frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 07 December 2023
DOI 10.3389/fsufs.2023.1287814

OPEN ACCESS

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RECEIVED 02 September 2023
ACCEPTED 20 November 2023
PUBLISHED 07 December 2023

CITATION
Han S and Cheng Y (2023) The impact of the COVID-19 epidemic on agricultural production strategy from the perspective of loss aversion. *Front. Sustain. Food Syst.* 7:1287814.
doi: 10.3389/fsufs.2023.1287814

The impact of the COVID-19 epidemic on agricultural production strategy from the perspective of loss aversion

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Agricultural products have the characteristics of high perishability, short life cycles, and low salvage, and agricultural production is easily affected by uncontrollable natural conditions. Therefore, farmers will face great risk when making agricultural production decisions. In addition, farmers have a high demand for basic income security, so they are typically loss-averse decision-makers. Simultaneously, the impact of the COVID-19 epidemic has undoubtedly increased their loss aversion. The piecewise utility function is an effective model for investigating decision-making with consideration of loss aversion, in which the loss aversion parameter will be adjusted by the epidemic to a certain degree. We innovatively involve the impact of COVID-19 epidemic by a quantitative correction factor in the loss-averse newsvendor model to deal with the decision-making problem of agricultural production and investigate the influences of the epidemic and farmers' loss aversion degree on the optimal production quantity and profits as well as the relationship between the epidemic situation and loss aversion. Through model analysis and numerical experiments on a specific agricultural product by Matlab software, it is found that the effect caused by the epidemic and the increased level of loss aversion will reduce farmers' production and income. Therefore, it is necessary to strengthen regular epidemic prevention and control and formulate corresponding support policies to stimulate farmers' production motivation. Maintaining relative stability in the agricultural market demand can also alleviate the negative impact of the epidemic to a certain extent. Faced with the impact of the epidemic, farmers need to do their best to control agricultural production costs to relieve their economic pressure.

KEYWORDS

agricultural production, the COVID-19 epidemic, loss aversion, utility function, production strategy

1 Introduction

As the category with the highest frequency of consumption in daily life, agricultural products are the most fundamental needs of people. They not only affect people's life and health, but also affect farmers' income and the development of the rural economy. Therefore, the issue is the key concern for governments and societies around the world. However, in recent years, the contradiction between supply and demand of agricultural products has become more and more prominent. Ensuring a stable supply of important agricultural products and achieving a balance of supply and demand has always been the top priority of agricultural development in various countries. From a global perspective, the United States and Japan have been in a leading position in the agricultural industry due to the high degree of agricultural mechanization and scale. Although China's output of various agricultural products is globally in a leading position, due to China's vast territory, people's rich eating habits, a wide variety of agricultural products, coupled with the limitations of agricultural production, the agricultural basic technology and facilities are relatively weak, and the agricultural products industry lags behind the United States and Japan. Recently China has comprehensively promoted the strategy of rural revitalization, among which industrial revitalization is the first (CPC Central Committee, State Council, 2018). Agricultural production, as the basis of rural industrial revitalization, is of great significance.

On the background of the rural revitalization strategy in China, with the successive introduction and implementation of relevant support and preferential policies in various places, a good opportunity has arisen for the rapid development of the agricultural production industry. However, at the beginning of 2020, a sudden outbreak of the COVID-19 epidemic swept across the country (National Health Commission, 2022), which brought with it a universally significant impact, and the agricultural product industry chain was not spared (Li Q., 2020; Xue and Sha, 2020). The output of various agricultural products in China has a year-on-year (YoY) decline to varying degrees. Taking several types of bulk agricultural products as examples, according to the data of the Ministry of Agriculture and Rural Affairs of China, from January to May 2020, the slaughtered volume of live pig slaughtering enterprises above the designated size was 61.7295 million, a YoY decrease of 33.9% (Ministry of Agriculture and Rural Affairs, 2020). The slaughtered volume in May was 13.8221 million, a year-on-year decrease of 27.8% (Ministry of Agriculture and Rural Affairs, 2020). In May, the live pigs inventory of 400 monitored counties decreased by 15.7% YoY; the inventory of reproductive sows decreased by 5.6% YoY (Ministry of Agriculture and Rural Affairs, 2020). According to the data from the National Bureau of Statistics, Chinese cumulative yarn output from January to May 2020 was 9.119 million tons, a YoY decrease of 18.1% (Ministry of Agriculture and Rural Affairs, 2020). From January to June 2020, Chinese main producing areas purchased 23.892 million tons of wheat, a YoY decrease of 8.4% (Ministry of Agriculture and Rural Affairs, 2020). From January to February 2020, the sales of the vegetable market in the Baishazhou agricultural and sideline products market in Wuhan City amounted to 2,200–2,400 tons, a decrease of about 42.31% compared with the same period in the previous year (Li G., 2020). The impact of the COVID-19 epidemic on the supply of agricultural products is obvious, and it has a wide-ranging and long-lasting impact. According to the current requirements of regular epidemic prevention and control, uncertainty will remain present in the agricultural product market for a period in the future. How to ensure people's "rice bag," "vegetable basket," and "fruit plate" in the epidemic environment is an important livelihood issue.

Agricultural production is characterized by perishability, short life cycle, low residual value, and sensitivity to natural conditions, which exposes farmers to increased risks in production decision-making. Moreover, farmers have a strong vision for basic revenue assurance, and a poor capacity to bear losses–this shapes farmers' loss aversion (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991; Kahneman and Tversky, 2000). However, impacted by the COVID-19 epidemic, farmers have faced greater challenges in basic living security, the degree of loss aversion has increased, and farmers' production decisions have become more complicated. The piecewise utility function provides an effective model tool for decision-making in a loss-averse environment (Wang and Webster, 2009). The epidemic's impact on the degree of loss aversion can be adjusted by prepending another parameter to the loss aversion coefficient. Therefore, this paper uses a piecewise utility function to study loss-averse farmers' decision-making regarding production under the impact of the epidemic, to explore the influences of factors such as the epidemic situation, loss aversion degree, and market demand on production decisions. Apart from existing literature, the main contribution of our study is that the impact of the COVID-19 epidemic is involved by a correction factor in the loss-averse newsvendor model to deal with the decision-making problem of agricultural production. We then emphatically investigate how the epidemic and farmers' loss aversion degree affect the optimal production quantity and profits as well as the relationship between the epidemic situation and loss aversion through model analysis and numerical experiments. Finally relevant countermeasures and policy suggestions that are meaningful, realistic, and feasible are put forward in consideration of those factors.

The rest of this paper is organized as follows. We review literature related to our work in Section 2. Section 3 provides variable definition in our study and the model framework. In Section 4, we derive the loss-averse farmers' production solutions considering the impact of the COVID-19 epidemic and conduct model factor analysis. We carry out numerical experiments and report observations in Section 5. In Section 6, we discuss the results and present some managerial insights according to the findings. The study is briefly concluded in Section 7.

2 Literature review

Prospect theory proposed by Kahneman and Tversky (1979) pointed out that, when people make decisions, the psychological utility brought about by gains and losses is different, and therefore they are more sensitive to losses than to comparable gains. The behavioral characteristic is called the loss aversion effect, and this loss aversion effect has a non-negligible influence in both risk decision-making and risk-free decision-making (Tversky and Kahneman, 1991; Kahneman and Tversky, 2000). Empirical research has proved that decision-makers do not always obey the assumption of perfect rationality. Moreover, loss aversion, as an important manifestation of bounded rationality, can more effectively reflect people's behavior in actual decision-making when applied to the newsvendor model.

