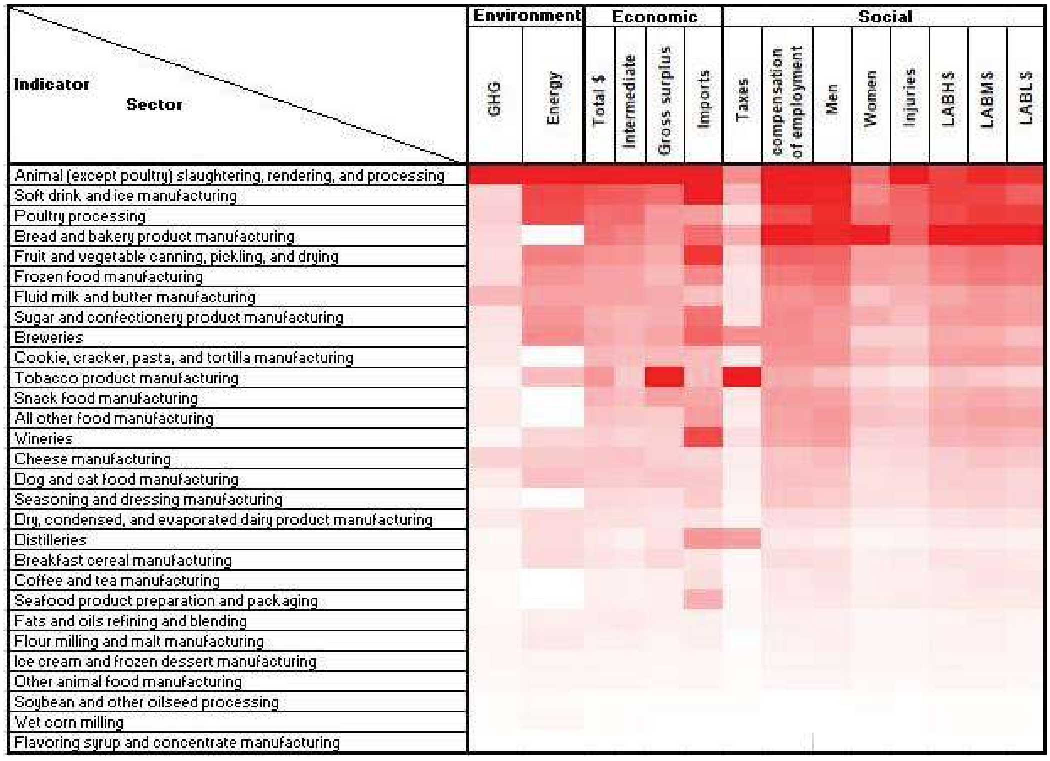

Figure 5. Heat map diagram illustrating the total impacts per food consumption category and indicator, based on the overall impact analysis (white represents the lowest and red represents the highest). Adapted from "Exploring the social, economic and environmental footprint of food consumption: A supply chain-linked sustainability assessment" by Kucukva et al., 2019, Institute of Electrical and Electronics Engineers [IEEE]. Copyright 2019 by IEEE.

The dwindling agricultural land area and agricultural workforce along with the climate change impact may also hinder the sustainability of the food industry. As the food industry touches multiple policy domains and a recognized dynamic system, multidisciplinary and integrated approaches would play a crucial role in the new food policy development. The integrated approach should include stakeholders at both the national and international levels while emphasizing the safety, quality, markets, and sustainability of food products that require contributions from all stakeholders. An updated food policy, standards, and regulations on land use, sourcing of food, and easy access to desired quality food would be required which not only reduces food waste but also lead to the sustainability of the food industry. In addition, the availability of environmental information may enable environmentally conscious consumers to select more environmentally friendly products and thus contribute towards the sustainability of the food industry. A broader sustainability check must be adopted for implementing any updated food policy, food standard, and production and consumption strategies in order to reduce risks to the sustainability of the food industry and avoid any rebound effects on society.

6. Conclusions

Growing concerns about climate change and the sustainability of the food industry led to the initiation of various activities to enhance the food supply, reduce food waste, and improve the sustainability of the food industry. Facilitating a shift towards more sustainable production and consumption patterns calls for the adoption of a comprehensive approach, where life cycle thinking is widely recognized as a crucial concept to support this objective. While the number of empirical publications on the topic may not be extensive, it has grown significantly in recent years, primarily driven by the concerns of consumers regarding food sustainability. Food demand and production are constantly changing with increasing and changing population demographics in different jurisdictions and the need to engage more workforce. The food industry touches transdisciplinary domains and thus integrated and multisectoral approach engaging all stakeholders would play a crucial role in a sustainable food policy which may enhance food self-sufficiency and security, reduce food waste, ensure desired quality food products, encourage and satisfy the associated workforce, and attract more investment to improve the sustainability of the food industry.

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Article

Discussion of Consumers' Preference for Food Product Traceability Information: Beijing Traceable Tomato Case Study

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Abstract: The paper exemplifies a practical application of combining MNL, RPL and LCM econometric models to study consumer preference heterogeneity in the multi-attributive setting, by analyzing a case study of information traceability preferences of Beijing consumers who buy fresh tomatoes in the post-COVID period. Methodologically, such application of different models (MNL, RPL, LCM) has initially allowed to identify general patterns in Chinese consumers' preference in the tomato traceability information, then to identify and categorize distinct groups of customers and finally to provide details to their 'marketing' profiles towards their willingness to pay. As a result, consumer groups in this study were classified around three key attributes of tomato traceability information which reflect their priorities: consumers from "Price sensitivity" group demonstrated a higher willingness to pay for information on how products were produced (production condition) and products' certification; "Testing Information Preference" group was willing to pay for the information about tomato's product quality detection, and "Official Authority Approval Preference" group has developed priority for information on production condition. Such methodological approach provides rather precise characteristics about three different consumer groups, and thus fills in the existing lacunae in the literature and can serve a guiding tool for designing a regional food safety policy. The suggested methodology is transferrable for analyzing consumers' choices for traceability information about other food products and beyond China.

Keywords: China; choice experiment; consumer preference; food supply traceability; willingness to pay

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1. Introduction

The recurrent food safety incidents globally, and in China specifically, are results of the existing problem of information's asymmetry, when consumers do not have access to complete information about the food products they buy. This asymmetry is embedded in inefficiency of traceability information systems which fail to collect data on the product and pass it over to consumers. The information loss can happen at different points of food supply chain (Islam et al., 2022). This issue has affected consumers' welfare and pushed the governments to introduce strict food safety regulations. If adequately managed, a food information traceability system can reduce collusive behaviors among producers and distributors, and ultimately improve safety and quality of food products (Chen et al., 2020). In the post-COVID-19 global context consumers have significantly changed their shopping and consumer behavior, paying more attention to what they buy and seeking more detailed information about food product they intend to buy (European Institute of Innovation & Technology Food, 2020). In their turn, national governments also require a nuanced understanding of the demand for food attributes in order to create an associated system of quality and safety control.

While an obvious meaning of the traceability concept can be described as tracing down information about origins of a product, there is discrepancy among existing official definitions. For example, Codex Alimentarius defines it as "the ability to follow the movement of a food through specified stage(s) of production, processing and distribution" (FAO, 2024), which represents main stages in the food chain management. A different approach is incorporated in ISO 9000's definition: "ability to trace the history, application or location of that which is under consideration" (International Standards Organisation [ISO], 2000). Olsen and Borrit (2013) noted that in the previous version of ISO's definition, the definition contained a clarification on the traceability tool – "by means of recorded identification", which was later removed. Thus, it shows that there is space for different interpretations and ambiguity.

Then it comes to consumers, they search for more data on food products to make their decisions about purchasing and consuming food, but obviously, they don't usually apply themselves high-tech methods to analyze the quality and safety of the product they buy. However, they are willing to pay for the traceability information of the product they plan to buy by choosing those products that are covered by the established schemes of certification, for example, labeling them as organic food (Janssen & Hamm, 2012).

Indeed, a traceability information system is beneficial for consumers, but there might be different pieces of the information that can produce a different impact on consumers, and in fact, different groups of consumers might develop different preferences for specific traceability information attributes. The rich empirical research has confirmed the heterogeneity of consumers' preference for attributes of traceability information on food products. Hempel and Hamm (2016) concluded that consumers' preferences should not be generalized, as they vary depending on product type and consumers' place of residence. For example, while in Germany consumers showed a clear preference for the regional origin of honey they bought (Bissinger & Herrman, 2021), in Italy consumers showed a higher degree of heterogeneity in their preference for mountain beef (Linder et al., 2022). Chinese urban consumers' willingness to pay for food correlated with the degree of their trust in the government's food safety supervision (Liu et al., 2019).

An important remark should be made that not all consumers with a preference for more detailed product information are willing to pay a high price for such traceability information (Jin et al., 2017). Many would opt out and use immediate attributes, such as price, taste, and freshness in their purchase decision-making (Zhu & Lee, 2018). Likewise, governments are seeking a more differentiated approach in managing traceability systems, for example, to distinguish current key data elements (KDEs) from linking KDEs (Gravani et al., 2023). The argument that the obligatory incorporated traceability information system will raise the costs of a whole supply chain and increase the price for traceable agricultural products in general (Liu et al., 2019) explains why no unified traceability information has been yet introduced.

As shown above with the cases from the literature review, one may argue that different groups may seek different pieces of traceability information and different tools to obtain such data. Thus, it is difficult to generalize, and it would be beneficial to develop a case study methodology that can be adjusted for a specific market, a product, or a consumer group. Methodological techniques vary from the application of the best-worst scaling method (Linder et al., 2022) to combinations of logit models RPL+LCA (Wang et al., 2024) or MNL+RPL (Liu et al., 2019). In this paper, we would like to discuss the complexity of dealing with multiple preferences and provide an example of how to identify different groups of consumers of the same product based on the preference for a specific attribute of the traceability information by using a combination of MNL, RPL and LCM models. We have chosen the tomato (*Solanum lycopersicum),* which is a vegetable in culinary terms since it is a popular staple crop in China, as well as in other Asian countries, such as India (Sarkar et al., 2024).

Previous studies using empirical data to estimate consumers' preference and willingness to pay (WTP) in food consumption have certain limitations. The full characteristics of consumers and their preferences are difficult to capture, and measuring these differences is a methodological challenge. This study is not free of such limitations, but it offers a practical approach to develop a methodology that can be adjusted to further studies which could investigate more cases of preferences of specific consumers' groups in different settings. The suggested application of combining MNL, RPL, and LCM models creates a logical deductive approach: to distinguish general heterogeneity in consumers' preference and then to elaborate its further specifications. RPL or MNL models alone cannot explain sources of heterogeneity in preferences, but adding LCM addresses this limitation.

This study used traceability information for organic tomatoes being sold in Beijing as a case study based on a choice experiment (CE), in order to analyze consumers' preferences and willingness to pay (WTP) for food traceability information attributes, and to develop further knowledge on the heterogeneity of consumers in Beijing. These results enhance understanding of consumers' purchasing behavioral differences according to the food traceability information and preference patterns among different types of consumers. In its turn, such findings can improve marketing strategies for food producers and retailers and in fact, can be integrated in the general food policy formulation, at least at the Beijing city's administrative level.

The remainder of this paper is organized as follows. It explains the design of the econometric framework based on consumer utility theory, and then provides details of the experimental design, descriptive statistics and empirical analysis. Finally, we briefly summarize findings of this research.

