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Assessment of the Most Appropriate Measures for Mitigation of Risks in the Agri-Food Supply Chain

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Abstract: The present paper embarks on an investigation of the main risks associated with agri-food supply chains. A total of 11 key risks, namely Natural disasters of a global or local scale; Workers' strikes; Change in government regulations or safety standards; Supply chain disruptions due to social or political unrest; Short term raw materials or products (expiration issue); Seasonality; Food safety incidents; Lack of smooth interconnection with other chain participants and Market and pricing strategies, economic crises and seven root risks (Natural disasters of a global or local scale; Workers' strikes; Change in government regulations or safety standards; Rapid deterioration of raw materials (expiration) due to seasonality; Food safety incidents; Fraud in the food sector; Market and pricing strategies, economic crises) are applicable to all four stages of the agri-food supply chains were identified. An expert survey together with the Best-Worst Multi Criteria Decision Making method was employed as the main research tools. The most important root risks for agri-food supply chains are natural disasters of a global or local scale; workers' strikes; change in government regulations or safety standards; rapid deterioration of raw materials (expiration), seasonality; food safety incidents; fraud in the food sector; market and pricing strategies economic crises. The most appropriate risk mitigation measures for each of the root risks were derived and assessed.

Keywords: agri-food; supply chain; risk; expert survey; Best-Worst Method (BWM); food security

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1. Introduction

Nowadays, the agri-food supply chains are characterized by increased susceptibility and vulnerability to various external shocks [1]. This has changed in the previous four years, as earlier the food supply chains were considered to be relatively stable and secure [2]. Two main events which have completely reshaped the scientific focus over the agri-food supply chains were the COVID-19 pandemic [3] and the Russian invasion of Ukraine [4]. The COVID-19 pandemic interrupted the flow of both the final agri-food products and its production means (fertilizers, veterinary medicine, etc.) which raised the food security issue in the developing World [5,6]. The Russo-Ukrainian war and Russian naval blockade of the Ukrainian ports created an even bigger food security problem in the least developed World as due to lowered demand, the prices for main agri-food products such as maize, wheat and sunflower oil have increased drastically, causing malnutrition incidents and even provoking social unrest in the least developed World [7]. The developed World has also faced challenges posed by the insecurity of the agri-food supply chains [8]. It prompted additional Government measures for increasing the resilience and sustainability of agri-food supply chains [9]. Although due to its ad hoc nature, most Government measures, undertaken with the aim of increasing the sustainability of agri-food supply chains, lack the scientific background. Another serious issue arousing from the unsustainable agri-food supply chains is excessive food loss [10–12]. One of the main research avenues in sustainability/resilience science begins with the investigation of the main risks, relevant to the investigated object [13]. Following this approach, the present paper aims at revealing the most important risks in agri-food supply chains. To go further, in this paper, not only the main root risks, which cause the other risks to emerge, were identified and assessed, but also possible mitigation measures were proposed in the current study.

The present paper is structured as follows: the literature review presents the peculiarities of the agri-food sector and introduces its main risks, creating a theoretical background for the research; the Methodological section introduces the methods applied for the research and explains its rationale; the results and discussion part presents the main research findings, and the Conclusions part summarizes the research and acknowledges the research limitations.

2. Literature Review

2.1. The Peculiarities of the Agri-Food Supply Chains

According to Siche [14], the food supply chain is a complex network connecting the agricultural (agro) system and the final consumer, characterized by production, packaging, distribution and storage processes. Recently, the food supply chain, such as other supply chains, is affected by significant population growth, as well as climate changes, competition in the main resources such as land, water and energy, changing demand and consumer values and ethical changes [15]. The food supply chain needs the ability to change nimbly in the event of unforeseen circumstances that cause supply disruptions as the whole chain must remain unbroken. According to Manning and Soon [15], such ability is provided by implemented innovations, the pursuit of efficiency and resource management. Thus, this requires a continuous improvement process, attention to strengthening the supply chain and the occurrence of possible internal and external unforeseen events that must be prepared in changing the suppliers, intermediaries, stock levels, etc. Various disruptions in supply chains cause significant financial and operational losses to a company [16]. Hendricks and Singhal's [17] evaluation shows that analysis of 519 disruptions impacted a 10% decline in stock market value, whereas a subsequent study of 885 disruptions provoked a 107% operating income decline, a 114% decline in sales returns and a 93% in asset returns [18]. In the most severe cases of disruption, supply chains may collapse and never recover [16]. In the food supply chain, disruption is particularly relevant to quality issues, and since each process in the supply chain is very closely related, even a small delay or disruption in one of the processes can cause a serious butterfly effect [3], spreading throughout the whole supply chain [19]. For example, the demand for year-round availability of seasonal fresh foods has led to the creation of global supply chains in which the gaps between the stages of production and consumption are alarming [20]. The food system itself faces various challenges and global changes such as climate change, extremely rapid urbanization, unexpected political or financial crises and natural disasters. All of these increase the challenges for food suppliers to meet the ever-changing demand [21]. Thus, ensuring the efficiency, resilience and stability of the food supply chain becomes a considerable task for food producing and retailing companies. In comparison to other industries, the food supply chain is distinguished not only by the fact that it is necessary for daily life, but also by its characteristics such as seasonality, specific legislation strictly regulating food safety and changing product quality (applies to perishable products) [2,22].