The research of Schweitzer and Cachon (2000) and Ho et al. (2009) found that loss aversion has a certain influence on the retailer's optimal order quantity decision. When Wang and Webster studied the loss aversion newsvendor model, they constructed a loss aversion utility function with zero as a reference point and proved that the optimal order quantity for a newsvendor decreases with the increase of loss aversion without considering the cost of stock-out (Wang and Webster, 2009). Ma et al. (2016) studied the optimal solution of the loss aversion newsvendor model under the assumption of supply and demand uncertainty and analyzed the impact of loss aversion and supply and demand uncertainty on optimal decision-making and optimal expected utility. Under the framework of expectation theory, Wen derived the optimal order quantity of loss-averse newsvendor and conducted a comparative statistical analysis, proving that the optimal order quantity is simultaneously affected by various cost parameters, demand distribution, and the degree of loss aversion (Wen, 2005). Liu et al. (2013) studied a newsvendor model in which two loss-averse retailers sell two substitutable products, respectively, and proved that, under certain conditions, such a newsvendor model demonstrates a Nash equilibrium, and any retailer's equilibrium order quantity decreases as the degree of loss aversion increases, and it increases with the increase of the product substitution rate. Shen et al. (2004) studied the procurement decision-making of loss-averse manufacturers for customized parts, and analyzed the existence of optimal procurement decisions, as well as the influence of loss aversion degree and demand uncertainty on optimal procurement strategies. In addition, some scholars have extended the newsvendor model based on loss aversion and studied the consideration of out-of-stock loss (Wang and Webster, 2009; Ma et al., 2012; Liu et al., 2014; Zhang, 2016; Liu et al., 2017; Zhuang et al., 2017), secondary production/ordering (Ma et al., 2012; Zhang, 2016), price-quantity joint decision-making (Gu, 2016; Mandal et al., 2018), and other related issues. The research on the newsvendor model of loss aversion provides a theoretical framework for the research of this paper, but very little of the extant research concerns itself with the field of agricultural products.

Recently, some scholars have considered the influence of risk attitude on decision-makers in their research on agricultural product-related decision-making, for example, Just and Zilberman (1983), Mishra and Barry (1997), Hazel et al. (2002), Goodwin and Mishra (2006), Kazaz and Webster (2011), Zonneveld et al. (2020), and Hossain et al. (2022). And some results have also appeared in the research on agricultural product decision-making under the environment of loss aversion. However, the research results are less specific to the production of agricultural products in consideration of loss aversion. Sun et al. (2013) established an ordering decision-making model for fresh agricultural products based on inventory capacity constraints, analyzed the influence of parameters such as inventory constraints, loss aversion, residual value, and price on the optimal order quantity of fresh agricultural products, and verified the results through an example. Huang et al. (2017) paid attention to the selection of agricultural product suppliers, established a supplier evaluation index system according to the characteristics of fresh agricultural products, established a loss/gain utility function from the perspective of loss aversion, and used the projection method to achieve the ranking and selection of alternative suppliers. Anand et al. (2019) applied prospect theory to examining farmers' economic incentives to divert a share of their land to bioenergy crops and conducted numerical simulation to identify the impact of loss aversion on bioenergy crop adoption. Other scholars have focused on the impact of loss aversion factors on the optimization of agricultural product supply chains. Yang (2018) studied the problems of a revenue sharing contract for a two-stage supply chain composed of loss-averse agricultural product suppliers and risk-neutral retail e-commerce under the drop-shipping model, and he analyzed the impact of loss aversion on contractual coordination of the agricultural product supply chain. Zheng et al. (2014) constructed a basic model of a two-level contract agricultural supply chain composed of farmers with loss aversion and price reference effect and risk-neutral companies and introduced the price reference effect of economic theory to find that farmers' price reference point, their degree of loss aversion, and the increase in the fluctuation of purchase price will reduce the income of the company and farmers. Scholars have conducted some useful explorations on the impact of loss aversion in agricultural product decision-making and have generally proved that loss aversion will have a negative impact on some level on agricultural production, pricing, and supply chain coordination under various circumstances. However, relevant research is still relatively scarce, and quantitative research on agricultural production decisions considering loss aversion in the special context of the COVID-19 epidemic is not extant.

Due to the characteristics of agricultural products and their important role in people's livelihood insurance, the related issues of agricultural production decision-making have always been the focus of academic research. Scholars have explored from different angles, within different situations, and/or in relation to different types of agricultural products. Some scholars have paid attention to the factors affecting farmers' production decisions. Nerlove (1956), Behrman (1977), and Askari and Cummings (1977) found that the price of agricultural products was the primary factor affecting the production decision-making behavior of farmers, while Dariush et al. (2009) believed that the income level of farmers' families was the main factor determining the willingness of farmers to work. According to Serra et al. (2010), policy changes and household internal characteristics had a comprehensive impact on farmers' production behavior. Taylor and Adelman (2003) analyzed the impact of agricultural policy changes on output and income in different rural markets through the production function and utility function of farmers. Other scholars have focused on the production/ordering/inventory/pricing problems of agricultural products. Hingley et al. (2008) studied the ordering problem of fresh agricultural products retailers in Italy and the United Kingdom. Hsu et al. (2010) solved the optimal decision of agricultural products retailers based on the purpose of maximizing profit per unit time. Cai et al. (2010) provided the optimal ordering/pricing decision of fresh agricultural products with uncertain demand under preservation efforts. Sana (2010) established a multi-product inventory model in which the retailer's effort level affects the demand, and studied the optimal ordering strategy for agricultural products. Dye and Hsieh (2012) adopted an inventory model of fresh agricultural products with time-varying freshness decay rate and partial shortage lag to discuss retailers' replenishment plans and input costs of preservation technology. Ning et al. (2013) proposed an inventory model of fresh agricultural products considering the factors of time-varying perishability. Under the background of the rural revitalization strategy, research on agricultural production decision-making has emerged in an endless stream, and most of this work has been qualitative or quantitative analysis, and empirical research related to market supply and price, which provides reference suggestions for farmers, enterprises, and governments to formulate relevant decisions and policies, respectively. However, research on quantitative models focusing on agricultural production decision-making is relatively scarce, and even fewer research results are available that consider loss aversion. The impact of loss aversion factors on agricultural production decision-making in the context of the COVID-19 epidemic has not been covered.