2. Methodological Framework

Each of the selected methods contributes to a better understanding of the empirical data of this case study. First, the MNL model was used to capture general preferences for information about organic tomatoes among Beijing consumers. Then RPL model was used to calculate the specific preference of each group of consumers in the study. Finally, the LCM model was used for conducting more detailed calculations. Such progression of the used methods represents a logical process of this paper's analysis: transitioning from the MNL model to the RPL model we optimized the calculations, and by advancing from the RPL model to the MNL model we used for detailed elaboration of the results.

Paul Samuelson developed the revealed preference theory with the idea that consumers' preferences can be revealed by their purchasing behavior, and in its turn, their utility can also be affected (Samuelson, 1972). Utility theory, first developed by Lancaster (1966), provided a theoretical basis for a CE to evaluate product's attributes (Tarpey, 1973). It classifies goods according to their characteristics which, in its turn, can be measured with a utility tool (how useful they are to consumers). Following that, Lancaster assumed that since a product is a set of attributes, its characteristics and attribute quantities of product determine product's utility for consumers. Therefore, in a CE consumers' choice of goods can be translated into the choice of product's attributes, which then will reflect the consumers' preferences. In CE, consumers are required to choose from a set of optional attributes, instead of ordering or rating the traceability attributes information in a questionnaire survey, which comprehensively determines the probability of consumers' commodity selection based on attributes (Sarig, 2003).

Random utility theory (RUT) proposed by McFadden (1974) was chosen for this study as it considers choice as a discrete event. According to RUT or Random Utility Maximization (RUM), consumers are making choices about buying products following their attraction or utility, which is taken as a random variable. The model is efficient in measuring consumers' access to buy and value of goods. It fits our purpose to analyze consumers' behavior towards buying organic tomatoes.

2.1. Consumer Utility Components

According to the above theories, product's utility for consumers consists of two parts:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \tag{1}$$

V_{nj} is the total utility of the decision maker (n) for alternative option j, which can include option attributes and personal characteristics. ε_{nj} is random and represents the factors affecting U_{nj} but not in V_{nj}. In this paper, we assume that ε_{nj} is subject to Gumbel independent identically distributed (Train, 2009).

The utility to consumers when choosing i in scenario t as:

$$U_{nit} = V_{nit} + \varepsilon_{nit} \tag{2}$$

$V_{nit} = \beta' X_{nit}$ is the deterministic combination. β' is a parameter vector of structural preference weighted by exogenous variables in determining utility; X_{nit} is the attribute vector of the alternative options i; ε_{nit} is the random term.

Based on above models and tomato traceability information, the utility function model of consumer n for alternative options i in choice set t as:

$$U_{nit} = ASC + \beta_{1n}ENV_{it} + \beta_{2n}PFI_{it} + \beta_{3n}TSC_{it} + \beta_{4n}PTR_{it} + \beta_{5n}PC_{it} + \beta_{6n}GLP_{it} + \beta_{7n}CSP_{it} + \beta_{8n}PRI_{it} + \varepsilon_{nit} \tag{3}$$

ASC is the specific constant and represents other attributes without considering; $i = 1,2,\cdots N$ is consumers; t is the number of choice set; $n = 1,2$ is option A or B; U_{nit} is the individual utility; PRI_{it} is the price of 1 catty (0.5kg) of tomatoes in choice set t, which is in alternative options i; PPC_{it} (plant production conditions), PFI_{it} (pesticide and fertilizer information), TSC_{it} (transportation and storage conditions), PTR_{it} (product testing report), PC_{it} (product quality certificate PC), GLP_{it} (government-led platform), and CSP_{it} (companies self-built platform) are the attribute levels in alternative options j respectively. ε_{nit} is the random term.

2.2. Probability of Consumer's Choice

- Model 1: MNL model

Following the hypothesis of random term distribution and the form of utility functions (Van Wezemael et al., 2014), the Multinomial Logit (MNL) model can be used to analyze discrete choice experimental data if individual preferences are assumed to be homogeneous. This model follows the hypothesis of Independence from Irrelevant Alternatives (IIA), and the random terms follow the independent identically distributed I extremal distribution. The probability of decision maker n in alternative choosing option i is shown as Equation (4).

$$P_{ni}=\frac{\exp\left(V_{ni}\right)}{\sum_{j=1}^{J}\exp\left(V_{nj}\right)}=\frac{\exp\left(x_{ni}^{'}\beta\right)}{\sum_{j=1}^{J}\exp\left(x_{ni}^{'}\beta\right)} \tag{4}$$

- Model 2: RPL model

Several studies on food labeling have shown that heterogeneity needs to be considered while studying consumers' preferences (Ortega et al., 2011; Wongprawmas & Canavari, 2017). If consumers' heterogeneity is expected, a more flexible discrete choice model should be used, such as the Random Parameters Logit (RPL) model (Van Wezemael et al., 2014), which assumes that consumer's preferences are heterogeneous. In this paper, β follows the normal distribution. Then the probability of decision maker n in alternative choosing option i is shown as Equation (5).

$$P_{ni}=\int\frac{\exp x_{ni}^{'}\beta}{\sum_{j=1}^{J}\exp\left(x_{ni}^{'}\beta\right)}f\left(\beta\right)d\beta \tag{5}$$

- Model 3: LCM model

When the mixed distribution $f(\beta)$ is discrete, the Mixed Logit Model becomes the Latent Class Model (LCM). N individuals are divided into S classes, assuming that each class is composed of homogenous consumers. Equation (6) is the probability of decision maker n in alternative choosing option i.

$$P_{ni}=\sum_{s=1}^{s}\frac{\exp(x_{ni}^{'}\beta_{s})}{\sum_{j=1}^{J}\exp(x_{nj}^{'}\beta_{s})}R_{ns} \tag{6}$$

R_{ns} is the probability that decision-maker n in class s.

$$R_{ns}=\frac{\exp(\theta_{s}^{'}z_{n})}{\sum_{r}\exp(\theta_{r}^{'}z_{n})} \tag{7}$$

In Equation (7), z_n is a series of observable factors affecting the decision-maker types, such as sociodemographic characteristics et al., and $\theta_r^{'}$ is the parameter vector of decision makers in class S (Ortega et al., 2011).

Compared with MNL, RPL contains the consumers' heterogeneity function and does not follow the IIA hypothesis. LCM enables researchers to free the strict hypothesis of individual heterogeneity and unfounded distribution hypothesis (Greene & Hensher, 2003). This paper uses Maximum Likelihood Estimation (MLE) for analyzing parameters.

2.3. WTP Calculations

Based on the parameters estimated by the above models, we can calculate consumers' WTP. The value of WTP is a marginal rate of substitution between the non-monetary attribute and the cost. In MNL and RPL, it is a ratio of the non-monetary attribute coefficient to the monetary attribute coefficient.

$$WTP_{i}=-\frac{2\beta_{i}}{\beta_{p}} \tag{8}$$

i is an attribute level, β_i is the marginal utility of an attribute level relative to the reference level; p is the price attribute and β_p is the marginal utility of the price attribute. The bootstrap method proposed by Krinsky and Robb (1986) can be used to obtain the confidence interval of WTP.

3. Experimental Design and Data Description

Data collection in this study was conducted during the period from October 2019 to January 2023. The participants were randomly sampled from residents in Beijing.

3.1. Pre-Survey

To test and, if necessary, re-adjust a main questionnaire, before the formal CE, a pre-survey as market interviews were conducted on October 27–31, 2019. We randomly interviewed seven consumers at the exit of a supermarket in Haidian District, Beijing, and collected information about 9 residents through online interviews. The interviewees were residents in Beijing who used to shop at the same food supermarket.

While it is difficult to find precise data on how many customers buy groceries in an average food supermarket in Beijing, an informal assessment from a shop assistant in Changping, a residential area in Beijing, suggested 400-500 people shopping daily in late 2019, and the number has visually fallen in 2022, possibly due to increasing online orders (Telephone interview with Anonymous, Hualian Supermarket, 13 January 2023).

The pre-survey result has shown that Beijing consumers did care about traceability labels for vegetables (Table 1). Ten people (7 offline and 3 online) found traceability labels very helpful in identifying high-quality food products. Four people (online respondents) thought that traceability labels were helpful. Meantime, two online respondents people acknowledged that traceability labels were not very helpful.

Table 1. Pre-Survey: Consumers' preference in traceability information.

N of respondents	Assumption about vegetable traceability labels
10	Very helpful
4	Helpful
2	Not very helpful

The main tool the respondents used to receive information about the products was scanning traceability codes from food packaging or from supermarket shelves (usually in the form of QR codes). Consumers scanned traceability codes with their mobile phones or personal computers to obtain requested food traceability information (15 people used smartphone scan codes to obtain traceability information, and only one offline respondent was using their personal computer to get such traceability information).

3.2. Questionnaire Design

3.2.1. Tomato Traceability Information

The tomato supply chain includes production, processing, product inspection, packaging, storage, and transportation, so a traceability system should provide consumers with information about the mentioned above processes. According to the National Industry Standards of the People's Republic of China – "NY/T 1993-2011 Operating rules for quality and safety traceability of Agricultural Products-Vegetables" (in Chinese "农产品质量安全追溯操作规程-蔬菜"), the information on commercially sold vegetables should contain data about origins, production, information, packaging, storage, transportation, sales and inspection. To identify key characteristics related to the production phase, we referred to International Finance Corporation (2020) handbook on food safety, which included "producing environment", "pesticide and fertilizer" and "product detection". Additional factors, such as "product certification", "transportation of tomatoes", "storage" and "qualification of the industrial entity that produced tomatoes", were added following the literature review (Jin et al., 2017; Yin et al., 2017). Thus, these six key factors were used in this study as the tomato traceability information attributes.

3.2.2. Traceability Platform Information

According to the pre-survey on agricultural retail markets in Beijing, there are mainly three types of platforms that inform about vegetables' production traceability: government-led, companies self-built, and third-party certified ones.

3.2.3. Price Information

According to the data on tomato market prices collected by the Key Agricultural Products Market Information Platform, which is supported by the Ministry of Agriculture and Rural Affairs of the People's Republic of China, the average price of tomato from June to November 2019 was 3.6 yuan/catty (supermarket price, 1catty = 0.5kg). The statistics of the Ministry of Commerce of China showed that prices for tomato in the Beijing Xinfadi agricultural market was within the range of 1.5–6 yuan/catty (Ministry of Commerce, Market Operation and Consumption Promotion Department, 2020). Referring to Gao and Schroeder's (2009) method for setting the price range of target objects, 33% and 66% upward float, and 33% downward float were taken as the price range. Considering the seasonal characteristics of Beijing tomato sales and to simplify calculations, the price attribute was set as 2.4 yuan/catty, 3.6 yuan/catty, 4.8 yuan/catty, and 6 yuan/catty.

Based on the above attributes, effect coding in the CE specified that when an attribute is selected, it is "1"; the reference attribute level is "−1" and others are "0" (Tonsor et al., 2009; Wongprawmas & Canavari, 2017). The reference levels of two attributes are "Industrial Entities

Qualification Certificate" (IEQ) and "Third-Party Certification" (TPC) respectively in this study. The attributes assignments in the CE are shown in Table 2.

Table 2. Attribute variables and assignment of quality safety traceability information.