These criteria determine specific requirements for transportation, storage and processing. In the very concept of the food supply chain, one should distinguish supply chains using agricultural raw materials, for which seasonality is a particularly significant criterion, and the food production chain (industrial factor), which is not obtained from agricultural raw materials such as crops or livestock [22]. For which, seasonality is not of crucial importance, although still significant.

Food products can be divided into fresh agricultural products (for example, fresh vegetables and fruits) and processed products (for example, various snacks and canned food) [2]. Meanwhile, the food supply chain can be divided into the supply of critical production such as raw materials, ingredients that have a direct impact on the quality of the final food product and the supply of non-critical raw materials and services that have a remote impact on the quality of the final product (for example, real food additives, packaging or logistics services) [19].

2.2. Risks, Specific to the Agri-Food Supply Chains

Some authors' [23,24] insights indicate that one of the most important reasons for the emergence of local food supply chain constraints is the nature of the market such as distances, poor relationships with retailers and consumer behavior that prevent producers from reaching a larger customer base or penetrating a wider market, and thus increasing their sales. Other notable issues that are not directly related to the characteristics of food supply chains are the lack of skilled labor, which forces companies to become dependent on immigrants, as well as the lack of transfer of good supply chain management. Risks associated with agri-food supply chains through the lens of its various stages have been also investigated [25,26]. This type of analysis distinguishes risks related to self-sufficiency or, in other words, simply supply. This is due to the impossibility of getting the necessary supplies due to natural calamities, ineffective communication between different stages of the supply chain, etc. [27,28]. Chaudhuri et al. [26] also distinguished the causes of risk such as poor sourcing contacts, absence of suppliers or dependence on several suppliers. Peck [29], while analyzing various risks of the food supply chain, also singles out the risk of losing the main supplier as one of them. Meanwhile, storage and transportation risks are distinguished by Esteso et al. [30] as one general group of risks manifested by inappropriate stocks, product storage conditions and unavailability of vehicles, while Nyamah et al. [31] divide it into two separate groups—logistics and (product) storage. Technology risk, according to Moazzam et al. [32], delays in distribution (dispatch) are also possible for the group of storage risks, as well as the possibility for contamination of food products. These authors distinguish the remaining risk groups differently. Ali et al. [33] distinguish social risks that may have consequences for the reliability of the supply chain, and its management requires the examination of public actions both in the market and within the company. This risk manifests itself through employee strikes, failures of the public distribution system as well as technological risks. Another group of risks is the demand risk, which is usually determined by market changes, for example, rumors about the expiration of goods lead to an irrational increase in demand, which is not predicted. On the other hand, Davis et al. [34] separated production risks that arise from the variability of the processes used (lack of process standard), the possibility of contamination (contagion), downtime due to equipment failures, process errors and other reasons, the lack of formal production planning and the use of outdated technologies. Manning and Soon [15] and Peck [29] analyzed the factors of the food supply chain that can cause danger (risk) and distinguished the contamination of products (food safety incidents), risk of their return. However, Peck [29], unlike other authors, distinguished the risks of loss of access (due to terrorism, blockades, protests or local quarantines due to industrial pollution, animal diseases, etc.) and loss of room (as a result of fire, flood or other disaster) separately. Oglethorpe and Heron [35] together with Davies and Ollus [36] highlight the risks caused by the lack of skilled workers. In their classification, Manning and Soon [15] distinguish risks associated with the food supply chain such as infectious animal diseases not mentioned by other authors; fraud in the food sector—counterfeiting of food products including falsification of substitutes; market and pricing strategies; economic crises. The following factors that may endanger the food supply chain such as natural disasters of a global or local scale affecting suppliers or neighboring countries (e.g., low yields, droughts, war, floods, fire, etc.); technological incidents and infrastructural threats (unfortunate events at the supplier's farm or own production company; data loss and communication breakdown) were also distinguished by Manning and Soon [15]. The validity of the risks identified during the analysis and their possibility of becoming a limitation can be determined by case studies. Vlajic et al. [37] analyzed the meat processing sector and found that the supply chain faces the following problems that prevent the sector from achieving higher efficiency and higher profits: lack of supplies (raw materials); stock (end products) expiring; low consumption of raw materials (end products); low line productivity; low quality of final products leading to products returns. It can be noted that in the limitations that occurred due to the previously identified groups of supply and production risks are established. Thus, the risks of the agri-food supply chain can be divided into three main groups of risk factors such as dependence on suppliers and contracts; variability, visibility and traceability of suppliers; production disruptions [26]. The examined risks associated with the agri-food supply chains were grouped according to the stages of agri-food supply chains which they do affect. Such classifications allow for identifying the most important risks, which are relevant to all stages of the agri-food supply chains (see Table 1 below). As Ivanov et al. [38] suggests, measures aimed at increasing the viability and sustainability of the supply chains must be directed at more than one of its stages in order to achieve significant improvements. Following this approach, we focus our further investigation onto risks, which are relevant to all four stages of the agri-food supply chains considered to be posing the most severe threat to the viability of the agri-food supply chains.