The COVID-19 epidemic broke out rapidly across the country and even globally after multiple cases of infection were found in Wuhan, China, in December 2019 (National Health Commission, 2022). Since the outbreak of the epidemic, most of the governments around the world has taken strict precautions and implemented strict control, reduced non-essential production and consumption activities, and tried their best to curb the spread of the epidemic, which has had a great impact on all walks of life and the overall national economy. Although the world has passed the epidemic period and basically returned to normal production, the impact of the epidemic may persist for a long time due to the complex situation of the epidemic overseas and its spread through some regions. McDonald (2020) indicated that a period of social distancing (SD) can leave a post-SD economy with both stimulatory and depressive effects. Since the outbreak of the COVID-19 epidemic, many scholars, such as Xue and Sha (2020) and Li Q. (2020), have conducted research on its overall impact on the Chinese national economy, social production, and life. When major sudden risks occur, any link of production, circulation and sales will be shocked, which will have an impact on agricultural production. In particular, with the increasingly close connection of various subjects in the agricultural production chain, the chain reaction effect on agricultural production and operation after the occurrence of risks will be more intense (Pu and Zhong, 2020; Jaacks et al., 2021). The Food and Agriculture Organization of the United Nations (FAO) and The World Health Organization (WHO) released interim guidance for food businesses in relation to COVID-19 and indicated that the food production safety is critical to surviving the current epidemic (FAO, 2020). Scholars are also paying special attention to the impact of the epidemic on agricultural production. Zhang et al. (2020) adopted a dynamic panel model and spatial Durbin model to estimate the direct and indirect effects of COVID-19 on agricultural production and a growth accounting method to identify the channels by which epidemics affect agriculture. Thanh et al. (2022) examined disruptions to agricultural activities, income loss and food insecurity during the COVID-19 period and revealed that a large percentage of farmers experienced income loss and that the COVID-19 disruptions to agricultural activities significantly increased the likelihood of worrying about food insecurity. Specific to the impact of the epidemic on Chinese agricultural product industry, based on the national agricultural product wholesale price index released from December 2019 to April 2020, Jiu empirically tested the marginal effect of the epidemic on the wholesale price of agricultural products and pointed out that the COVID-19 epidemic has affected the wholesale price of agricultural products and had a positive impact, and its marginal effect has far exceeded the effect of the Spring Festival holiday (Jiu, 2020). Pan et al. (2020) employed web crawler technology and text mining method to explore the influence of COVID-19 on agricultural economy and mitigation measures in China and showed eight aspects that reflected the impact of COVID-19 on China's agricultural economy. Xu and Sun (2021) pointed out that China needs to pay attention to the changes in the production and sales of agricultural products caused by the epidemic; actively learn lessons to prepare response strategies; further promote the cooperation between government, business, media, and agriculture; increase agricultural insurance; strengthen international agricultural trade cooperation; and achieve the steady development, transformation and upgrading of agriculture. Regarding the impact of the COVID-19 epidemic on the agricultural product industry, the above studies are mostly explained from a qualitative perspective. Relevant quantitative analysis and model research is almost entirely non-existent, as is research on the impact of the epidemic in the agricultural product field in light of loss aversion.

To sum up, as research on the newsvendor model has deepened and the loss-averse newsvendor model considering behavioral factors has expanded, scholars globally have achieved fruitful results in the theoretical and practical explorations in this direction, which provide an important theoretical basis and methodological basis for the research of this paper. However, the application of this research on a specialized background and within a specialized economic environment is still relatively scarce. The proposal and implementation of the rural revitalization strategy provide an excellent opportunity for the development of the agricultural product industry, but the relevant research is still mainly based on the qualitative analysis of policies and empirical research. Few quantitative studies focus on the optimization of agricultural production decision-making, especially in the context of loss aversion. On the other hand, due to the impact of the COVID-19 epidemic, the agricultural product industry presents a specific objective environment. Analysis of the impact of the epidemic on agricultural production decisions can help to judge the development of the industry and provide a reference for future responses to public or natural emergencies. However, most of the research in this area is still in the stage of qualitative elaboration, and it is difficult to effectively guide the development practice of the Chinese agricultural product industry. The relevant quantitative analysis is in urgent need of a breakthrough. This paper takes the newsvendor model of loss aversion as the theoretical framework; comprehensively considers the influence of loss aversion within the epidemic situation, market demand, and other factors; studies the production decisions for agricultural products through quantitative model analysis; and deeply analyzes the relationship between farmers' production decisions and various influencing factors. Therefore, the present research can provide reference and suggestions for farmers' countermeasures in the face of the epidemic situation and the policy formulation of relevant government departments.

3 Variable definition and model framework

Suppose a loss-averse farmer faces the marketing season of a single agricultural product and takes utility maximization as the decision criterion. Here, $\lambda \geq 1$ is the loss aversion coefficient of the farmer, and the larger it is, the higher the degree of loss aversion is. In particular, the loss aversion coefficient is often measured by empirical methods, and this paper assumes that this parameter is known. The increase in the degree of loss aversion caused by the impact of the epidemic is expressed by a correction factor of γ where $\gamma \geq 1$. Models that consider both loss aversion and the impact of the epidemic can closely fit the characteristics of the agricultural product industry and are targeted.

The market demand x of the agricultural product is a random variable defined on $[0, +\infty)$, whose probability density function is $f(\cdot)$ and whose cumulative distribution function is $F(\cdot)$. Before the start of the sales season, farmers need to decide the production quantity q and the unit production cost is c. After the production of agricultural products is completed, the farmers deliver them to the dealers at the wholesale price p (fixed price determined by the market). If the distributors' demand is higher than the production quantity, the unmet demand will cause farmers to lose the opportunity to obtain more income (regardless of the cost of out-of-stock). If the distributors' demand is less than the production quantity, the agricultural products will have to be disposed of at a price lower by s than the wholesale price, resulting in a loss. Supposing that $p > c > s$ and the income of the farmer is defined as $\pi(q)$, $U(\pi(q))$ represents the utility of the farmer, and the definitions of related variables are shown in Table 1.

The above problem P1 can be expressed as follows:

$$\max_{q \geq 0} \; EU(\pi(q))$$

That is, farmers need to decide the optimal output of agricultural products to maximize their expected utility, where E is the expectation operator.

First, for loss-averse farmers, the income $\pi(q)$ can be expressed as follows:

$$\begin{aligned} \pi(q) &= p\min(q,x) - cq + s(q-x)^+ \\ &= (p-c)\left[q-(q-x)^+\right] - (c-s)(q-x)^+ \\ &= (p-c)q - (p-s)(q-x)^+ \end{aligned} \tag{1}$$

According to formula E1, set $\pi(q)$ equal to 0; the break-even point $Q(q)$ of the farmer can be calculated, and the $Q(q)$ can be obtained as follows:

$$Q(q) = \frac{(c-s)q}{p-s} \tag{2}$$

When actual demand falls below the break-even point, farmers face losses. Taking the impact of loss aversion into account, based on a specific reference point, farmers are more sensitive to losses than to comparable gains. In supply chain research, the loss aversion effect is often characterized by a linear piecewise utility function, which is expressed as follows:

TABLE 1 Variable and symbolic representation.

Variable	Symbol
Production cost	c
Wholesale price	p
Salvage value	s
Production	q
Market demand	x
Demand probability function	$f(\cdot)$
Demand distribution function	$F(\cdot)$
Loss aversion coefficient	λ
Epidemic correction factor	γ
Income	$\pi(q)$
Utility	$U(\pi(q))$

$$U(\pi) = \begin{cases} \pi - \pi' & \pi \geq \pi' \\ \lambda(\pi - \pi') & \pi < \pi' \end{cases} \tag{3}$$

In the above formula, π' represents the income reference point of the decision maker. Without loss of generality, this paper sets this reference point as 0, namely $\pi' = 0$.