Attribute	Variable	Assignment
Quality and safety traceability information	Plant Production Conditions (e.g., soil, air, water quality, etc., FPC)	PPC=1；PFI=0；TSC=0；PTR=0；PC=0
	Pesticide and Fertilizer Information (PFI)	PPC=0；PFI=1；TSC=0；PTR=0；PC=0
	Transport and storage conditions (TSC)	PPC=0；PFI=0；TSC=1；PTR=0；PC=0
	Product Testing Report (PTR)	PPC=0；PFI=0；TSC=0；PTR=1；PC=0
	Product Certification (PC)	PPC=0；PFI=0；TSC=0；PTR=0；PC=1
	Industrial Entities Qualification certificate (IEQ)	PPC=−1；PFI=−1；TSC=−1；PTR=−1；PC=−1
Platform types	Government-led (GLP)	GLP=1；CSP=0
	Companies self-built (CSP)	GLP=0；CSP=1
	Third-party (TPC)	GLP=−1；CSP=−1
Price	Price (PRI)	PRI1=2.4；PRI2=3.6；PRI3=4.8；PRI4=6
Control Variables	Gender (GEN)	1=male，0=female
	Age (AGE)	21.5=[18,25]，27.5=(25,30]，35=(30,40]，45=(40,50]，55=(50,60]，60=(60,+)
	Education (EDU)	12=High school and below, 15=Junior college, 16=Bachelor, 19=Master degree and above
	Income (INC)	1.5=(0,3000]，4=(3000,5000]，7.5=(5000,8000]，9=(8000,10000]，15=(10000,20000]，20=(20000 ,+)

3.3. Simplifying the Questionnaire

In this study, each choice set contains two options: "Choice" and "No Choice". In order to ensure that respondents can only maximize their utility by showing their preferences (Penn, et al. 2014), respondents are required to make choices in forced-choice sets in experiments, that is, respondents must choose one in every choice set, and the choice sets do not include "Not making a choice" item. There are three attributes under each option in questionnaires from the above attribute levels setting, and each attribute has at least three attribute levels. In the case of two options, a total of $(6 \times 3 \times 4)^2 = 5184$ different attribute levels will be theoretically generated.

In order to simplify calculation (Mukerjee & Wu, 1999; Loeppky, 2012), based on the condition that the products attributes have been defined, this study applies the fractional factorial design method and orthogonal design to obtain choice sets. Orthogonal design means that using orthogonal code to make the sum of inner product in choice sets any two columns is zero. In order to get a smaller orthogonal design, we used Ngene 1.1.1 software to select 36 choice sets with different attribute levels, and then generate 9 different "blocks", namely 9 different questionnaire versions, so that respondents only need to make 4 choices in each questionnaire. According to the D-error offered by software, the efficiency of orthogonal design can be reflected. D-error of orthogonal questionnaire is 0.0413 in this study, which proves that our simplification is scientific and efficient. Following Wongprawmas and Canavari (2017), this study uses the method of combining pictures and words.

One of the simplified choice sets as Table 3. Each participant was given 5 choice sets (including a repeat scenario) before they were told that the tomatoes differed only in three attributes, and other attributes were the same.

Table 3. Choice Set Example Scenario 1: Which tomatoes would you buy?

	A	**B**
		
Quality and safety traceability information	Pesticide and fertilizer information	Industrial entities qualification certificate
Platform types	Government-led	Third-party
Price	3.6 yuan/ catty	4.8 yuan/ catty

3.4. Formal CE

The formal CE was from January 17–31, 2020. Due to COVID-19 in China, we conducted experiments on consumers by online questionnaires. The surveyed group was a random sample of consumers who have purchased in "Freshippo" APP during the above period. Freshippo is a retail chain for groceries and fresh goods in China. It exemplifies the creation of a new shopping experience through complimenting online and offline operations in retail stores, warehouses, and the online orders department. As of March 31, 2022, we had 273 self-operated Freshippo stores, primarily located in tier-one and tier-two cities in China.

It is common that online questionnaires can be prone to such problems, as sampling frame error, no answer error, and response bias (Couper, 2000; Lessler & Kalsbeek, 1992). However, as the target group investigated in this study consisted of consumers who intended to buy traceable food, these consumers had to scan QR codes or entered traceable codes on the web to get traceability information, so they must have been able to use smartphones or other electronic equipment. Therefore, the sampling frame error in this online survey is relatively low.

In addition, all questions in questionnaires were forced choice sets, and the multiple-choice questions were strictly regulated. The respondents could only submit the questionnaire answers after they had answered all questions, which reduced the number of errors caused by incomplete answers. The online questionnaire was designed to set the minimum finishing time for each page in order to increase the attention of respondents in this study. Besides, the research team also ran three times manual sampling tests and eliminated obviously unreasonable answers. Validation questions, repeated questions, and small probability event questions were used to control the questionnaire answers (Gao et al., 2015).

In the process of filling in questionnaires, the randomness and validity of samples were strictly controlled. For randomness, respondents selected in the experiments were consumers who intended to buy traceable food. The questionnaires were set as "Are you more willing to buy food with traceability information than ordinary food?" to filtrate eligible samples. For validity, respondents were required to use electronic equipment, such as smartphones or computers to fill in questionnaires, and the survey location was limited to Beijing by IP address. Finally, we got 597 valid questionnaires, and the sample statistical characteristics are shown in Table 4.

Table 4. Statistical characteristics of the investigated samples.

Variables	Options	Samples	Proportion (%)
Gender	male	273	45.73
	female	324	54.27
Age	[18–25)	87	14.57
	[26–30)	144	24.12
	[31–40)	219	36.68
	[41–50)	108	18.09
	[51–60)	30	5.03
	[61, +)	9	1.51
Education	High school and below	24	4.02
	Junior college	93	15.58
	Bachelor	411	68.84
	Master degree and above	69	11.56
Income	(0,3000]	30	5.03
	(3000,5000]	81	13.57
	(5000,8000]	132	22.11
	(8000,10000]	144	24.12
	(10000,20000]	159	26.63
	(20000, +)	51	8.54
With children aged below 0–12 or old people older than 65	Only child	144	24.12
	Only old man or woman	57	9.55
	None	165	27.64
	Both	231	38.69

4. Empirical Results

4.1. Consumers' Preference for Tomato Traceability Information and WTP

In our RPL model, we assume that the random utility is normally distributed, and Halton draws 1000 times for estimating. The results are shown in Table 5.

Table 5. MNL and RPL model estimation results.

	MNL		RPL	
Variables	Mean	SE	Mean	SE
ASC	0.246***	0.056	0.253***	0.085
Plant Production Conditions (e.g., soil, air, water quality, etc., FPC)	0.481***	0.090	0.572***	0.155
Pesticide and Fertilizer Information (PFI)	−0.291***	0.096	−0.388**	0.170
Transport and Storage Conditions (TSC)	−0.566***	0.086	−1.017***	0.148
Product Testing Report (PTR)	0.507***	0.087	0.927***	0.170
Product Certification (PC)	−0.008	0.085	0.071	0.139
Price (PRI)	−0.521***	0.032	−1.324***	0.170
Government-led Platform (GLP)	0.677***	0.065	1.241***	0.158
Companies Self-built Platform (CSP)	−0.327***	0.058	−0.586***	0.107
STDEV (FPC)	/	/	0.775***	0.259
STDEV (PFI)	/	/	0.938***	0.273
STDEV (TSC)	/	/	0.486*	0.286
STDEV (PTR)	/	/	0.895***	0.231
STDEV (PC)	/	/	0.345	0.287
STDEV (GLP)	/	/	0.809***	0.171
STDEV (CSP)	/	/	0.480***	0.161
STDEV (PRI)	/	/	1.454***	0.202
Number of respondents	597			
Sample size was observed	2388			
Log likelihood	−991.16		−856.98	
AIC	1998.32		1745.97	
BIC	2042.25		1833.82	

Notes: (1) "*", "**" and "***" represent significance at the statistical level of 10%, 5%, and 1%; (2) The price unit is yuan/ catty (0.5kg).

There is a similarity between the MNL model and the RRL model, which not only reflects the characteristics of traceability information attributes but also indicates that estimation results are robust. Among the five attribute levels of traceability information, the means of FPC and PTR are positive and statistically significant, indicating that these two attribute levels are relative to the reference attribute level (IEQ) to provide positive marginal utility to consumers.

In contrast, the means of PFI and TSC are negative and statistically significant, indicating that these two attributes brought more negative marginal utility to consumers than at the reference attribute level. The means of PC are not statistically significant, indicating that there is no significant difference between the utility brought by PC and the reference attribute.

Differences in traceability information platforms also produced different impacts on consumers. For the traceability information platform, the means of GLP are positive and statistically significant, indicating that this attribute level brings more positive marginal utility to consumers than the reference attribute level (TPC). The means of CSP are negative and statistically significant, indicating that this attribute level brings more negative marginal utility to consumers than TPC. The mean of price is negative, indicating that it brings negative marginal utility to consumers.

Comprehensively, the marginal utilities of six attribute levels in traceability information were ranked: PTR > PPC > IEQ ≈ PC > PFI > TSC. Thus, the results showed that consumers were concerned about tomato planting conditions and detection situations, and consumers' preference for product certification was not significant. In addition, consumers showed a low preference for pesticide and fertilizer information. The marginal utility of three attribute levels of traceability platform was in the following order as: GLP > TPC > CSP.

This result shows that consumers trust the authority of a Government-Led platform. It is consistent with the conclusions of Liu et al. (2019) and Wu et al. (2019) on the Chinese apples' traceability labels.

According to the RPL model, the WTP for premiums (relative to a reference level) of tomato traceability information attributes were estimated to obtain means and standard errors. The bootstrap method proposed by Krinsky and Robb (1986) was used to obtain a confidence interval. The results of WTP are shown in Table 6.

Table 6. Estimated results of WTP.

Attributes	Mean	SE	Confidence Interval
Plant Production Conditions (FPC)	0.864	0.250	[0.476,1.316]
Pesticide and Fertilizer Information (PFI)	−0.586	0.260	[−1.038, −0.160]
Transport and Storage Conditions (TSC)	−1.536	0.244	[−2.008, −1.168]
Product Testing Report (PTR)	1.400	0.262	[0.984, 1.890]
Product Certification (PC)	0.106	0.210	[−0.246, 0.462]
Government-led Platform (GLP)	1.874	0.242	[1.516, 2.322]
Companies self-built Platform (CSP)	−0.886	0.168	[−1.192, −0.626]

Notes: (1) 95% confidence interval in Table V; (2) The unit of willingness to pay is yuan/catty (0.5kg); (3) The reference level of Attribute 1 is Industrial Entities Qualification Certificate, and the reference level of Attribute 2 is the Third-Party platform.

Among the six attribute levels of the tomato traceability information, consumers have the highest WTP premium for PTR, which is 1.400 yuan/catty (0.5kg). The second preferred attribute is the FPC, 0.864 yuan/catty (0.5kg). Among the three traceability information platforms, consumers have the highest WTP premium for GLP, which is 1.874 yuan/catty (0.5kg).

4.2. Analysis of the Heterogeneity of Consumer Preference

According to the difference in the standard error of WTP, consumers are also characterized by heterogeneity due to differences in their preferences for the attributes of traceable agricultural products. Therefore, this study further introduces covariates such as age, gender, education, and monthly income per capita to the LCM model for analysis.

The statistically significant preference heterogeneity in the RPL model can be translated into different classes (Class) in the LCM model, in order to identify distinct consumer groups (Table 7). It shows that the consumers' preference for price (PRI) in Class 1 (33.1%) is significantly higher than for other attributes (absolute value). As this consumer group is concerned more about products' prices, we define it as the "Price Sensitivity" (PS) Class. Class 2 (26.1%) shows that the second identifiable consumer group obtained the highest level of utility from the PTR, and the TSC is the lowest, so we entitled this class as the "Testing Information Preference" (TIP) Class. Compared with above two classes, the preference of consumers in Class 3 (40.8%) for GLP is higher than other attributes (absolute value), indicating that this consumer group has the highest preference for traceability information provided by GLP. We called them an "Official Authority Approval Preference" (OAAP) Class. Further analysis of age (AGE), gender (GEN), education (EDU), and income (INC) relative to the PS Class indicated that male consumers with higher education and lower per capita monthly income are more likely to be in TIP Class. Younger women are more likely to represent the OAAP Class.