Table 1. Detected risks relevant to agri-food supply chain of different stages.

	Risks Detected	**Stages of the Food Supply Chain**			
		A	**B**	**C**	**D**
		Supply	**Production**	**Distribution**	**Consumption**
1.	Failure of the supplier to ensure a stable supply of raw materials (products).	1; 11; 20			
2.	Absence (loss) of suppliers or dependence on several suppliers	2; 7; 11; 17	5; 7; 11; 17	5; 7	
3.	Absence of a central contracting authority	1			
4.	Poor quality of supplied raw materials (products)	1; 2; 4; 6	2; 6	15	
5.	**Natural disasters of a global or local scale**	1; 3; 20	1; 3; 20	1; 3; 20	17; 20
6.	**Workers' strikes**	1; 10; 12	1; 10; 17	1; 17	1; 17
7.	Lack of qualified workers		4; 5; 20	5; 17; 20	
8.	Outdated, inefficient technologies or practices used	1	1; 2; 8	1; 2; 8	
9.	**Infrastructure problems**	3; 17; 20	3; 17; 20	3; 17; 20	3; 17; 20
10.	Infectious diseases of animals	3	16		
11.	**Change in government regulations or safety standards**	2; 4; 18; 19	4; 19	4; 19	4; 18; 19
12.	Lack of supply visibility (location, quantity)	2; 12; 17	2; 12		
13.	Initial price volatility	2; 8; 13	9:18		
14.	**Supply chain disruptions due to social or political unrest**	2; 3; 5	3; 5	3; 5	3; 5
15.	Poor supply contracts	2; 7; 8	13; 17		
16.	**Short term raw materials or products (expiration issue)**	4; 6; 11; 12	4; 7; 11; 12	4; 8; 11	4; 8; 9; 11; 12; 16; 17
17.	**Seasonality**	2; 7; 9; 16	9; 17	15; 17	9; 15; 17; 18
18.	Low consumption of raw materials		6; 11		
19.	Low line productivity	6; 14	6; 9; 14		
20.	Low quality of final products		6; 9		

Table 1. *Cont.*

Risks Detected		Stages of the Food Supply Chain			
		A	B	C	D
		Supply	Production	Distribution	Consumption
21.	Variability of production processes, no established standards		2; 17		
22.	**Food safety incidents**	3; 5; 12	2; 5; 12	2; 5; 14	5; 14
23.	Downtime (due to equipment failure, process disruptions, etc.)		2	14	
24.	Lack of formal production planning		2; 14		
25.	Lack of knowledge in effective distribution			4	
26.	**Lack of smooth interconnection with other chain participants**	1; 12	4; 12	4	4
27.	Insufficient warehouse capacity			1; 2; 9; 13	
28.	Improper handling of production, loading and unloading in another place			1; 7; 8	
29.	Improper packaging and protection			1; 8; 18	
30.	Losses during transportation			1; 15	
31.	Vehicles not available on time			1; 2	
32.	Shipping/unloading delays			2; 12; 17	
33.	Shipping errors			2; 8	
34.	Poor logistics contracts			2; 8; 14	
35.	Transport failures			2; 8; 11	
36.	Failure to apply appropriate conditions (e.g., temperature).			2; 12	
37.	A sudden increase in demand				1; 10; 11; 17
38.	Forecast discrepancies				1; 9
39.	**Fraud in the food sector**	1; 3; 7	1; 3; 7; 18	1; 2; 3; 18	1; 3; 18
40.	Product returns				3; 5; 12; 14
41.	**Market and pricing strategies, economic crises**	3; 7; 8; 9; 12	3; 9; 12; 14	3; 7; 12; 18	3; 11; 14
42.	Awkward shopping (no one stop scenario)				3; 14
43.	Consumers' personal beliefs, empathy for animals				4; 12

Source: Compiled by authors based on 1—Rathore et al. [25], 2—Chaudhuri et al. [26], 3—Manning and Soon [15], 4—Oglethorpe and Heron [35], 5—Peck [29], 6—Vlajic et al. [37], 7—Azizsafaei et al. [39], 8- Manning et al. [40], 9—Tavakoli Haji Abadi & Avakh Darestani [41], 10—Ali et al. [42], 11—Mogale et al. [43], 12—Moazzam et al. [32], 13—Khan et al. [44], 14—Oliveira et al. [45], 15—Behzadi et al. [46], 16—Ali et al. [33], 17—Ray [47], 18—El Ayoubi, & Radmehr [48], 19—Ramos et al. [49] and 20—Hobbs [50].