4 Model solving and factor analysis

In this section, we first construct a newsvendor model that comprehensively considers loss aversion and the impact of the epidemic. As mentioned above, the epidemic impact is measured by the shift in farmers' degree of loss aversion. When the epidemic situation is severe, farmers are more sensitive to losses–that is, the epidemic correction factor γ is larger, indicating that the farmers' degree of loss aversion has increased. When the epidemic situation is relatively stable, farmers' sensitivity to losses is reduced—that is, the epidemic correction factor γ is smaller, indicating that the deviation of farmers' loss aversion is small.

Presupposing the above definition and symbol setting, in order to solve problem P1, firstly, the expected utility expression of the loss-averse farmers is given by the following Theorem 1.

Theorem 1: For loss-averse farmers, their expected utility under the influence of the epidemic can be expressed as follows.

$$EU(\pi(q)) = (p-c)q - (p-s)\left[\begin{array}{l}(\gamma\lambda - 1)\int_0^{Q(q)} F(x)dx \\ +\int_0^q F(x)dx\end{array}\right] \tag{4}$$

Proof. Refer to Appendix A1.

The utility calculation expression of the loss-avoiding farmer is clearly given in Theorem 1. When all variable values are known, if the farmer's production is q, the corresponding expected utility $EU(\pi(q))$ can be calculated according to formula E4. Since the expected utility takes the risk of demand uncertainty and the impact of the epidemic into account, it can better measure the expected benefit of a loss-avoiding farmer, which is beneficial for the farmer to better measure and control potential risks and make production decisions accurately and efficiently.

Returning to problem P1, farmers make decisions on the amount of production to maximize their expected utility. From the expected utility expression given by Theorem 1, the optimal production can be given by the following theorem.

Theorem 2: For the loss-averse farmers under the impact of the epidemic, there is a unique optimal production q^* that enables them to obtain the maximum expected utility, and q^* satisfies the following first-order conditions:

$$(p-c) - (p-s)F(q^*) - (\gamma\lambda - 1)(c-s)F(Q(q^*)) = 0 \tag{5}$$

The corresponding maximum expected utility calculation expression is as follows:

$$EU\left(\pi\left(q^*\right)\right)=(p-c)q^*-(p-s)\left[\begin{array}{l}(\gamma\lambda-1)\int_0^{Q(q^*)}F(x)dx\\+\int_0^{q^*}F(x)dx\end{array}\right] \tag{6}$$

Proof. Refer to Appendix A2.

Theorem 2 shows that, under the impact of the epidemic, for a loss-averse farmer, when the loss aversion coefficient and other relevant parameters are given, the unique optimal production can be calculated and determined by formula E5, and then the maximum utility can also be obtained by formula E6. Any deviation in production will reduce the utility value somewhat. For the loss-averse farmers, due to the consideration of demand fluctuations and the impact of the epidemic, the optimal production volume determined by maximizing utility is relatively prudent and conservative, and its purpose is to reduce and control potential risks.

Note that if $\gamma=1$, that is, regardless of the impact of the epidemic or after the epidemic is completely dissipated, farmers' loss aversion does not shift, and their optimal order quantity q_λ^* and maximum expected utility $EU\left(\pi\left(q_\lambda^*\right)\right)$ can be expressed as the following formulas E7 and E8, respectively. By comparison, it is not difficult to find that formulas E7 and E8 are special cases of formulas E5 and E6 when $\gamma=1$.

$$(p-c)-(p-s)F\left(q_\lambda^*\right)-(\lambda-1)(c-s)F\left(Q\left(q_\lambda^*\right)\right)=0 \tag{7}$$

$$EU\left(\pi\left(q_\lambda^*\right)\right)=(p-c)q_\lambda^*-(p-s)\left[\begin{array}{l}(\lambda-1)\int_0^{Q(q_\lambda^*)}F(x)dx\\+\int_0^{q_\lambda^*}F(x)dx\end{array}\right] \tag{8}$$

Through a simple proof, the optimal production volume q^* and the maximum utility value $EU\left(\pi\left(q^*\right)\right)$ for the farmers are monotonically increasing with respect to the wholesale price *p*, monotonically increasing with respect to the residual value *s*, and monotonically decreasing with respect to the cost *c*. It is beneficial to increase farmers' production and revenue when *p/s* increases or *c* decreases. These conclusions are consistent with the previous traditional newsvendor model and related research specific to the field of agricultural products, which is easily understood and will not be described in detail in this article.

Next, we focus on the relationship between the production decision q^* or the maximum utility value $EU\left(\pi\left(q^*\right)\right)$ and the loss aversion coefficient λ or the epidemic correction factor γ or other factors.

Proposition 1: For loss-averse farmers under the influence of the epidemic, their optimal production q^* and maximum utility value $EU\left(\pi\left(q^*\right)\right)$ are monotonically decreasing with respect to the loss aversion coefficient λ.

Proof. Refer to Appendix A3.

Proposition 1 points out that under the influence of the epidemic, either the optimal production q^* or the maximum utility $EU\left(\pi\left(q^*\right)\right)$ of the loss-averse farmers decreases with respect to their loss aversion coefficient λ. That is to say, when λ increases, the degree of loss aversion increases; thus, farmers will tend to produce less agricultural product, which leads to a corresponding decrease in income.

When the impact of the epidemic is taken into account, the decision-making bias caused by loss aversion is consistent with the research conclusions when considering loss aversion alone. Because farmers often rely on the basic living security provided by their income from agricultural products, they cannot bear the risks and losses in the production of agricultural products and develop an attitude of loss aversion. If farmers just have a single source of income, and the income level is low and the level of living security is not high, their loss aversion will be intensified, resulting in more conservative production of agricultural products, and both production volume and corresponding income will decline.

Proposition 2: For loss-averse farmers under the influence of the epidemic, their optimal production q^* and maximum utility value $EU\left(\pi\left(q^*\right)\right)$ are monotonically decreasing with respect to the epidemic correction factor γ.

Proof. Refer to Appendix A4.

Proposition 2 points out that, under the influence of the epidemic, loss-averse farmers' optimal production q^* and the maximum utility $EU\left(\pi\left(q^*\right)\right)$ have a negative correlation with the epidemic correction factor γ. That is to say, when γ increases, the epidemic impact increases; thus, farmers will tend to produce less agricultural product, which in turn leads to a corresponding decrease in income. The epidemic impact on farmers' production of agricultural products is relatively easy to understand. During the outbreak stage, or when the situation is severe, the epidemic correction factor γ is relatively large, resulting in a sharp drop in the production of agricultural products and farmers' corresponding income. When the epidemic situation is more stabilized, the epidemic correction factor is small, which will increase the production volume of agricultural products and farmers' corresponding. Therefore, the effective control of the epidemic has an obvious role in promoting the production of agricultural products.

Proposition 3: For the loss-averse farmers under the influence of the epidemic, the production cost *c* decreases monotonically with respect to the loss aversion coefficient λ and the epidemic correction factor γ.

Proof. Refer to Appendix A5.