Table 7. LCM Model Estimation Results.

Variables	Class 1	Class 2	Class 3
ASC	−0.193 (0.387)	0.096 (0.254)	0.128 (0.097)
Plant production Conditions (PPC)	2.111*** (0.574)	−0.924** (0.422)	0.432*** (0.167)
Pesticide and Fertilizer Information (PFI)	−0.350 (0.600)	0.664** (0.298)	−0.484*** (0.169)
Transport and Storage Conditions (TSC)	−1.494*** (0.463)	−2.499*** (0.494)	−0.331** (0.160)
Product testing report (PTR)	0.931** (0.416)	3.750*** (0.870)	0.022 (0.151)
Product certification (PC)	−0.862 (0.734)	0.432 (0.308)	0.155 (0.141)
Government-led (GLP)	1.690** (0.796)	0.911*** (0.205)	0.769*** (0.102)
Companies self-built (CSP)	−1.280** (0.571)	−0.928*** (0.215)	−0.225** (0.097)
Price (PRI)	−3.819*** (0.882)	−1.236*** (0.268)	0.001 (0.053)
Age (AGE)	/	−0.010** (0.004)	−0.025*** (0.004)
Gender (GEN)	/	0.347** (0.147)	−0.236* (0.124)
Education (EDU)	/	0.651*** (0.161)	−0.059 (0.123)
Income (INC)	/	−0.380*** (0.147)	0.060 (0.123)
Probability	0.331	0.261	0.408
Number of respondents		597	
Sample size was observed		2388	
Log likelihood		−821.66	
AIC		1717.32	
BIC		1920.47	

Notes: (1) the figures in brackets are SE. of the estimated coefficients. (2) "*", "**" and "***" represent significance at the statistical level of 10%, 5%, and 1% respectively. (3) The price unit is yuan/catty (0.5kg). (4) When the samples were divided into three categories, AIC and BIC were the smallest ones. (5) The reference level of Attribute 1 is the Industrial Entities Qualification Certificate, and the reference level of Attribute 2 is the Third-Party platform.

5. Conclusions

In this paper, we analyzed the preference of consumers in Beijing for tomato traceability information attributes based on a choice experiment (CE) and measured their willingness to pay for such data (WTP). Meanwhile, the heterogeneity of consumers was also estimated.

Since the consumers' answers to price in the questionnaires are discrete data, this paper used the "discrete choice model" to estimate the consumers' willingness to pay. First, the MNL model, which is the basic type of Logit model, was applied to analyze the data. However, the MNL model can be used for estimating average preferences and cannot identify inter-individual heterogeneity. The most commonly used model for data heterogeneity analysis is the RPL model. The MNL model satisfies the assumption that the random error term follows the strict IID (Independent Identical

Distribution), while the RPL model relaxes this restriction and allows parameters to vary randomly between individuals. The heterogeneity of individuals can be described by the distribution of model parameters (mean value, standard deviation), and the heterogeneity can be studied better. Further, the LCM model is a statistical analysis technique that combines latent variable theory with categorical variables and can analyze potential categorical variables that may exist other than categorical variables with statistical correlation. Unlike MNL and RPL models, LCM is a semi-parametric model that does not require preselection of specific assumptions about the distribution of parameters between individuals (Greene & Hensher, 2003). In LCM, groups are composed of a limited number of identifiable individuals with the same preferences, and preferences are heterogeneous among groups. One of the advantages of LCM over RPL is that it can shed light on systemic causes of preference changes (Tabi & del Saz-Salazar, 2015), that is, whether there may be potentially unobservable heterogeneity.

The results showed that compared with the reference level of preference for tomatoes provided with industrial entity's qualification certificates, Beijing consumers were more willing to pay higher premiums for retrieving information about the production environment and product quality detection, which have been calculated at 1.400 yuan/catty and 0.864 yuan/catty respectively. They were not willing to pay higher premiums for pesticide and fertilizer information, transportation, and storage conditions. The influence of product certification was almost the same as the reference level. In general, the marginal utility brought to consumers by the six attributes of traceability information has been ranked from high to low as: Product testing report > plant production conditions > industrial entity qualification certificate ≈ product certification > pesticide and fertilizer information> transportation and storage conditions.

As for analyzing the preference for three traceability information platforms, compared with the reference level of a third-party platform, consumers were more willing to pay a higher premium of 1.874 yuan/catty for a government-led platform, but are not willing to pay a premium for a private companies' internal reporting platform. In general, the marginal utility brought to consumers by the three attributes of traceability platforms are ranked from high to low as: Government-led platform > third-party platform > companies' internal platform.

In addition, differences in consumers' characteristics such as gender, age, education, and monthly income, determine that consumers have produced different preferences for tomato traceability information. Through the LCM model, consumer groups in this study were classified around three key attributes of tomato traceability information which reflect their priorities: "Price sensitivity", "Testing Information Preference" and "Official Authority Approval Preference". The "Price Sensitivity" group has a higher WTP for information on tomatoes' production condition and product certification of tomatoes they buy. The "TIP" group developed the highest WTP in the information about tomato's product quality detection, and the second priority was information about pesticides and fertilizers usage. The "OAAP" group only has a higher WTP for information on production conditions. All three groups preferred to receive the traceability information from government-led platforms.

The findings in this paper are in line with the previous research on consumers' preferences and willingness to pay for food products traceability information, showing heterogeneity of consumers' preferences. However, the suggested combination of research methods, such as obtained sample data by CE method, and using MLP estimation method to analyze MNL, RPL, and LCM models under the two consumer conditions of homogeneity and heterogeneity, has allowed to draw patterns in these preferences and classify consumers into three groups based on their priorities. This, on one hand, matches the theory of revealed preference, and on the other, gives concise information about the key priorities for these groups that can be beneficial in updating a marketing strategy for food enterprises.

Moreover, according to the characteristics of relevant research on WTP, previous studies on WTP were aimed at a hypothetical commodity that did not appear in the market and then calculated the price to be paid by consumers. This study abstracts a conceptualized "traceable tomato" by starting from the real traceable tomato in the market and further integrating other food attributes. The results obtained not only meet the technical requirements of WTP measurement but also are more credible (Perni et al., 2021). The choice experiments that we have designed included many traceable tomato' attributes, which addressed consumers' concerns. However, all these attributes cannot be fully reflected upon during the moment of purchase. Therefore, adding these attributes into the choice experiment as "attribute information" is not only useful to study the WTP of consumers but also shows that calculated WTP is matching the "attribute" that consumers care about, so findings are credible.

Food safety is an integral part of the Chinese national food security policy. Integrating a whole traceability information system into the food supply chains might not be feasible cost-wise, neither through public or private funds, at least in the near future. The application of AI and new technologies, such as Blockchain Technology (BT) can potentially provide a base for a comprehensive food information traceability system (Feng et al., 2020). However, to reap the full benefits of BT, technological advancement should be accompanied with “the right managerial effort to improve the consumers’ WTP” (Brusset et al., 2024).

Since this research is embedded in the local context (the Beijing area) and a specific product, the exact findings cannot be extended to other areas and other food products, but the chosen methodology can be used as an example of how to approach the heterogeneity of consumers’ preference regarding food product traceability information. The suggested methodological approach can be replicated for future research on other food products, and in different geographical contexts, and thus, it will be useful for further methodological discussions in the food study field.

One of the key issues for Chinese food consumers is trust, since they have less trust in internal (corporate) traceability in food enterprises, as our study has shown, and as previous studies showed, sometimes doubt official food control certification (Liu et al., 2019). Thus, better knowledge of consumers’ priorities can be used together with the application of advanced technologies to enhance communication and trust between consumers and corporate and state actors, and as a result to improve national strategy for food security and system of food control in China. With the key priorities of consumers being clearly identified, in addition to managing obligatory controlling measures on food safety, policymakers can organize additional testing in the most efficient manner, while food producers can apply this detailed knowledge of marketing portfolios to maintain customers’ satisfaction and increase sales.

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Article

Medical Insurance Benefits and Labor Decisions of Middle-Aged and Elderly People: Evidence from Rural China

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Abstract: Studying the influence of expanded medical insurance coverage on the labor decisions of rural middle-aged and elderly individuals is advantageous in addressing the consequences of population aging on the labor market. This study utilizes the China Health and Retirement Longitudinal Study (CHARLS) from 2015 and 2018, employs the Difference-in-Differences (DID) approach to empirically investigate the effect of improved medical insurance benefits on the labor decisions of rural middle-aged and elderly individuals. The findings suggest that the increase in medical insurance benefits significantly raises the labor participation rate, labor force participation time, and labor migration among rural middle-aged and elderly individuals, while reducing their willingness for endless labor. Further analysis reveals that the increase of medical insurance benefits directly affects labor decisions by reducing the burden of medical expenses and indirectly influences labor decisions by affecting health conditions. The impact of increased medical insurance benefits on labor supply is more pronounced for the elderly and women compared to middle-aged individuals and men. Based on these findings, this study suggests the continuous improvement of medical insurance benefits for rural residents, the expansion of the scope of medical insurance coverage, and the gradual relaxation of participation restrictions in the medical insurance program.

Keywords: medical insurance; rural; middle-aged and elderly people; labor supply; labor migration

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1. Introduction

Population aging is a significant challenge facing human society in the 21st century. As of 2021, the global population aged 65 and above accounts for 10% of the total population. Among 194 countries and regions worldwide with available statistical data, 106 are experiencing an aging society (World Bank Group, n.d.). China, with the world's largest elderly population, had a rural elderly population proportion of 49.04% by 2020. Population aging is widely observed due to its large scale, rapid pace, and distinct regional disparities (Zhou et al., 2023). The challenges posed by aging are multifaceted, primarily leading to an increase in social burdens and labor shortages (Yang et al., 2022; Huang et al., 2019). Meanwhile, due to the imperfect social security system in rural China, elderly individuals in rural areas often persist in labor due to economic conditions, resulting in a significant "willingness for endless labor"(Xue & Li, 2022; Kobayashi et al., 2024). This excessive labor, whether viewed from the perspective of increasing welfare for rural elderly individuals, reducing social burdens, or maintaining a balance between labor market supply and demand, is undoubtedly unsustainable (Nahid et al., 2023). Therefore, on one hand, there is a desire to increase labor supply among rural middle-aged and elderly individuals. On the other hand, it is essential to prevent the exacerbation of excessive labor among this demographic. Resolving this "paradox" requires China to gradually improve its rural social security system. A robust social security system allows those capable of working to do so while providing retirement security for those unsuitable for labor (George & Wilding, 1984; Deng et al., 2022).

In China, the New Rural Cooperative Medical Scheme (NRCMS), which targets rural farmers, was officially launched in 2003. However, it still faced issues such as a low level of medical insurance benefits and low portability of medical insurance rights. In January 2016, the State Council issued "Opinions on the Integration of Basic Medical Insurance Systems for Urban and Rural Residents," which unified the medical insurance benefits for urban and rural residents, establishing Urban and Rural Resident Medical Insurance (URRMI) (Figure 1). In comparison to the NRCMS, the URRMI possesses the following characteristics: Firstly, the integration of urban and rural medical insurance follows the principle of "higher benefits, lower premiums, and broader coverage."