3. Materials and Methods

3.1. The Determination of the Most Important Risks of Agri-Food Supply Chains

A survey of experts was conducted in order to find out the most important risks of agri-food supply chains. The expert body consisted of 5 persons directly involved in the management of agri-food supply chains (head of agricultural cooperative; head of the Operations department of the vegetable wholesaler; head of the production in one of the TOP3 Lithuanian meat processing factory; logistics manager in one of the biggest Lithuanian retail chains; CEO of the NGO specializing in the provision of food for poor) and 3 scientists directly involved in the research of the supply chains. The expert survey was carried out in March–May 2022. During the preparation of the expert assessment, the identified risks were grouped according to their nature or intended purpose. It was determined that risks such as short-term raw materials or products (expiring) and seasonality are interrelated with the occurrence and possible solutions, so when preparing the questionnaire, these two risks were combined into one general assessment. Meanwhile, the limitations of both infrastructure problems and the lack of smooth interconnection with other chain participants are compounded, containing other risks that may arise for very different reasons. Moreover, the infrastructure in the company is directly related to the availability of capital, but this study aims to investigate non-financial solutions. For these reasons, in order to ensure the reliability of the study and to avoid ambiguities, it was chosen to study the risks of the lower hierarchical level, which cannot be decomposed into many other branches of risk. Thus, the assessment in the study was narrowed to 7 root cause risks (out of 11 initially identified main risks relevant to agri-food supply chains) (see Table 2). This helps to ensure robustness of the results as it is considered that expert survey-based MCDMs provide the most robust results when dealing with a maximum of 10 alternatives at the same hierarchical level [51].

Table 2. The possible agri-food supply chain root risk mitigation measures and categories of solution.

Root Risk	Risk Mitigation Alternatives	Category of Solution
	Root Risk 1	
Natural disasters of a global or local scale	1. Alternative suppliers of services or raw materials (products)	For prevention, to eliminate the consequences
	2. New production plans	For prevention, to eliminate the consequences
	3. Using the latest technology (for monitoring the weather)	To eliminate the consequences
	4. Maintaining adequate stock levels of key raw materials (products).	For prevention
	Root Risk 2	
Workers' strikes	1. Creating a sense of teamwork in the organization	For prevention
	2. Attention to the well-being of employees	For prevention, to eliminate the consequences
	3. Provide additional manpower to support basic operations during the strike	For prevention, to eliminate the consequences
	Root Risk 3	
Change in government regulations or safety standards	1. Development of technological progress in the company	To eliminate the consequences
	2. Hiring an expert in the field of government regulations, other regulations and safety standards	To eliminate the consequences
	3. Creating a contingency plan	For preparation

Table 2. *Cont.*

Root Risk	Risk Mitigation Alternatives	Category of Solution
Root Risk 4		
Rapid deterioration of raw materials (expiration), seasonality	1. Effective design of storage facilities, allowing to maintain the quality of products (raw materials) as long as possible; ensuring proper temperature regulation and maintenance throughout the supply chain process.	t eliminate the consequences
	2. Preservation, freezing, drying or conversion of raw materials (products) into a semi-finished product; use of modified atmosphere packaging systems.	For prevention
	3. Searching for suppliers from other countries in order to ensure the supply of seasonal products throughout the year	To eliminate the consequences
Root Risk 5		
Food safety incidents	1. Self-control—regular food safety checks and maintenance of proper hygiene conditions at workplaces; investigating the causes of identified food safety incidents	For prevention, to eliminate the consequences
	2. Creation of product traceability, cancellation, return procedures and their regular testing	To eliminate the consequences
	3. Implementation of a data culture that is transparent and accessible to all participants in the supply chain	To eliminate the consequences
Root Risk 6		
Fraud in the food sector	1. Regularly identify the place of possible occurrence of fraud and apply appropriate preventive measures to it.	For prevention
	2. Having an expert in the team who knows legal regulations and aspects.	For prevention
	3. Use various databases to track information about fraud in the food sector and tools (equipment) to assess the company's vulnerability	For prevention
Root Risk 7		
Market and pricing strategies, economic crises	1. Pricing the product and creating value according to the segmented user, respectively	For prevention
	2. Horizontal cooperation to ensure market and price security.	For prevention, to eliminate the consequences
	3. Budgeting and planning, including financial contingency plans	For prevention

Source: compiled by authors.

3.2. Using the Best-Worst-Method

Multiple Criteria Decision Making (MCDM) methods are widely used in order to determine the best of the compared alternatives, which allow them to be ranked according to their importance, taking into account the purpose of the evaluation [52]. Various multi-criteria decision methods have been developed—for example, the Analytical Hierarchy Process (AHP) is used to provide a quantitative form for qualitative methods. The Fuzzy method is characterized by the use of indefinite sets and separate directions [53]. Best-Worst-Method (BWM)—an MCDM method developed by Jafa Rezaei in 2015 [54]—is similar in its application to the AHP method [54]. However, differences can be observed when comparing AHP and BWM. The AHP method requires $n (n - 1)/2$ pairwise comparisons, while BWM requires $2n - 3$ when n is equal to the number of analyzed alternatives. For example, when examining 7 alternatives, the BWM method performs 11 comparisons, and the AHP—as many as 21 comparisons [55]. Moreover, by using only $2n - 3$ pairwise comparisons, BWM is capable of avoiding the inconsistency problems, which are characteristic of some other MCDMs such as AHP or SWARA [56] so is considered to provide more reliable results [57]. BWM is also preferred when investigating new concepts or objects, which are only scarcely supported by the literature [58]. BWM has also been observed to provide more reliable benchmarks leading to more reliable rankings [54]. For these reasons, it was decided to use the BWM method for the research.