Proposition 3 shows that, for loss-averse farmers to make stable production decisions under the epidemic influence, the production cost *c* monotonically decreases with respect to the degree of loss aversion and the impact of the epidemic. That is to say, when farmers' degree of loss aversion is low, the production cost farmers are willing to invest is higher, and they can maintain the output and income of agricultural products to a certain extent. However, when their degree of loss aversion increases, the production cost farmers are willing to invest is also reduced accordingly. The epidemic environment also has an impact on farmers' willingness to invest in costs. When the epidemic situation is severe and the impact is large, farmers need to control costs and maintain relatively stable output and income to ease economic pressure. When the epidemic situation improves and the impact lessens, farmers can accept relatively higher production costs.

Proposition 4: For farmers with loss aversion under the influence of the epidemic, the loss aversion coefficient λ decreases monotonically with respect to the epidemic correction factor γ.

Proof. Refer to Appendix A6.

Proposition 4 shows that for loss-averse farmers to make stable production decisions under the influence of the epidemic, the degree of loss aversion decreases monotonically with the severity of the epidemic. That is to say, in order to maintain a stable production volume and income, farmers' degree of loss aversion needs to be adjusted with the change of the epidemic situation. Even if farmers' loss aversion is high, they can maintain a certain production and income when the epidemic situation is stable; but when the epidemic situation is severe, farmers' loss aversion needs to be reduced to maintain relatively stable production and income. As mentioned above, farmers' loss aversion stems from their strong demand for basic living security, and it is difficult to bear the losses in agricultural production. If farmers have more abundant sources of income, such as stable work remuneration in the secondary and tertiary industries in rural areas, or sideline income, or some production and living subsidies provided by the government, farmers' income level and stability will be improved and their livelihood will be ensured to a large extent, which will reduce their loss aversion and abate the negative impact of the epidemic, which in turn helps to maintain a certain production volume and income for farmers.

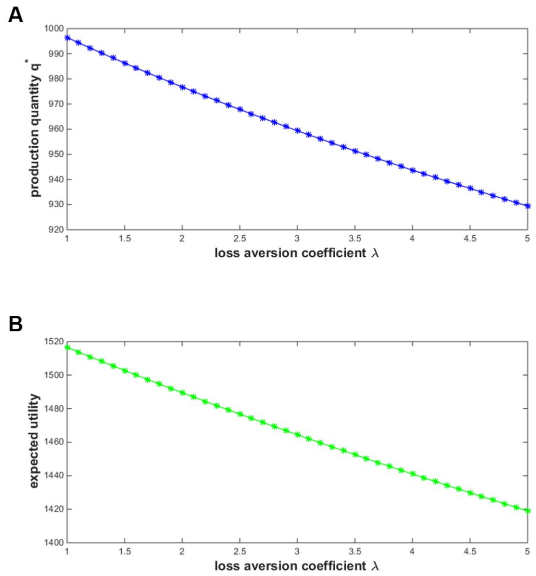

FIGURE 1
The impact of the loss aversion coefficient on farmers' production and utility.

5 Numerical experiments

For loss-averse farmers, the previous article presents the optimal production decision while considering the impact of the epidemic and analyzes the impact of the epidemic situation, loss aversion, and other factors on the optimal production decision and maximum income. To better verify the above conclusions, this section uses numerical examples to further explore the relationship between relevant parameters and farmers' production decisions and maximum benefits. The conclusions obtained according to the example analysis can provide useful reference and enlightenment for farmers' decision-making and the formulation of relevant government policies.

The numerical example in this section makes the following assumptions: Take the Wendan pomelo that is abundant in the Putian area as an example. The market demand x follows a normal distribution with mean $\mu = 1000$ and standard deviation σ. Other relevant parameters are set as follows: the unit wholesale price of Wendan pomelo is $p = 5$ yuan per catty, the unit production cost is $c = 3$ yuan per catty, and the unit residual value is $s = 1$ yuan per catty.

Given demand standard deviation $\sigma = 300$, Figures 1A,B presents the effect of loss aversion coefficient λ on farmer production q^* and expected utility $EU\left(\pi\left(q^*\right)\right)$. The figure shows that the increase of the loss aversion coefficient has a negative impact on farmers' production and utility, which verifies the conclusion of Proposition 1. The increase in the degree of loss aversion will lead farmers to a relatively conservative production decision, and the production volume and corresponding income will be reduced. The reason for farmers' loss aversion is that their living security depends on the income of agricultural products. If the production of agricultural products suffers losses, it will impact their basic living standards. Therefore, if farmers' sources of income and income level can be increased through government subsidies, employment expansion, and the development of secondary and tertiary industries, their basic living can be guaranteed to a greater extent, which will help to reduce their loss aversion and to promote their motivation to produce agricultural products; this will further ensure the market supply of agricultural products.

Given the demand standard deviation $\sigma = 300$, Figures 2A,B presents the impact of the epidemic correction factor γ on the farmer's production q^* and expected utility $EU\left(\pi\left(q^*\right)\right)$. The figure shows that the increase of the epidemic correction factor has a negative impact on farmers' production volume and utility, which verifies the conclusion of Proposition 2. The increase of the epidemic correction factor means that the epidemic impact is intensified, making farmers less confident in the market, which will lead farmers to make relatively conservative production decisions, and the production volume and corresponding income will be reduced. When the epidemic situation stabilizes, with the reduction of the epidemic correction factor, the epidemic impact will gradually decrease, and farmers' production volume and income will gradually increase. When γ is reduced to 1, that is, the epidemic impact has completely subsided, farmers' production and income will return to normal levels. Therefore, taking various measures to control the epidemic and minimize its impact is of great significance for ensuring the production and supply of agricultural products.

Given the loss aversion coefficient $\lambda = 1.3$ and the epidemic correction factor $\gamma = 1.2$, Figures 3A,B presents the impact of the demand standard deviation σ on the farmer's production q^* and expected utility $EU\left(\pi\left(q^*\right)\right)$. The figure shows that the increase in the standard deviation of demand has a negative impact on farmers' production and utility. An increase in the standard deviation of demand indicates more volatility in the market, and for farmers who are loss-averse under the epidemic impact, both production and income will decline. Relatively stable market demand prompts farmers to increase production and obtain more income. Specific agricultural product markets have obvious seasonal characteristics. Through the cultivation and research and development of new off-season agricultural products or the introduction of policy support by