This results in an increase in the level of medical insurance benefits and a reduction in the proportion of medical expenses borne by individuals. For example, concerning the hospital reimbursement rate, which experienced the most significant change, rural residents initially enjoyed under the NRCMS, where the hospitalization reimbursement rate was 56.6%, this rate increased to 69.3% after the implementation of the URRMI. Secondly, the NRCMS was originally organized at the county level, meaning that individuals could be reimbursed for medical expenses within their county, but if they sought medical care outside the county, they needed to follow specific procedures for approval and reimbursement rates were limited. In contrast, the URRMI operates at the city level, and individuals seeking medical care within the city face no restrictions. Furthermore, it encourages areas with the necessary conditions to implement provincial-level integration, thereby increasing the portability of medical insurance rights (Wang et al., 2019; Ren et al., 2022; Lin et al., 2024).

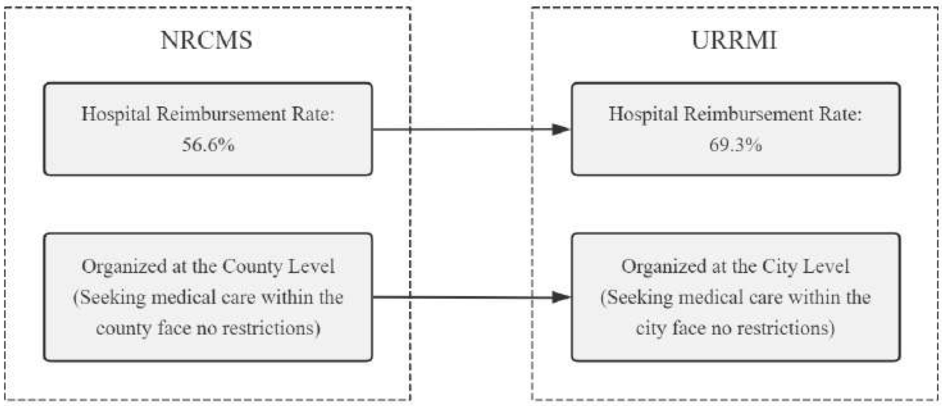

Figure 1. Changes in medical insurance benefits in rural China.

In the literature related to the impact of health human capital on labor market performance, numerous studies indicate that improving health human capital can promote labor force participation and reduce labor force exit (Bradley et al., 2013; Currie & Madrian, 1999; Bradley et al., 2007; Royalty & Abraham, 2005; Chłoń-Domińczak et al., 2024; Lu & Wu, 2023). Scholars have conducted extensive research on public health insurance in China. Shen et al. (2017) employed the Difference-in-Differences (DID) method to estimate the impact of the New Rural Cooperative Medical Scheme (NRCMS) on labor supply outcomes. The NRCMS had a positive influence on agricultural working hours and non-agricultural labor force participation rates, while reducing the likelihood of being unable to work due to illness and taking sick leave. After the integration of the NRCMS and the Urban Resident Basic Medical Insurance (URBMI) into the URRMI, a few scholars have evaluated the policy effects of the URRMI from the perspectives of improving health, increasing healthcare service utilization, promoting social integration, and social participation (Huang & Wu, 2020; Qin et al., 2021). For example, Zhou et al. (2023), based on 2018 data from the Dynamic Monitoring Survey of Migrant Populations, analyzed the impact of the URRMI on the labor supply of migrant workers. The study found that this medical insurance significantly enhanced the labor force participation rate of migrant workers and improved the quality of labor supply. Rui (2019), starting from the perspective of the accessibility of healthcare for migrant workers, found that migrant workers who participated in the URRMI reduced their weekly working hours by 8.45% compared to those who did not participate, leading to a significant reduction in overtime work among migrant workers.

From the existing research, empirical studies on the policy effects of medical insurance integration, especially regarding its impact on vulnerable rural populations, are relatively limited. Given this, this study takes the integration of urban and rural medical insurance as a point of entry to investigate the impact of increased medical insurance benefits on the labor decisions of rural middle-aged and elderly individuals. The innovation and practical value of this study, compared to previous research, lies in several aspects: First, it focuses on the impact of increased medical insurance benefits on the labor decisions of rural middle-aged and elderly individuals. Previous studies primarily focused on the establishment of medical insurance in rural China, and whether the improvement of medical insurance benefits would have a more profound impact on labor decisions has not been extensively explored. In China, most people already have basic medical insurance coverage. Hence, the impact of increased medical insurance benefits on labor decisions, in comparison to the mere possession of insurance, is a topic that warrants long-term research in the future. Second, the study addresses the issue of the "willingness for endless labor" among rural middle-aged and elderly individuals. Compared to the commonly studied labor hours in labor economics, the notion of a willingness for endless labor is a more intriguing topic. This is particularly relevant in rural China, where residents have relatively low incomes and are compelled to engage in labor throughout their lives until they are physically unable to work. This situation has negative implications for the well-being of the elderly. Third, the study further examines the situation of rural middle-aged and elderly individuals engaging in labor migration. While urbanization in China is progressing rapidly, there remains a surplus of agricultural labor. How to facilitate the transition of surplus rural labor and study the impact of increased medical insurance benefits, especially the portability of such insurance, is a topic of significant practical importance.

2. Theoretical Analysis

2.1. Impact of Increased Medical Insurance Benefits on Labor Supply

In this paper, drawing upon the household production decision model, we elucidate the labor supply function through an optimization process, which determines the allocation of labor and leisure time, considering the constraints encountered by the household. It is assumed that the household utility function of a farmer has the following form:

$$\mathrm{U}\ (T_O,\ T_L,\ Y) = 1, \tag{1}$$

In the above model, T_O denotes the time spent by individuals on working; T_L denotes the time spent by individuals on leisure consumption; Y denotes consumption of goods. Farmers face the following constraints on time and income budget:

$$T = T_O + T_L \tag{2}$$

$$\mathrm{P_Y Y} = \mathrm{T_O\ W_O} + \mathrm{V} \tag{3}$$

In Equation (2), we delineated the temporal constraint faced by the farm household: T denotes the household's total time endowment, partitioned into the household's working time T_O and leisure consumption time T_L. Notably, T_L is influenced by its healthy capital stock H. Equation (3) is the household's income budget constraint, which indicates that the total household consumption expenditure is equal to the disposable income. This income specifically includes labor income and other non-labor income. P_Y denotes the market price of Y. W_O denotes the market wage rate for labor. V is the household's other non-labor income, such as government subsidies, contributions from friends and relatives.

Based on the household utility function of equation (1), incorporated the constraints detailed in Equations (2) and (3), the optimal Lagrangian function can be derived as follows:

$$Z = U(T_O, T_L, Y) + \lambda_1 (T - T_O - T_L) + \lambda_2 [T_O\ W_O + V - P_Y Y] \tag{4}$$

The optimal solution for the labor supply is as follows:

$$T_O^* = T_O^* [W_O\ (H),\ T_L(H)] \tag{5}$$

According to Grossman's (1972) health demand theory, increased health investments, such as the medical service utilization, will enhance health capital stock and an improve health status. Moreover, the degree of medical service utilization is closely related to an individual's health insurance participation. Therefore, if health is considered as a product, the medical insurance serves as an input for the production of health. Consequently, the functional form of individuals' health production can be expressed as:

$$H = H\ [M\ (P_N)] \tag{6}$$

In the above equation, M denotes the individual's medical service utilization. As analyzed previously, individuals can enhance their health capital by increasing their medical service utilization, thereby improving their health status.

Consequently, medical service utilization has a positive effect on the production of health, ($\partial H/\partial M > 0$). P_N denotes the proportion of reimbursement by the medical insurance that individuals participate in, and the reimbursement proportion has a positive effect on the utilization of health services by individuals ($\partial M/\partial P_N > 0$). By substituting the health production function from Equation (6) into the labor supply equation in Equation (5), and solving for the partial derivatives with respect to medical insurance, the following expressions are obtained:

$$\frac{\partial T_O^*}{\partial P_N} = \left(\frac{\partial T_O^*}{\partial W_O} \cdot \frac{\partial W_O}{\partial H} + \frac{\partial T_O^*}{\partial T_L} \cdot \frac{\partial T_L}{\partial H}\right) \frac{\partial H}{\partial M} \cdot \frac{\partial M}{\partial P_N} \tag{7}$$

Given that both $\frac{\partial H}{\partial M}$ and $\frac{\partial M}{\partial P_N}$ are non-negative, the impact of medical insurance on labor supply ultimately depends on $\frac{\partial T_O^*}{\partial W_O}\cdot\frac{\partial W_O}{\partial H}+\frac{\partial T_O^*}{\partial T_L}\cdot\frac{\partial T_L}{\partial H}$. where $\frac{\partial T_O^*}{\partial W_O}\cdot\frac{\partial W_O}{\partial H}$ denotes the health effect of medical insurance on labor supply through output, and since good health status promotes individuals' labor productivity, making $\frac{\partial T_O^*}{\partial W_O}\cdot\frac{\partial W_O}{\partial H}$ positive; $\frac{\partial T_O^*}{\partial T_L}\cdot\frac{\partial T_L}{\partial H}$ denotes the health effect of medical insurance on labor supply through leisure consumption. With improved medical insurance benefits, the increase of reimbursement ratio of rural residents makes the expected medical expenditure decrease and improve the health, according to the theory of precautionary savings, the participants will reduce the current savings, resulting in reduced labor time, making $\frac{\partial T_O^*}{\partial T_L}\cdot\frac{\partial T_L}{\partial H}$ negative.

Overall, individuals perceive that the marginal utility of improved medical insurance benefits for labor output exceeds the marginal utility for leisure consumption, they will increase their labor supply. Given the significant enhancement of medical insurance benefits, it is posited that farmers will increase their labor supply.

Based on the above analysis, this paper proposes the following hypothesis:

H1: Improved medical insurance benefits can promote the labor supply of middle-aged and elderly people in rural areas.

2.2. Impact of Increased Medical Insurance Benefits on Labor Migration

Traditional labor economics theory posits that the utility level an individual derives from choosing a particular job is primarily composed of two elements: the wage compensation of the job itself and the non-wage welfare benefits tied to it (Bonar, 1891; Conte, 1980; Swanson, 1994). Accordingly, this paper, drawing on the research by Hong and Ning (2020), and hypothesizes that the individual's mobility decision is a response to the difference in the level of utility between urban and rural employment. The utility function can be expressed as follows:

$$U_i\,(J^b)=\alpha\, W^b+\beta H^b-\delta I^b \tag{8}$$

In the above equation, W^b denotes the earnings of laborers working within the village; H^b denotes the expected benefits from the medical insurance for laborers employed locally; and I^b denotes the cost incurred for local medical treatments, including the transportation cost incurred for medical treatment and the loss of income due to reduced working hours during medical treatment. When the location of medical treatment is the same as the workplace, $I^b \geq 0$. α, β, and δ denote the unit level of utility generated by each benefit (cost), respectively, all of which are positive.

The utility function expression for laborers employed outside the village (J^a) can be articulated as follows:

$$U_i\,(J^a)=\alpha\, W^a+\beta H^a-\theta C^a-\delta I^a \tag{9}$$

In the above equation, W^a denotes the wage income of laborers employed outside the county, and under general circumstances, $W^a > W^b$. H^a denotes the expected benefits from the medical insurance for laborers employed outside the village, H^a depends on the medical insurance benefits' coverage extent and portability. Higher portability equates to better health insurance benefits for migrant workers and lower medical costs. C^a denotes the search costs for employment in towns or cities, with $C^a > 0$. I^a denotes the cost of medical treatment away from one's county, constrained by the NRCMS's reimbursement rules, the laborers who employed outside can only get a higher percentage of reimbursement compensation when they seek medical treatments within their county.