3.3. Steps for Using the BWM Method

1. Alternative solutions to the studied case are identified $\{c_1, c_2, \ldots, c_n\}$.
2. The best A_B (most influential or most important) and worst A_W (least influential or least important) alternatives are determined (Table 3)
3. Using a rating scale from 1 to 9, pairwise analyzes are performed comparing the best alternative identified in the first step together with the rest (Table 4).

Table 3. Explanation of pairwise comparison of AHP method.

Estimate	Definition	Explanation
1	Equally important	The significance of both indicators in relation to the research object is the same
3	Moderately important	One indicator is slightly more important than the other
5	Important	One indicator is more important than the other
7	Major	One indicator is much more important than the other
9	Absolutely important	One indicator is incomparably more important than the other
1, 4, 6, 8	Intermediate values	Used to reach a compromise when making decisions between two side-by-side options

Source: Saaty & Sodenkamp [59].

Table 4. An example of using the Best-Worst-Method.

	The Best Alternative	**The Worst Alternative**	
Criterion (X)	A	B	
The Best Alternative Compared to Others	**Alternative C**	**Alternative D**	**Alternative E**
Best alternative: A			
Other Alternatives Compared to the Worst		**Worst Alternative: B**	
Alternative C			
Alternative D			
Alternative E			

Source: Compiled by authors based on Kalpoe [60].

The significance scale proposed by Saaty and Sodenkamp [59], also used for the AHP method (Table 3).

The estimation evaluates the importance of alternatives. The preference of the best alternative over the rest is obtained by vector A_B = (aB_1,aB_2, . . . ,aB_n). aBj indicates the preference of the best alternative B compared to alternative j [54].

For example, criterion X is considered, which can be solved from 5 alternatives: A, B, C, D and E. In the first stage, it is determined which of the 5 alternatives is the most suitable for solving the considered criterion X, and which is the worst [60]:

4. Using a rating scale from 1 to 9, pairwise analyzes are performed comparing the worst alternative identified in the first step together with the rest. The preference of the worst alternative over the rest is obtained by vector $A_W = (a_1W, a_2W, \ldots, a_nW)$. a_jW indicates the preference of the best alternative *j* compared to the worst alternative *W*.
5. Then the optimal weights of alternatives $(w_1^*, w_2^*, \ldots, w_n^*)$ are determined. With A_B and A_W the weight vector w^* is calculated, which must meet such conditions: $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$; j = 1, 2,. . . , n. The final decision is made according to the following decision:

$$\min_{\xi,w} \xi$$

$$\text{s.t.} \left| \frac{w_B}{w_j} - a_{B_j} \right| \leq \xi, \text{for all j}$$

$$\left| \frac{w_j}{w_W} - a_{j_W} \right| \leq \xi, \text{for all j}$$

$$\sum_{j=1}^{n} w_j = 1, w_j \geq 0, \text{for all j},$$

ξ is the optimal exact value obtained by calculating vector weights.

These calculations estimate the optimal weights $w_1^*, w_2^*, \ldots, w_n^*$ and ξ^*.

3.4. Compatibility of Expert Opinions

Since the expert evaluation is based on knowledge and experience, experts' approaches to the raised problem may differ. In order to use expert assessments in decision-making, it is particularly important to assess the compatibility of expert opinions. When the opinions of only two experts are available, the correlation coefficient r is enough to determine their compatibility, but when examining the compatibility of a group of experts, the concordance coefficient W should be calculated [61]:

$$w = \frac{12S}{r^2 m(m^2 - 1)}.$$

r—the number of experts, m—the number of evaluated objects and S—the sum of the squares of the deviations of the rank sums and the general average, which is calculated according to the formula:

$$S = \sum_{j=1}^{m} \left(r \times j - \frac{1}{2} r(m+1) \right)^2.$$

In some cases, multiple objects are assigned the same rank. The concordance coefficient is then calculated according to the following formula:

$$W = \frac{12S}{r^2(n^2 - 1) - r\sum_{j=1}^{r} T_j}.$$

T_j is the associated rank index of the jth expert, which can be calculated by the formula:

$$T_j = \sum_{i=1}^{H_j} \left(t_i^3 - t_j\right).$$

H_j is the number of the jth expert of equal ranks and t_i is the number of the i-th group of equal linked ranks. Expert assessments are considered agreed when the value of the concordance coefficient is close to 1, and when the values differ significantly, the value of W is close to 0 [61]. Using the BWM method, to make sure the compatibility of experts' assessments and the reliability of the obtained weights, the ratio of consistency between opinions CR (Consistency Ratio) by using the Consistency Index (CI) is calculated. Using the BWM method, CR is calculated according to the following formula:

$$CR = \frac{\xi}{CI}$$

ξ is the optimal exact value obtained by calculating vector weights and CI is fixed a_{BW} value (Table 5):

Table 5. Fixed compatibility index values.

a_{BW}	1	2	3	4	5	6	7	8	9
CI value	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Source: Mohammadi and Rezaei [62].