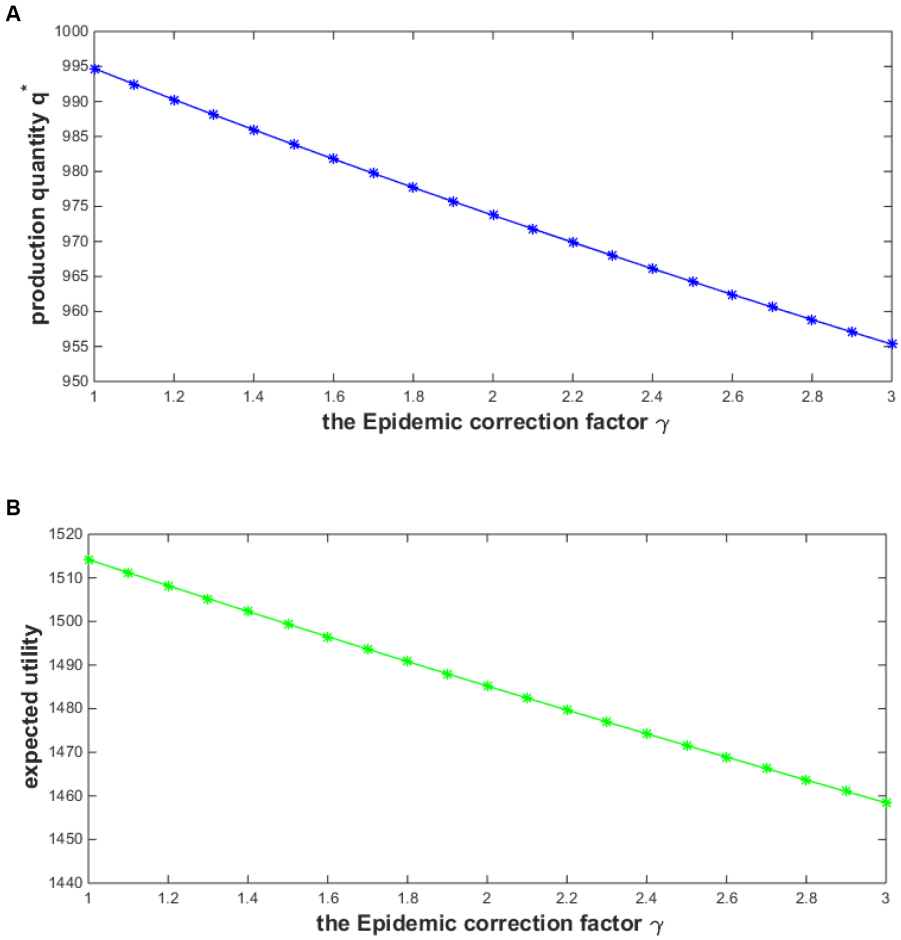

FIGURE 2
The impact of the epidemic correction factor on farmers' production and utility.

government departments, farmers can try to maintain the balance of market demand for agricultural products in various periods, which can improve farmers' production enthusiasm to a certain extent, and thus effectively mitigate the negative impact of the epidemic. By further observing the impact of the demand standard deviation on the production volume of agricultural products in Figure 3, we see that, considering the dual effects of loss aversion and the epidemic, when the demand fluctuation is small, its impact on the production volume is minimal, which further confirms the importance of maintaining stable demand for agricultural products.

Given the production quantity $q^* = 900$, Figures 4A,B presents the correlation between the loss aversion coefficient λ and the epidemic correction factor γ and the production cost c. The figure shows that, for loss-averse farmers to make stable production decisions under the influence of the epidemic, the production cost decreases with the increase of the loss aversion coefficient or the epidemic correction factor, which verifies the conclusion of Proposition 3. When farmers' living security difficulties lead to increased loss aversion, or when the severe epidemic situation leads to an aggravation of the negative impact, farmers will either be under greater economic pressure or have significantly less confidence in the market and will be more conservative in terms of cost input of agricultural production, trying to maintain a certain production volume and income by controlling costs.

Given the production quantity $q^* = 900$ and the demand standard deviation $\sigma = 300$, Figure 5 presents the effect of the epidemic correction factor γ on the loss aversion coefficient λ. The figure shows that, for the stable production decisions of loss-averse farmers under the influence of the epidemic, the loss aversion coefficient decreases with the increase of the epidemic correction factor, which verifies the conclusion of Proposition 4. Both loss aversion and the epidemic impact will lead to a reduction in farmers' production. Under severe epidemic circumstances, in order to maintain production at a certain level and ensure the supply of agricultural products, it is necessary to reduce farmers' degree of loss aversion through some policy measures that can augment farmers' motivation to produce and alleviate the negative impact of the epidemic. When the epidemic situation improves, the relevant preferential and subsidy policies can be moderately reduced. Even if farmers' loss aversion is improved, the production and supply of agricultural products can be maintained at a certain level.

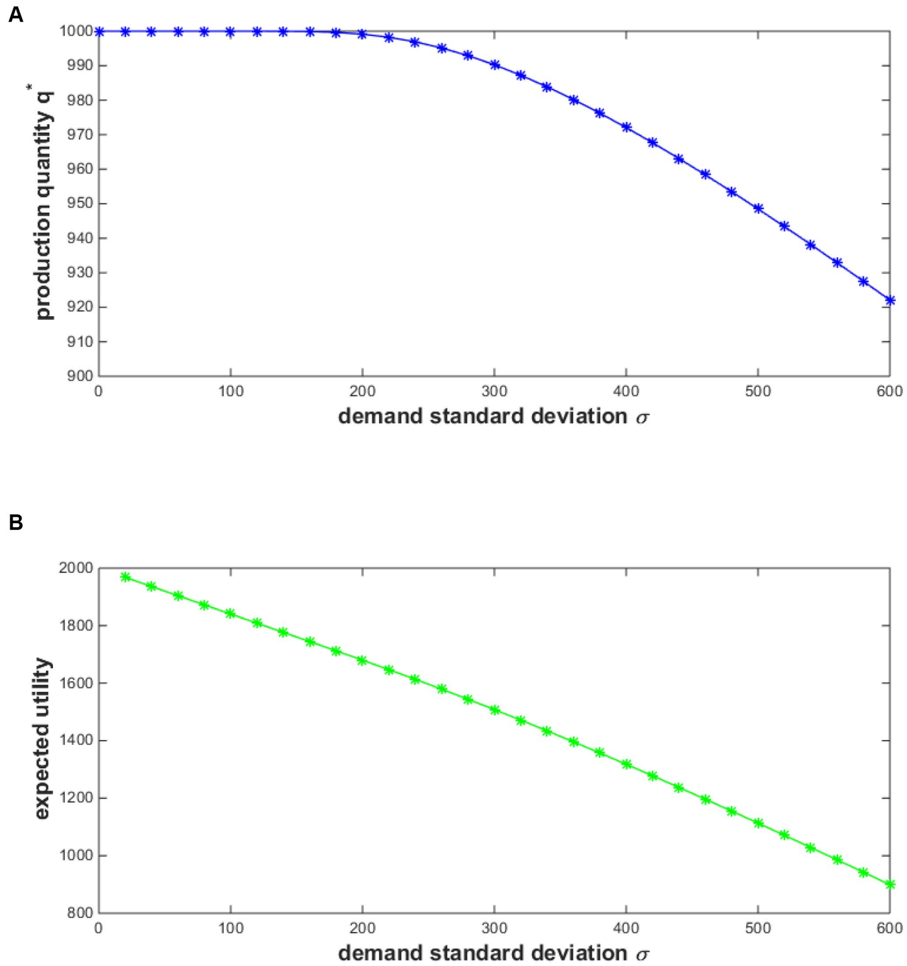

FIGURE 3
The impact of the demand standard deviation on farmers' production and utility.

6 Results discussion and management insights

6.1 Results discussion

According to the derivation of the model properties and the verification of the numerical experiments, the following results can be clearly obtained:

(1) Increased loss aversion will reduce farmers' production and income. This conclusion conforms to previous studies (Wen, 2005; Wang and Webster, 2009; Ma et al., 2016; Liu et al., 2017). The characteristics of farmers' loss aversion are derived from their excessive dependence on income from agricultural products, and it is difficult for them to bear any loss in agricultural production. Once loss aversion has increased due to a specific environment, farmers' production decisions will be more conservative, and the production volume will decrease accordingly, which will not only reduce farmers' income but also affect the supply of agricultural products. Therefore, the government should introduce measures to fundamentally reduce the extent of farmers' loss aversion to enhance their production motivation, such as considering expanding employment channels, to increase farmers' income sources and income levels.