In the case of non-portability of medical insurance benefits, $I^a > I^b \geq 0$. α, β, θ, and δ denote the unit utility level generated by each benefit (cost), and α, β, θ, and δ are all greater than 0, respectively.

Based on the logic outlined, comparing the net utility levels of laborers choosing different employment locations:

$$D=U_i\,(J^a)-U_i\,(J^b)=[\alpha W^a+\beta H^a-\theta C^a-\delta I^a]-[\alpha W^b+\beta H^b-\delta I^b] = \alpha(W^a-W^b) + \beta(H^a-H^b) - \theta C^a-\delta(I^a-I^b) \tag{10}$$

Obviously, the laborers will choose migration if and only if D ≥ 0. The condition of labor migration is:

$$\alpha(W^a-W^b)+ \beta(H^a-H^b) \geqslant \theta C^a-\delta(I^a-I^b) \tag{11}$$

Equation (11) shows that the decision of labor migration is influenced not only by the wage differentials between urban and rural jobs but also by the extent to the portability of their medical insurance benefits across different employers and locations.

Before the integration of urban and rural medical insurance, rural laborers typically participated in the NRCMS at their registered residences. The NRCMS, managed at the county level, has led to a segmented and fragmented operation of China's rural medical insurance system between urban and rural areas. According to the regulations of the NRCMS, the medical insurance rights and benefits of highly mobile rural laborers could not be maintained or transferred with changes in employment location. Therefore, assuming all other conditions remain constant, the loss of medical insurance benefits ($\beta(H^a–H^b)$) and increased medical costs ($\delta(I^a–I^b)$) when working outside the county, could lead to a decrease, or even a negative net utility D, deterring laborers from choosing labor migration.

Compared with NRCMS, URRMI embodies stronger portability in terms of co-ordination level, medical treatment in places away from one's hometown, reimbursement catalogs and reimbursement benefits, and reduces the complex and cumbersome reimbursement applications and procedures. This may encourage rural laborers to engage in non-agricultural employment in prefecture-level cities.

Based on the above analysis, the following hypotheses are proposed in this paper:

H2: The integration of urban and rural medical insurance can promote labor migration of middle-aged and elderly people in rural areas.

3. Materials and Methods

3.1. Data Source

The data used in this study is derived from the China Health and Retirement Longitudinal Study (CHARLS). Given that the integration of urban and rural medical insurance mainly took place in 2016, the study uses the most recent data from the 2015 and 2018 CHARLS two-wave dataset. To accurately isolate the intensive marginal effects of the urban and rural medical insurance integration policy on health from other medical insurance programs, the following selection process was carried out: Firstly, individuals who participated in both 2015 and 2018 were selected, including those who participated in the NRCMS in 2015 and those who participated in both the NRCMS and the URRMI in 2018. Secondly, individuals without insurance coverage, participants in Urban Employee Medical Insurance (UEMI), participants in commercial medical insurance, and non-local insurance participants were excluded from the data. Lastly, data without identifiable insurance status were removed. Following this selection process, a balanced two-wave panel data set was created.

3.2. Description of Variables

3.2.1. Dependent Variable

In academic research on the mechanisms of medical insurance's impact on the labor force, specific measurement indicators for labor decisions can generally be categorized into two main types: one relates to labor supply (Flabbi & Mabli, 2018; Bradley et al., 2007; Coe et al., 2012), and the other pertains to labor location choice (Gong & Sims, 2023; Boschmann, 2011; Brown & Scott, 2012). Regarding labor supply, this study primarily considers labor participation, labor hours, and the willingness for endless labor. As for labor location choice, this study mainly focuses on labor migration.

Labor Participation and Working Hours. The CHARLS follow-up questionnaire inquired about the time spent on four types of work over the past year, including agricultural self-employment, employment, non-agricultural self-employment, and assisting with family business activities. To calculate the average weekly working hours for each type of work, we multiplied the number of working months for each category by 4.35, the number of working days per week, and the number of hours worked per day, then divided the result by 52. By summing the average weekly working hours for all categories, we obtained the overall average weekly working hours. Regarding labor participation, individuals with working hours greater than zero were considered to be participating in labor and were assigned a value of 1, while the rest were assigned a value of 0.

Willingness for endless labor. We used an indicator related to the anticipated age at which individuals plan to stop working, which was included in the CHARLS questionnaire. Respondents were asked, "At what age do you plan to stop working, meaning you will stop all money-earning activities and will no longer assist with family business activities, and you will not engage in work that is more physically demanding than leisure activities?" For the sample, individuals who indicated an age above 80 or those who planned to work until they were very old, such as "working until the end of life," were assigned a value of 1; otherwise, they were assigned a value of 0.

Labor migration. We primarily determined labor migration based on the CHARLS follow-up questionnaire, where respondents were asked, "Where do you work/do business most of the time?" If the response indicated a location outside the same village as the current place of residence, it was assigned a value of 1; otherwise, it was assigned a value of 0.

3.2.2. Independent Variable

Participation in rural middle-aged and elderly individuals' medical insurance types (MIT). Referring to the options for individual sample participation in medical insurance types in the CHARLS questionnaire, samples of rural middle-aged and elderly individuals who participated in the NRCMS and URRMI were retained. According to the characteristics of the difference in difference (DID) model, relevant dummy variables were set. The group dummy variable was set as follows: samples of rural middle-aged and elderly individuals who fully participated in both survey periods (participated in the NRCMS in 2015 and the URRMI in 2018) were designated as the "treatment group" and defined as 1, while samples that participated in the NRCMI in both 2015 and 2018 were designated as the "control group" and defined as 0. The time dummy variable was set as follows: 2015 was defined as 0, and 2018 was defined as 1. The "treatment group" consisted of a total of 2,890 individuals, while the "control group" consisted of 14,238 individuals.

3.2.3. Covariates

We select covariates from five levels. Individual characteristics, which include gender (female = 1, male = 0), age, marital status (married = 1, unmarried = 0), income, education, number of children. Personal health behaviors, which mainly include whether the individual smoking (smokes = 1, does not smoke = 0), exercise (exercises = 1, does not exercise = 1), and drinking (consumes alcohol = 1, does not consume alcohol=0). Personal health status, which is represented using Self-Assessment Health (very good = 1, good = 0.8, fair = 0.6, poor = 0.4, very poor = 0.2). Quality of medical institution services and medical costs, which are represented by the satisfaction level with medical institution diagnosis and treatment (referred to as Satisfaction).

The descriptive statistics of the variables can be found in Table 1.

Table 1. The descriptive statistics of the variables.

Variables	2015			2018			2015–2018
	(1) control	(2) treatment	(3) (2)−(1)	(4) control	(5) treatment	(6) (5)−(4)	(7) full sample
Labor Participation	0.659	0.595	−0.06***	0.707	0.709	0.002	0.678
Working Hours	16.456	15.494	−0.962	18.620	20.607	1.987***	17.625
Willingness for Endless Labor	0.608	0.667	0.060***	0.028	0.014	-0.014	0.331
Labor Migration	0.278	0.297	0.019	0.304	0.344	0.040*	0.296
Gender	0.538	0.546	0.008	0.536	0.544	0.007	0.538
Age	60.763	60.332	-0.431	63.737	63.307	−0.430	62.186
Marital Status	0.831	0.844	0.013	0.808	0.825	0.017	0.822
Income	5.442	6.008	0.566***	8.007	8.1666	0.158*	6.7840
Education	3.762	3.963	0.201*	3.762	3.963	0.201*	3.796
Number of Children	3.144	2.833	−0.311***	3.125	2.829	−0.296***	2.656
Smoking	0.290	0.261	−0.029	0.279	0.248	−0.031	0.279
Exercise	0.954	0.931	−0.023***	0.895	0.892	−0.002	0.922
Drinking	0.337	0.327	−0.010	0.312	0.317	0.005	0.324
Self-Assessment Health	0.594	0.609	0.015**	0.567	0.598	0.031***	0.584
Satisfaction	2.664	2.583	−0.080**	2.677	2.580	−0.097***	0.616

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.2.4. Research Model

The transition from NRCMS to URRMI provides a natural experiment for studying the specific impact of the medical insurance system on labor in this research. Therefore, we employ the Difference-in-Differences (DID) method. Following the fundamental steps set by the DID model, two sets of dummy variables are constructed. First, the "treatment group" and the "control group" dummy variables. The treatment group consists of residents who participated in the NRCMS in the base year 2015 and chose to participate in the URRMI during the experimental period. In contrast, the control group includes residents who were already part of the NRCMS in 2015 but did not join the URRMI during the experimental period. Second, policy time dummy variables. By comparing the differences in labor conditions between the treatment group and the control group, the study systematically analyzes the impact of improved medical insurance benefits on rural middle-aged and elderly individuals. Based on the analysis above, the regression model for the DID method is as follows:

$$Y_{it}=\beta_0+\beta_1\, DID_{it}+\beta_2\, Treat_i+\beta_3\, Time_t+\delta X_{it}+\epsilon_{it} \tag{12}$$

$$DID_{it}=Treat_i \times Time_t \tag{13}$$

In the equation, subscript i represents the individual, and t represents the time period. Y_{it} is the dependent variable, which refers to the labor-related index of individual i in period t. DID_{it} is the core independent variable. The coefficient β_1 has an economic interpretation, signifying the extent to which the improvement in rural residents' medical insurance benefits after the integration of urban and rural medical insurance impacts the labor of rural middle-aged and elderly individuals. $Treat_i$ is the group dummy variable. If individual i belongs to the treatment group, $Treat_i$ is defined as 1. Otherwise, if i belongs to the control group, $Treat_i$ is defined as 0. $Treat_t$ is the time dummy variable. If the individual is in the experimental period after the implementation of the integrated medical insurance (in 2018), $Treat_t$ is set to 1. Otherwise, if the individual is not in the experimental period, $Treat_t$ is set to 0. ϵ_{it} represents the error term. The selection of covariates variables X_{it} is based on Grossman's (1972) theory of health capital demand and relevant literature.

4. Results

4.1. Regression DID

As labor participation, willingness for endless labor and labor migration are all binary variables, Probit regression is employed for models (1), (3), and (4), while the classical Ordinary Least Squares (OLS) regression is used for working hours in model (2). The regression results and marginal effects can be found in Table 2.

The increase in medical insurance benefits increases the log odds of labor participation among rural middle-aged and elderly by 0.185. As a marginal effect, it results in a 5.69% increase in labor participation rate, which is statistically significant at the 1% level. The increase in medical insurance benefits significantly increase the working hours for rural middle-aged and elderly by 3.076 hours. This indicates that the integration of urban and rural medical insurance indeed stimulates the labor supply of rural middle-aged and elderly individuals, not only in terms of labor participation but also by significantly increasing the working hours.

The increase in medical insurance benefits reduces the willingness for endless labor of rural middle-aged and elderly individuals. The integration of urban and rural medical insurance lowers the log odds of endless labor willingness by 0.452. As a marginal effect, it leads to a 9.48% decrease in the willingness for endless labor, which is statistically significant at the 5% level.

The increase in medical insurance benefits promote rural middle-aged and elderly individuals' engagement in labor migration. The integration of urban and rural medical insurance increases the log odds of labor migration by 0.167. As a marginal effect, it results in a 3.10% higher probability of engaging in labor migration, which is statistically significant at the 10% level.

Table 2. The results of the DID (Difference-in-Differences) regression.