The value of a correctly calculated CR ranges from 0 to 1. A total of 0 represents complete agreement and 1 represents complete disagreement [62]. In cases where the CR is obtained as more than 1, a compatibility problem is identified and the assessment in question was performed inaccurately.

The Likert scale used in this study is intended for experts to evaluate the decisions, however, without giving the possibility of ranking, which is required to calculate the concordance coefficient. Therefore, it is not possible to calculate the compatibility of the experts' answers obtained using the Likert scale. The non-parametric hypothesis about the equality of population distributions was used to determine the compatibility of experts' opinions applying the Kruskal–Wallis H) criterion. This method makes it possible to assess whether the data between different groups have the same distribution [63].

4. Results and Discussion

4.1. Compatibility of Expert Opinions

The non-parametric hypothesis about the equality of population distributions was tested for the responses obtained on the Likert scale using the Kruskal–Wallis criterion (Table 6). When analyzing the answers of the experts, the Kruskal–Wallis p value of 0.351 was obtained, which is higher than the significance level α (0.05), so the H 0 hypothesis about the uniformity of the distributions of the variables should be accepted and the answers of the experts differ insignificantly, so they can be considered consistent.

Table 6. Results of Kruskal–Wallis test.

Test Statistics	Value
Kruskal–Wallis H	7.8
df	7
Asymp. Sig.	0.351

Best–Worst scale response consistency.

For the answers obtained in the scale of the Best–Worst method, the ratio of agreement between opinions CR was calculated (Table 7). When evaluating the answers given by the experts individually, it was noticed that in the case of the fifth expert, the answers to the three questions are not compatible.

Table 7. Consistency between expert opinions in Best–Worst scale.

Experts / Valued Factors	The Ratio of Compatibility between Opinions								The Average of the Concordance of All Expert Opinions	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**All Responses Received**	**After Eliminating Inconsistent Responses**
Root Risk 1	0.02	0.03	0.04	0.03	0.23	0.06	0.06	0.04	0.05	0.05
Root Risk 2	0.08	0.04	0.05	0.00	0.09	0.05	0.04	0.29	0.06	0.06
Root Risk 3	0.05	0.02	0.11	0.02	**1.28**	0.06	0.07	0.02	0.06	0.04
Root Risk 4	0.05	0.00	0.07	0.00	**0.93**	0.55	0.55	0.03	0.10	0.07
Root Risk 5	0.00	0.00	0.00	0.08	**1.16**	0.24	0.03	0.05	0.07	0.05
Root Risk 6	0.07	0.02	0.17	0.36	0.05	0.11	0.17	0.04	0.07	0.07
Root Risk 7	0.03	0.02	0.02	0.05	0.02	0.03	0.03	0.03	0.03	0.03

Source: compiled by authors.

In order to ensure the reliability of the research results, three answers from the fifth expert were eliminated from the further analysis of the research data. The opinions expressed by the rest of the experts are perfectly aligned on almost all questions. When comparing the answers of all experts to each of the research questions by deriving the averages of CI and ξ mean ranks, it can be seen that the opinions are aligned in this aspect of the comparison and after eliminating the three unaligned questions of the fifth expert, this compatibility among the experts was improved.

4.2. The Evaluation of Root Risks in Agri-Food Supply Chains

The expert survey (Figure 1) showed that the most important risk from those examined is natural disasters of a global or local scale, while the least important risk is fraud in the food sector. The rest risks are ranked as follows: market and pricing strategies and economic crises are the second most important risk for agri-food supply chain; the rapid failure of raw materials or products and their seasonality—the third most important risk; almost identically important is the risk of food safety incidents (the fourth place). Less important compared to places 2–4 are changes in government regulations or safety standards (ranked in fifth place) and the risk of strikes by workers (sixth place).