(2) The increase of epidemic correction factors will reduce farmers' production and income. The result on the impact of the epidemic is the main contribution of this work. The improvement of the epidemic correction factor means that the epidemic situation is severe, and farmers' market confidence is insufficient, which will lead to farmers' low production drive and thereby to reduced production volume and income. At present, with normal prevention and control, the epidemic situation tends to be stable, indicating that the correction factor and the impact of the epidemic are reduced, and that farmers' production and income are steadily recovering. Therefore, it is of great significance to ensure the production and supply of agricultural products to take various measures to control the rebound of the epidemic, and, specifically, to pay attention to the spread of the epidemic in local areas and to contain its large-scale spread.

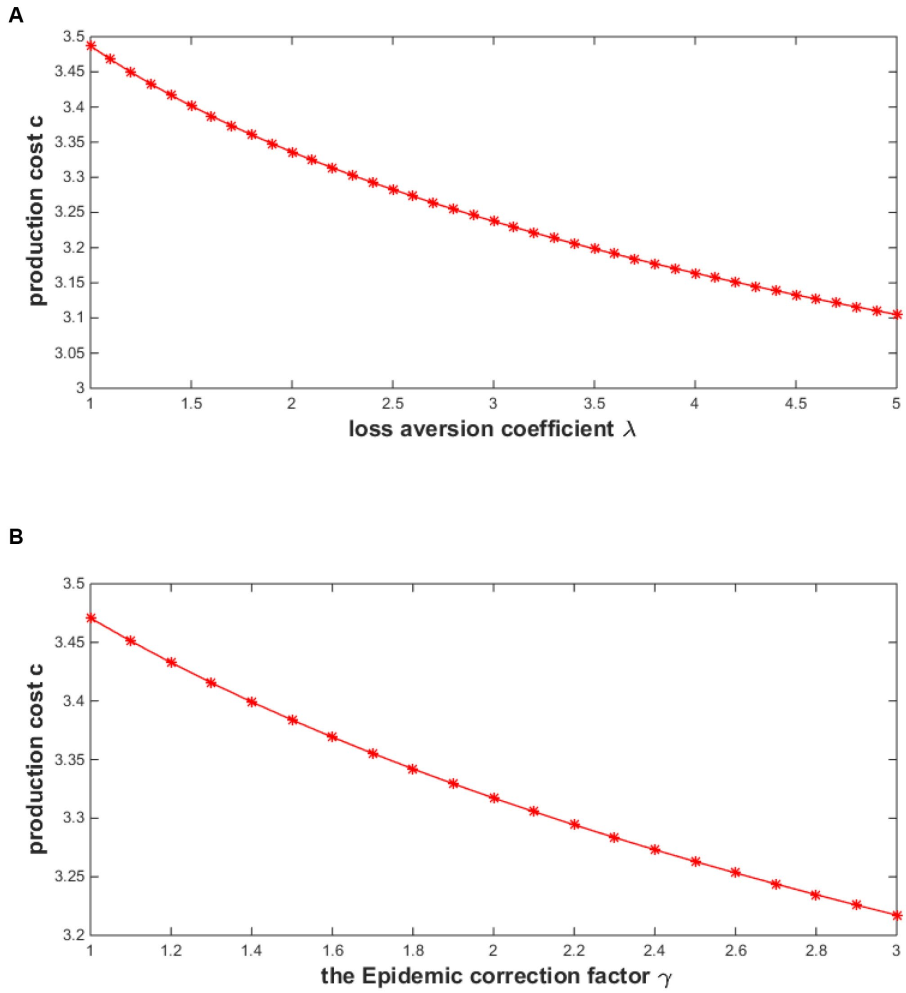

FIGURE 4
The impacts of the loss aversion coefficient and epidemic correction factor on production costs.

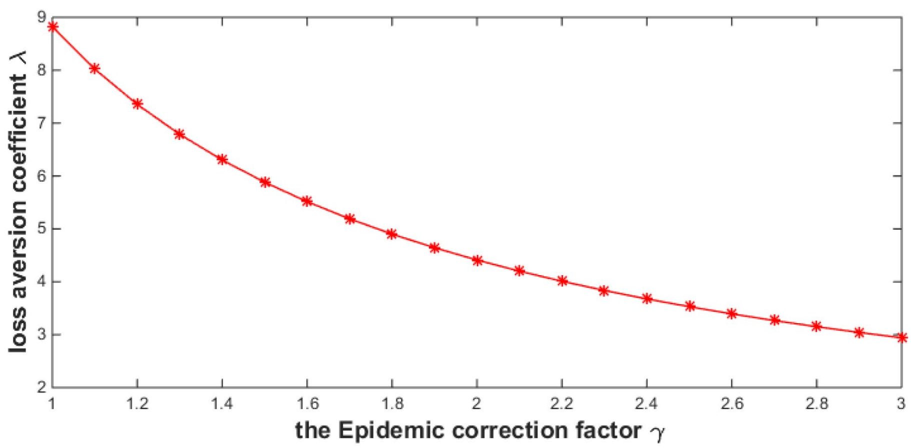

FIGURE 5
The impact of the epidemic correction factor on the loss aversion coefficient.

(3) The increase in the standard deviation of demand will reduce farmers' production and income. This result keeps consistent with previous studies (Ma et al., 2012; Liu et al., 2014; Zhang, 2016). The standard deviation of demand represents the degree of market volatility. When the degree of market volatility is large, farmers who avoid losses under the influence of the

epidemic will respond by reducing their production, and their income will also decline. The relative stability of market demand encourages farmers to strengthen their production drive and can also alleviate the negative impact of the epidemic to a certain extent. Taking into account the seasonal characteristics of the agricultural product market, such measures as agricultural technology innovation, new agricultural facilities construction, and effective demand guidance can be adopted to balance the market demand for agricultural products in different periods as much as possible.

(4) When a stable production decision is made, the production cost decreased with the increase of the loss aversion degree or the epidemic correction factor, and the loss aversion degree decreased with the increase of the epidemic correction factor. The investigation on the relationship between the epidemic situation and other factors is another significant originality of this paper. Farmers will consider the issue of production cost control, especially when the source of income cannot be guaranteed or they are faced with a more serious impact of the epidemic, the basic living pressure of farmers is greater, and the enthusiasm for agricultural production is greatly reduced. Farmers react by keeping their input in agricultural production cost conservative and try to maintain a certain output and income through cost control. On the other hand, since both loss aversion and the impact of the epidemic will reduce farmers' production and income, it is necessary to adopt some policy measures to reduce farmers' degree of loss aversion once the epidemic situation is severe, to maintain the stable production of agricultural products and ensure their supply. As the epidemic situation warrants a more normal control stage again, support policies can be appropriately relaxed. Even if farmers' loss aversion degree improves, the reduction of the epidemic correction factor can maintain a certain level of agricultural production and supply.