Variables	(1) Labor Participation	(2) Working Hours	(3) Willingness for Endless Labor	(4) Labor Migration
DID	0.185***	3.076***	-0.452**	0.167*
	(0.0584)	(0.954)	(0.200)	(0.101)
Treat	−0.166***	−1.352**	0.102	−0.160*
	(0.0432)	(0.686)	(0.0796)	(0.0871)
Time	0.289***	2.640***	−2.368***	0.0175
	(0.0269)	(0.417)	(0.0752)	(0.0496)
Gender	−0.179***	−3.693***	0.0931	−0.308***
	(0.0299)	(0.476)	(0.0768)	(0.0593)
Age	−0.0329***	−0.495***	−0.0151***	−0.0282***
	(0.0015)	(0.0231)	(0.0044)	(0.0034)
Marital Status	0.300***	4.360***	0.0332	−0.183***
	(0.0289)	(0.421)	(0.0884)	(0.0635)
Income	0.0211***	0.661***	−0.0106	0.0339***
	(0.0039)	(0.0600)	(0.0092)	(0.0085)
Education	−0.0196***	−0.0612	−0.0167**	−0.00794
	(0.0030)	(0.0479)	(0.0070)	(0.0057)
Number of Children	−0.0015	0.170	0.0522**	0.0183
	(0.0082)	(0.127)	(0.0263)	(0.0212)
Smoking	0.0721**	0.661	−0.0282	−0.0137
	(0.0306)	(0.482)	(0.0677)	(0.0533)
Exercise	0.642***	4.479***	0.00483	0.0414
	(0.0398)	(0.588)	(0.126)	(0.0971)
Drinking	0.266***	2.963***	−0.0564	0.0458
	(0.0273)	(0.439)	(0.0630)	(0.0498)
Self-Assessment Health	0.732***	9.340***	0.00722	0.0418
	(0.0571)	(0.871)	(0.143)	(0.109)
Satisfaction	−0.0050	0.115	0.0558**	0.0345*
	(0.0103)	(0.162)	(0.0261)	(0.0208)
Marginal Effect	0.0569***		−0.0948**	0.0513*
Provincial Fixed Effects	YES	YES	YES	YES
N	15975	15981	3775	4558
Adjust R^2	0.1230	0.1207	0.4016	0.1198

4.2. Robustness Checks

4.2.1. Parallel Trends Test

Parallel trends are a prerequisite for the Double Difference (DID) method to correctly identify causal effects. To test this, we employ an event study method to assess the parallel trends. By testing whether the regression coefficient is significantly different from 0, it indirectly verifies whether the pre-existing parallel trend is met. Figure 1 shows that coefficient is not significant in the periods before the policy intervention (i.e., in 2011 and 2013), indicating that the pre-existing parallel trend is satisfied:

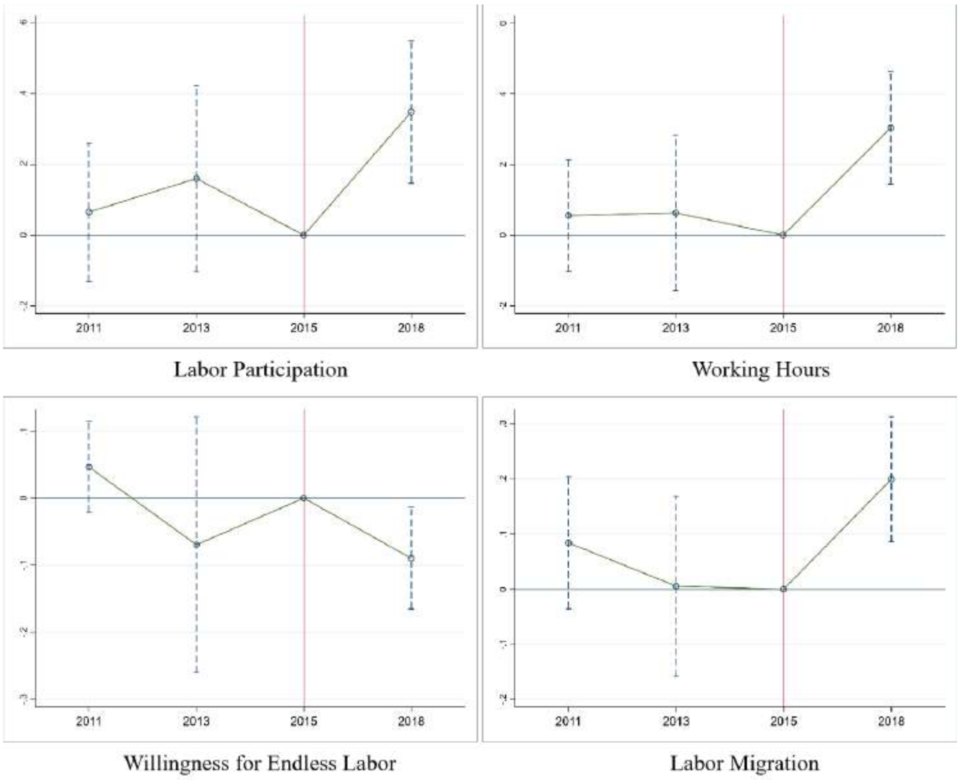

Figure 2. Results of the Parallel Trends Test.

Note: 95% confidence intervals are represented by short dashed lines. In the years preceding the policy shock (2015), the regression coefficients fall within the 95% confidence intervals that include zero. This demonstrates that there were no significant differences between the treatment groups and the control groups before the implementation of the policy, indicating no systematic bias and fulfilling the basic premise of the parallel trends test necessary for DID analysis.

To rigorously assess the robustness of our regression findings, we employed both the Propensity Score Matching-Difference in Differences (PSM-DID) approach and placebo tests for validation. The outcomes from these methods are consistent with those obtained from the baseline Difference in Differences (DID) regression analysis. Detailed regression results are provided in the Supplementary Materials.

4.3. Regression DID

In order to examine the mechanisms through which an increase in medical insurance benefits resulting from the integration of urban and rural medical insurance affects labor decisions, intermediate variables were selected. Figure 4 presents a diagram of the pathways involved, which includes four main paths:

(1) Direct path: increase in medical insurance benefits leads to changes in labor decision-making.

(2) Indirect Path 1: increase in medical insurance benefits affects labor decision-making through changes in medical burden.

(3) Indirect Path 2: increase in medical insurance benefits affects self-assessment health by influencing the medical burden, which, in turn, leads to changes in labor decision-making.

(4) Indirect Path 3: increase in medical insurance benefits affects labor decision-making through changes in self-assessment health.

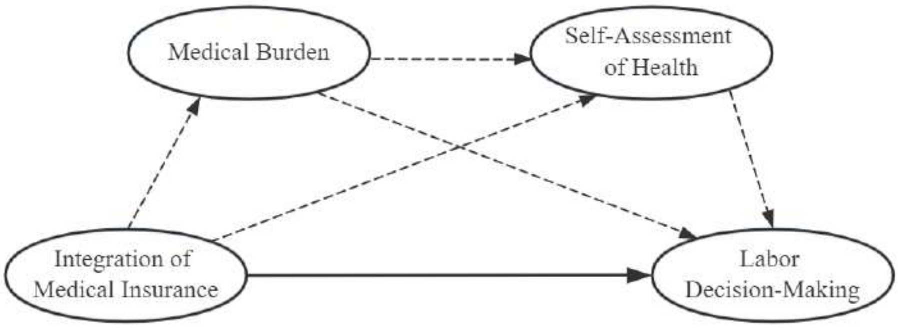

Figure 3. The impact pathways of increased medical insurance benefits on decision-making.

Note: Solid lines represent the direct pathway through which increased medical insurance benefits affect labor decision-making, while dashed lines represent the indirect pathways through which these benefits influence labor decision-making.

Table 3 presents the empirical results of the impact mechanisms of increased medical insurance benefits on rural middle-aged and elderly individuals' labor decisions following the integration of urban and rural residents' medical insurance. From the results, it can be observed that the impact of increased medical insurance benefits on labor decision-making is primarily achieved through a reduction in the medical burden.

In terms of labor participation and working hours, increased medical insurance benefits significantly reduce the medical burden. This reduction in the medical burden may lead to increased demand for leisure, thereby decreasing working hours. However, the reduced medical burden also significantly improves health, which, in turn, enhances labor productivity, leading to a significant increase in working hours.

Regarding the willingness for endless labor, the decrease in the medical burden reduces the economic pressure on farmers, lowers their concerns about the future, and makes them more willing to retire in the future. This results in a significant decrease in the willingness for endless labor. On the other hand, the reduction in the medical burden also improves health, which may make farmers more willing to work endlessly. However, overall, the improved medical insurance benefits significantly reduce the willingness for endless labor.

Regarding labor migration, increased medical insurance benefits significantly increase the likelihood of engaging in labor migration. This may be due to the fact that medical insurance integration reduces the medical burden, leading to improved health. Improved health, in turn, makes rural middle-aged and elderly individuals more willing to engage in labor migration.

Table 3. The results of the DID (Difference-in-Differences) regression.

Panel A	Medical Burden	Self-Assessment Health	Labor Participation
DID	−0.0344**	0.0082	0.0422**
	(0.0153)	(0.0092)	(0.0201)
Medical Burden		−0.0970***	−0.0260**
		(0.0053)	(0.0117)
Self-Assessment Health			0.2070***
			(0.0193)
Panel B	Medical Burden	Self-Assessment Health	Working Hours
DID	−0.0344**	0.0082	2.1907**
	(0.0153)	(0.0092)	(1.0141)
Medical Burden		−0.0970***	−1.9604***
		(0.0053)	(0.5910)
Self-Assessment Health			8.6251***
			(0.9736)
Panel C	Medical Burden	Self-Assessment Health	Willingness for Endless Labor
DID	−0.0260**	0.0108	−0.0632**
	(0.0130)	(0.0065)	(0.0284)
Medical Burden		−0.1079***	0.0294*
		(0.0046)	(0.0176)
Self-Assessment Health			0.0099
			(0.0302)
Panel D	Medical Burden	Self-Assessment Health	Labor Migration
DID	−0.0267*	0.0109	0.0403
	(0.0150)	(0.0083)	(0.0329)
Medical Burden		−0.1030***	0.0091
		(0.0045)	(0.0196)
Self-Assessment Health			0.0565*
			(0.0338)

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.4. Heterogeneity Analysis

Regressions are conducted for different age and gender groups (Table 4).

Panel A presents the regression results based on age groups. We divide individuals into middle-aged (Age < 60) and elderly (Age ≥ 60) groups, using the age of 60 as a dividing point. In terms of labor participation and working hours, the impact of increased medical insurance benefits on labor supply in rural middle-aged individuals is greater than that on elderly individuals.

As for the desire for willingness for endless labor, elderly individuals exhibit a significantly lower willingness compared to middle-aged individuals, possibly because aging makes elderly people value rest and leisure more and their physical capacity cannot support strenuous work. Retirement desires are stronger among the elderly.

However, concerning the impact on labor migration, the impact is more significant for elderly individuals than middle-aged individuals. The reason may be that most elderly individuals work within their own villages, and the improvement in their health makes them more willing to work outside. Most middle-aged individuals already work outside the village, so the impact of medical insurance on them is less pronounced.

Panel B shows the results of the gender-based regressions. In terms of labor participation and working hours, the impact of increased medical insurance benefits on the labor supply of female is greater than that on male. This is likely due to the generally lower health status of women in rural middle-aged and elderly populations (in this study, the mean self-assessment health for men and women are 0.6027 and 0.5686, respectively). The improvement in women's health caused by the enhanced medical insurance benefits makes them more capable of engaging in labor. Additionally, since women generally have lower health statuses and the increased medical insurance benefits reduce the medical burden, women may have a stronger desire to retire.