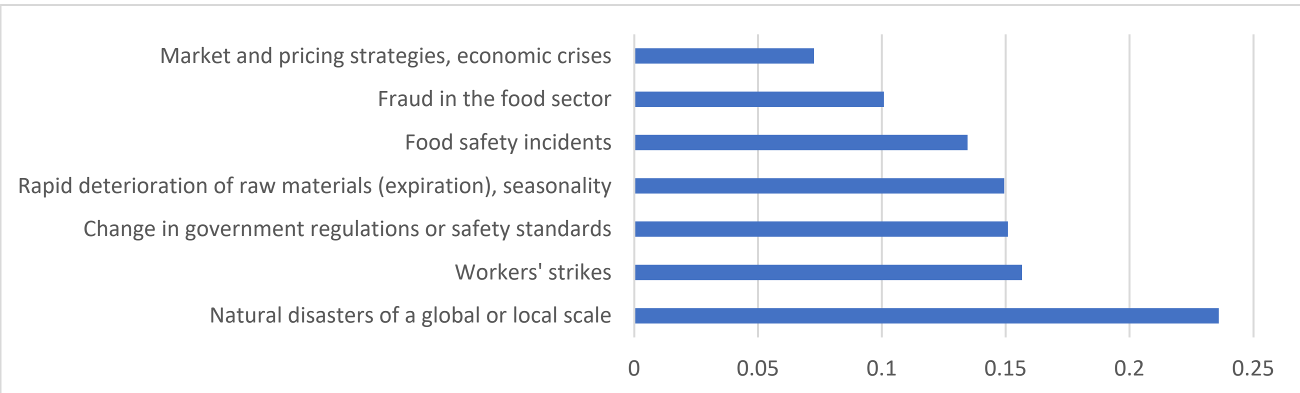

Figure 1. The evaluation of the root risks in agri-food supply chains according to their importance.

4.3. The Determination of the Most Appropriate Risk Mitigation Techniques in the Agri-Food Supply Chains

Risk of natural disasters on global or local scale management (R1). We have investigated both measures in preparation for the possible manifestation of this risk and for the mitigation of the consequences if this risk manifests. Experts evaluated four solutions suitable for preparing for this risk. The best rated was the method of risk management associated with the purposeful preparation of alternative services or raw material suppliers. This is when the possible risk and its probability is determined in the company's activities in the region and/or in a specific part of the supply chain (mean rank—0.5). In the event of a disaster, this would allow for maintaining supply chain agility, rapid organizational response and adaptation to the changes that have occurred. The method of risk management associated with the decision to maintain the level of the respective main raw materials (products) stocks, which would allow the continued smooth operation of the organization in the event of an accident, was rated worse (mean rank—0.27). The introduction of new technologies that allow forecasting the weather in the company was also evaluated not favorably enough (mean rank—0.14). However, drawing up new production plans, which could include other supply chain participants and define their cooperation and transparency support in the event of this limitation in the company's activities, was rated the worst among the analyzed solutions (mean rank—0.09). These findings are rather new, as typically the integration of knowledge management practices is considered focal in mitigating risks of natural disasters in agri-food supply chains [33]. This discrepancy may arise from the fact that most studies seek one solution for all risks associated with agri-food supply chains [64], whereas this study aims to determine the best possible solutions for each root risk.

Of the four solutions mentioned above, three can be adapted to deal with the consequences of this limitation. The assessment of experts in this matter is essentially identical to the methods of prevention of mentioned risk. The best way to overcome the consequences caused by this risk is to use the analysis of alternative service or raw material (goods) suppliers made during the preventive phase to continue to maintain the productivity and efficiency of operations. The lowest rated, as in the case of prevention, is the establishment of new production plans.

The second examined root risk *is employee strikes (R2)* that cause disruptions in the company's operations. When evaluating the solution methods aimed at overcoming the consequences of employee strikes, attention to the welfare of employees (mean rank—0.46) is the best solution method identified by experts. This method is extremely necessary during a strike in order to solve its causes and eliminate divisions so that when returning to work after the strike, the problems do not continue to transfer to work activities and do not interfere with the functioning of the company's activities. This finding corresponds to Wei et al. [65] insights into the importance of employee welfare for the firms' performance. The second most important solution method is maintaining clear and transparent communication between employees and the management (mean rank—0.33). Once a strike begins, daily communication reduces instability between workers and management, helping to avoid animosity once the strike is calmed down and everyone is back on the job. Otherwise, it is noticeable that there remains a clear division between the striking workforce and management, with a tendency to limit workers' grievances after a strike. Although being considered the best solution for the mitigation of the above-mentioned risk by some scholars [66], this solution was ranked second due to the fact that it is applicable only when the risk has already manifested, thus is suitable only for the mitigation of the consequences of the risk manifestation, but not for the prevention of it. The worst solution for dealing with the effects of workers' strikes was the use of additional labor to support the initial operation (mean rank—0.21). It is believed that this method is rated the worst because it solves the company's problems only with a short-term strategy. A company may continue to maintain uninterrupted operations during a strike, but this does not resolve the animosity of the workers and does not contribute to the control of the workers' strike.