6.2 Management insights

In summary, this paper puts forward the following targeted countermeasures and policy suggestions:

(1) The loss aversion degree of rural households has been increased due to the impact of the epidemic. Relevant government departments should formulate corresponding measures to broaden the income channels and improve the income level of rural households, such as increasing support for farmers' side businesses, encouraging and guiding farmers to start their own businesses, developing secondary and tertiary industries, strengthening the collective economy, promoting farmers' employment, and increasing production and living subsidies. Thus, by reducing farmers' loss aversion degree, the negative impact of the epidemic can be hedged. Most of China's agricultural financial subsidies are used to subsidize the prices of agricultural products, mainly grain, cotton, oil and pigs, which play a role in short-term, targeted, and timely financial subsidies designed to mobilize farmers' production drive, increase the output of agricultural products, stabilize the prices of agricultural products, and avoid the serious impact of rising agricultural prices on people's lives. Governmental agricultural subsidies should also focus on supporting large-scale business entities, actively guiding farmers' industrialization, and expanding farmers' income channels while increasing production and efficiency, especially focusing on subsidizing agricultural enterprises engaged in the production of grain, live pigs, and other bulk agricultural products.

(2) Ongoing epidemic prevention and control must be heeded, and every possible effort should be made to prevent a large-scale epidemic rebound. Effective epidemic control is of great significance to enhance farmers' production drive and ensure the market supply of agricultural products. International cooperation in epidemic prevention and control should be strengthened. While strengthening epidemic surveillance, joint prevention and control mechanisms at border ports should be established, and border trade should be conducted in accordance with local conditions to ensure that ports are not unilaterally closed again. The government should guide rural areas to strengthen their efforts in epidemic prevention and control, agricultural production and agricultural product supply guarantee. The government must further guide rural areas to increase the types and total amount of agricultural products and include agricultural products such as grain and oil, vegetables, meat, eggs and milk, and aquatic products in the scope of daily necessities during epidemic prevention and control. In areas where the epidemic is spreading, it is necessary to strengthen the transportation and supply of reserves, establish emergency stocks of agricultural products according to local conditions, and ensure that the stocks of important storable agricultural products can meet short-term consumption needs and potential needs in the case of regulation and control in emergencies. At the same time, the quality and safety of agricultural products should be ensured. For the market circulation of agricultural products such as vegetables and meat, we should pay attention to the inspection of agricultural products' standards and certificates, strengthen quality monitoring and supervision of agricultural products, promote standardized production, and ensure that agricultural products must be up to standard in both in terms of sufficient quantity and safety.

(3) Cultivation, research, and development of new off-season agricultural products and/or government policy support and guidance can help to maintain the stability of the market demand for specific agricultural products at various times, effectively boost farmers' production drive, and alleviate the negative impact of the epidemic. Relevant departments should carefully analyze the supply characteristics of agricultural products under epidemic prevention and control, pay close attention to the number of regional farmers and agricultural products enterprises and the overall output of agricultural products, strengthen the construction of cold storage facilities, increase agricultural products reserves, and promote stable market prices and orderly supply of agricultural products. The government should do a good job in agricultural production, market dynamic monitoring, forecasting and early warning, information release, etc., stabilize market expectations, accurately grasp the production situation and supply capacity

of regional agricultural products, pay close attention to the operation trend of agricultural products market, take the initiative to study and determine and respond to the supply and demand of agricultural products, and make timely responses once the supply of agricultural products is found to be interrupted. Promote the adjustment of the variety structure and production layout of agricultural products, support the development of off-season agricultural products in greenhouses, and further enrich the variety types of agricultural products to balance the market demand in each season.

(4) Faced with the rising degree of loss aversion caused by the impact of the epidemic, farmers also need to control production costs as much as possible. While the government helps to increase income by policies support, they themselves can control the situation in the way of cost reduction that alleviates the economic pressure caused by the epidemic. At the government level, agricultural scientific and technological innovation should be encouraged, especially in the core technologies such as agricultural biological breeding and the prevention and control of major disasters in animals and plants, and through the research and development and application of agricultural scientific and technological innovation technologies, while ensuring the effective supply of agricultural products during the epidemic prevention and control period, the production cost for farmers should be reduced. On the other hand, it is necessary to give full play to the disposal function of finance under major risks to prevent and resolve the impact of major risks on agricultural production. However, the current agricultural insurance is still based on the cost of insurance, and the degree of protection is far from meeting farmers' needs. Agricultural insurance should play a more important role in promoting the structural reform of the agricultural supply side and the development of agricultural industrialization, ensuring national food security, and providing more extensive and adequate risk protection for agricultural production. Therefore, insurance institutions should further promote the transformation of agricultural insurance from cost to income and from natural risk to market risk.

7 Conclusion

Although countries have passed the epidemic period and mostly returned to normal production, some countries and regions continue to see mutated strains of COVID-19, resulting in an unstable supply of agricultural products. It will take time for agricultural production to fully recover, and agricultural markets may still experience a downturn. Regulation of the international logistics of agricultural products and additional quarantine procedures will reduce the demand and efficiency of international agricultural trade; therefore, countries must solve supply bottlenecks and stabilize agricultural production in response to changes in the global economy. Clarifying the specific impact of the epidemic on agricultural production will provide a practical basis and policy guidance for the recovery of agricultural production in the normal phase of the epidemic, to build an institutionalized strategy to ensure agricultural production and to cope with risk shocks in the case of major public emergencies, which has important strategic significance for agricultural development and even economic development.

Taking the utility function as the decision-making criterion and considering the impact of the new crown epidemic, this paper studies the production decision-making of loss-averse farmers and explores the impact of the epidemic, loss aversion, market fluctuations, and other factors that influence farmers' production decisions and expected utility through model analysis and numerical simulation. For farmers who are loss-averse under the influence of the epidemic, their production volume and maximum income are both negatively affected by loss aversion, the epidemic, and market fluctuations. In particular, the impact of the epidemic has led to an increase in farmers' loss aversion, which has aggravated the further decline of farmers' production. In addition, through research on the relationship between production costs, the impact of the epidemic, and loss aversion, it is found that, when loss-averse farmers face the impact of the epidemic, they should control costs to relieve pressure and maintain a certain output and income. Based on the above research results, this paper puts forward countermeasures and policy suggestions from the perspectives of expanding farmers' income sources, strengthening normal epidemic prevention and control, balancing market demand at different periods, and appropriately controlling production costs, so as to enhance the production enthusiasm for loss-averse farmers, ensure the supply of agricultural products as much as possible, and alleviate the adverse effects brought by the epidemic.

The research in this paper provides a basis for the exploration of loss-averse farmers' production decisions under the influence of the epidemic and a theoretical reference for farmers to respond to the epidemic situation or similar public emergencies in the future. This paper also provides suggestions for the relevant government departments to formulate policies to help and benefit farmers more reasonably. In future research, further exploration should investigate the distribution of income between farmers and wholesalers in epidemic circumstances, as well as the related collaborative optimization of the supply chain.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SH: Formal analysis, Funding acquisition, Investigation, Methodology, Software, Writing – original draft. YC: Data curation, Formal analysis, Resources, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was supported by the Natural Science Foundation of the Fujian Province (2022J05255), the Social Science Foundation of Fujian Province

(FJ2021C076), and the Talent Introduction Project of Putian University (2020007, 2019018).

Acknowledgments

The authors thank the reviewers and the editors for their helpful comments.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1287814/full#supplementary-material

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