Table 4. Heterogeneity Analysis by Age and Gender.

Groups	N	Labor Participation	Working Hours	Willingness for Endless Labor	Labor Migration
			Panel A		
Middle-Aged（Age<60）	7068	0.2489***	3.0987**	0.0972	0.1021
		（0.0926）	（1.5814）	（0.0737）	（0.1298）
Elderly（Age≥60）	9716	0.0780	2.7475**	−0.4875*	0.3501*
		（0.0786）	（1.1582）	（0.2597）	（0.1908）
			Panel B		
Male	7905	0.1507*	2.1000*	−0.3913	0.1467
		（0.0778）	（1.2631）	（0.2831）	（0.1716）
Female	9223	0.2347***	4.3514***	−0.5153*	0.1869
		（0.0890）	（1.4475）	（0.2895）	（0.1318）

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

5. Discussion

5.1. Discussion

The increase in medical insurance benefits on labor supply can be attributed to two main effects: economic effect and health effect (Cameron & Trivedi, 1991; Hadley, 2003; Liu & Hu, 2022; Alfrey, 2024; Wang et al., 2024). The increase in medical insurance benefits, characterized by increased reimbursement rates and expanded coverage, reduces the medical burden on individuals, leading to a rise in relative income, which represents the economic effect of medical insurance. An increase in the economic effect may reduce precautionary savings and decrease labor supply. Conversely, the health effect generally stimulates labor supply because improved health conditions are likely to enhance labor productivity, resulting in higher labor rewards and, consequently, increased labor supply.

The research findings that increase in medical insurance benefits can promote the labor participation and working hours of rural middle-aged and elderly individuals. Simultaneously, it reduces their willingness for endless labor, which not only boosts societal labor supply but also prevents middle-aged and elderly individuals from overworking, allowing them to enjoy their later years. This is because, after the enhancement of medical insurance benefits, the reflection in terms of working hours shows that the health effect outweighs the income effect, leading to an increase in labor supply. However, regarding the willingness for endless labor, the income effect surpasses the health effect, resulting in a decreased willingness for endless labor. This confirms the initial premise that desire to increase labor supply among rural middle-aged and elderly individuals. On the other hand, it is essential to prevent the exacerbation of excessive labor among this demographic. It both elevates the level of societal labor supply and provides more leisure time for rural middle-aged and elderly individuals, thus enhancing their welfare. These findings underscore the significant policy implications, suggesting that future steps should involve further increasing the annual maximum payment limit and reimbursement rates for medical expenses, while reducing the deductible threshold. Additionally, efforts should be made to advance the unified planning of basic outpatient services under the URRMI, expand the coverage of chronic disease protection, and gradually shift from disease-based protection to expense-based protection. This will promote the level of outpatient treatment for chronic and severe illnesses to align with that of inpatient treatment.

The transition from the NRCMS to the URRMI also involves a change in the hierarchical level of medical insurance (Yip et al., 2019). The NRCMS generally only allows rural residents to seek medical care within their county, with many restrictions on seeking care outside of the county. URRMI extends the coverage area to the city level, allowing unrestricted access to medical care within the entire city. Traditional labor economic theory suggests that an individual's choice of work is influenced by the utility derived from two main components: the monetary rewards associated with the job and the non-wage benefits linked to it (Bonar, 1891; Conte, 1980; Swanson, 1994). Medical insurance is one such non-wage benefit. Under the NRCMS, for highly mobile rural labor, NRCMS benefits cannot be maintained or transferred as their employment location changes. In the framework of the URRBMI system, the insurance features enhanced portability in terms of pooling level, out-of-region healthcare, reimbursement directories, and reimbursement benefits, and simplifies the complex application and reimbursement procedures that rural households faced under the NRCMS. With the integration of the urban and rural medical insurance systems, the medical insurance benefits enjoyed by rural labor when working in different regions are becoming closer to those of locally employed individuals, which promotes labor mobility. The next step should involve raising the level of medical insurance pooling and implementing provincial or nationwide insurance pooling. Removing all restrictions on migrant workers participating in medical insurance at their place of employment would fill the social security gap for rural migrant workers and effectively improve their social security benefits.

Heterogeneity findings suggest that increase in medical insurance benefits has a relatively larger impact on labor decisions for traditionally vulnerable groups, such as the elderly and women (Cutler & Zeckhauser, 2000). This is likely because the marginal effect of increasing medical insurance benefits on labor decisions is greater for individuals with relatively lower levels of health. From this perspective, continuing to enhance medical insurance benefits is likely to increase labor supply and labor migration for those with lower levels of health, ultimately increasing their income. This, in turn, could help reduce income inequality resulting from differences in health status, contributing to a more equitable society.

5.2. Limitations

This study has certain limitations. Due to variations in the implementation progress, integration models, financing levels, and medical insurance benefits across different cities in the country, it was challenging to conduct a detailed analysis of policy intricacies due to constraints in the survey data. Subsequent research could explore the impact of urban-rural resident medical insurance integration on the labor decisions of rural middle-aged and elderly individuals from different regional and integration model perspectives, shedding light on the deeper institutional factors behind these effects.

Furthermore, we utilized data from 2015 and 2018 to analyze the policy impact differences. However, it is widely recognized that evaluating policy effects often requires a longer timeframe of three years or more. Data from 2015 and 2018 may not be sufficient for a comprehensive assessment of medical insurance policies. Therefore, future research should consider using a longer time span to more accurately assess the long-term effects of policies

6. Conclusions

The increase in medical insurance benefits significantly boosted the labor participation rate, working hours, and labor migration of rural middle-aged and elderly individuals, while reducing their willingness for endless labor. Regarding the mechanism of these effects, the increase in medical insurance benefits directly impacted labor decisions by reducing the medical burden. Furthermore, it influenced labor decisions indirectly by improving health conditions. In terms of heterogeneity, the impact of increased medical insurance benefits was more pronounced for the elderly and women compared to middle-aged individuals and men. Based on these findings, this study suggests the continuous improvement of medical insurance benefits for rural residents, the expansion of the scope of medical insurance coverage, and the gradual relaxation of participation restrictions in the medical insurance program.

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Supplementary Materials

Robustness Checks

1. Propensity Score Matching Difference-in-Differences (PSM-DID) Method

The PSM-DID method employs propensity score matching (PSM) to control for sample imbalances in observed characteristics. Specifically, we use the previously mentioned covariates to estimate propensity scores and perform a 1:1 K-nearest neighbors matching with replacement. The results show that the data matching quality is good (as shown in Figure 1). This minimizes significant differences between the treatment and control groups before policy implementation, reducing endogeneity concerns stemming from selective biases in residents' choices at the time of policy implementation. After matching, the impact of the increased medical insurance benefits on the labor decisions of rural middle-aged and elderly individuals is consistent in significance and coefficient size with the baseline regression results (as shown in Table 1).

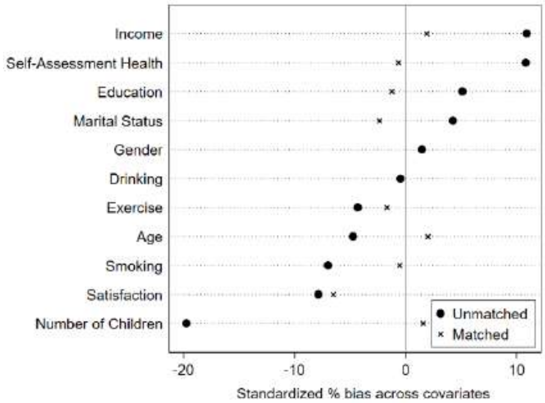

Figure 1. Results of Balance Test.

Table 1. PSM-DID Results.

Variables	Labor Participation	Working Hours	Willingness for Endless Labor	Labor Migration
PSM-DID	0.1565 **	3.0232***	−0.7503***	0.1731*
	(0.0787)	(0.7512)	(0.2555)	(0.0977)
Covariates	YES	YES	YES	YES
N	4872	4847	1240	1269
Adjust R^2	0.1187	0.1157	0.4287	0.1286

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2. Placebo Test

We employ a placebo test to eliminate estimation biases caused by changing heterogeneity features over time. Two periods of data, prior to the 2013 and 2015 policy interventions, are selected. Assuming that the policy intervention occurred in 2014, the DID method is reevaluated using the data. If the policy's impact is driven by heterogeneity factors that change over time, then this impact should persist, and similar effects should be observed in the placebo test results. If no policy impact is observed in the placebo test results, it indicates a low likelihood of the existence of time-varying heterogeneity effects. Table 2 shows that when the policy timing is shifted, the results are all insignificant, supporting the conclusion that the trend changes between the treatment group and control group are caused by the integration of urban and rural residents' medical insurance.

Table 2. Placebo Test Results.

Variables	Labor Participation	Working Hours	Willingness for Endless Labor	Labor Migration
DID	−0.0040 (0.0833)	−0.0767 (1.4548)	0.0974 (0.1536)	−0.2244 (0.1586)
Covariates	YES	YES	YES	YES
N	8765	8769	2446	2583
Adjust R^2	0.0521	0.0560	0.0564	0.0819

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

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Call papers for Vol. 2, Issue 4

1. Organizational Culture

(1) **Mission**: “Establish a mind for the heaven and earth, establish a destiny for the people, carry forward the unique knowledge for the sages, and create peace for all generations.” (Zhang Zai/Hengqu, Philosopher; 1020-1077 CE) | "横渠四句"：为天地立心，为生民立命，为往圣继绝学，为万世开太平)

(2) **Vision**: Establish a Scholar Community Center (SCC) as a change-maker to seek a way out for agriculture, seek development for rural areas, and seek well-being for farmers.

(3) **Beliefs**: Open, Global, Trust-worthy and Quality-assured.

(4) **Values**: Add Value Around You (i.e., the journal adds value to the author, who in turn adds value to the journal).

(5) **Motto**: A&R | Born to Shine.

(6) **SCC Philosophy**: Uphold Equality, Diversity & Inclusion (EDI).

(7) **Journal Philosophy**: Promise Less, Deliver More.

(8) **Editorial Slogans**: Pour Your Heart into A&R; Find a Way Forward.

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A&R is a peer-reviewed scholarly journal dedicated to being an international multidisciplinary and interdisciplinary platform for communicating advances in fundamental and applied studies on contemporary agricultural, rural and farmers' issues and policies, as broadly defined by the disciplines of economics, sociology, human geography and cognate subjects.

A&R publishes articles related with an emphasis on, but not limited to, the following:

(1) Sustainable agriculture and rural sustainable development.

(2) Farmer’s well-being, rural poverty alleviation and women’s studies.

(3) Smart agriculture, rural e-commerce and digital governance.

(4) Understanding and analysis of contemporary agricultural, rural and farmers' issues and policies (Chinese/domestic and global), as broadly defined by the disciplines of economics, sociology, human geography and cognate subjects.

(5) Other related novel sciences and technologies with agricultural and rural perspectives.

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Review Articles are overviews of a specific field of scientific literature. They aim to synthesise and evaluate recent primary literature on a topic, address controversies or provide a comprehensive list of references. Review Articles should not exceed 10,000 words (excluding references) with up to 100 references.

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Original/Research Articles are full-length scientific publications of original (i.e., unpublished) research. They should not exceed 8,000 words (excluding references) and a maximum of 12 images. Research articles over 8,000 words will only be accepted subject to Editorial decisions on needing a lengthier publication.

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