When examining the root risk of *a change in government regulations or safety standards (R3)*, one solution for preventing such a restriction (risk) and two solutions for dealing with its consequences were assessed. When evaluating the creation of a contingency plan as a solution to prepare for the occurrence of this risk, the majority of experts stated that it is neither a good nor a bad option (mean rank—0.23). Such an individual plan created by the company, which foresees various possible scenarios (based on the analysis of trends in previous regulatory changes) and their solution methods, could facilitate the company's adaptation to new standards or accreditation systems. When evaluating the two possible solutions to deal with the consequences caused by this risk, the opinions of almost all experts agreed and based on the majority it was determined that a good solution is the development of technological progress in the company (mean rank—0.57). This method would help to better (co)manage various supply chain processes, while also facilitating the process of introducing/adapting new requirements. Moreover, the reduction of human labor and the introduction of automatic processes would reduce the risk of incidents in the food production process and increase the safety of other sensitive elements of the supply chain. In addition, it increases the productivity and efficiency of the agri-food enterprises [67]. It should be noted that technological progress and adoption of innovation are considered to be one of the best solutions not only for agri-food supply chain risk mitigation [68], but also for increasing the whole performance level of the agri-food enterprise [69,70]. Meanwhile, hiring an expert in the field of government regulations and safety standards is considered by the majority to be neither a good nor a bad choice (mean rank—0.2).

Short-term raw materials or products (expiring), seasonality (R4). The only solution was found to prevent the occurrence of this risk, while two solutions were found to deal with its consequences. The assessed solution for the prevention of this risk is the preservation, freezing, drying or conversion of raw materials (products) into a semi-finished product; use of modified atmosphere packaging systems. According to the majority of experts, this decision was evaluated as a good choice to prevent the occurrence of the mentioned risk in the organization's activities (mean rank—0.3). This insight corresponds to Fellows' [71] suggestions and also allows for the reduction of food waste [72]. In the study two solution methods to overcome the effects of short-term raw materials (products), and seasonality was evaluated. The first is the search for suppliers from other countries to ensure the supply of a seasonal product throughout the year. At the end of the raw material (product) season in one's country, it (or its substitute) can be imported from another country, thus giving the consumer the opportunity to consume a seasonal product all year round. The second solution method is the efficient design of storage facilities, allowing to maintain the quality of products (raw materials) as long as possible, ensuring proper temperature regulation and maintenance throughout the supply chain process (mean rank—0.4). According to the majority of experts, the latter is more suitable than the former and is a very good choice for reducing the effects caused by this restriction. The storage temperature of food raw materials or products is particularly important for the validity of them, it is one of the criteria that has the greatest influence on the validity period. Meanwhile, the first solution method linked with searching for suppliers from other countries is a less suitable solution method than the previous one and, in the opinion of the majority of experts, it is rated as a moderate choice for solving the effects of the restriction (mean rank—0.3). This may be due to the fact that after the COVID-19 pandemic, the increased supply chain complexity started to be seen as more negative than a positive thing [73].

Another examined root risk—*food safety incidents (R5)*. Analyzing the solution methods to deal with the consequences caused by food safety incidents, the creation of product traceability, recall and return procedures and their regular testing was determined to be the best according to experts (mean rank—0.44). This finding confirms the necessity of introducing various quality control procedures into agri-food enterprises [74]. Companies could use the created procedures for tracing the causes of the incident of contaminated products, the procedures for canceling and returning the production or supply of products in order to deal with the incident as smoothly and quickly as possible in order to protect the reputation, reduce losses and determine the causes of the incident and prevent the occurrence of new ones. The second-best solution method is self-control and investigation of the causes of food safety incidents by conducting laboratory tests (mean rank—0.37). The least effective solution was the implementation of a transparent and accessible data collection method for all participants of the supply chain (mean rank—0.19). This may be due to the fact that this solution will only help to find who is responsible for the food safety incident [75] but not to prevent it. When choosing such a solution, one should move away from old processes related to operating systems and individual databases (isolated management of them) and choose digital transformation and technologies that could create a more coherent and agile food supply chain.

To manage the risk of *fraud in the food sector (R6)*, three preventive solutions have been identified, the best of which is the use of various databases that allow tracking information about fraud in the food sector and tools (equipment/technology) that allow assessing the company's vulnerability (mean rank—0.49). After identifying the products at risk of fraud, it is possible to introduce a more detailed monitoring of them to implement a traceability system in the activity. The second most effective method, according to experts, is the decision to regularly determine the specific location of possible fraud and apply individual preventive measures (mean rank—0.29). Preventive measures should depend on the location of fraud, for example, if fraud is possible when receiving raw materials from a supplier, supplier auditing should be introduced; in the event that fraud occurs as a result of raw materials (products) stored during production and distribution, various technologies should be used to better track products, monitor them, assess their correct or incorrect labeling and detect errors earlier. This solution was ranked second, not first possible due to the fact, that individual preventive measures must be devised for each company, thus no unified system of preventive measures can be applied [76]. The decision to hire or employ an expert in the team who knows legal regulations and other aspects was chosen as the least efficient way (mean rank—0.22). Such an employee in the team should be able to competently understand what can be required from the raw material supplier, manufacturer or product supplier, for example, what information should be provided on the product label, what quality it must meet according to regulatory legislation. Enforcing the relevant requirements can help reduce the likelihood of fraud. Such a low rank of this solution may be attributed to two different reasons: such a person/team may demotivate other employees revealing employers' distrust of them [77]. Another reason is associated with the costs of hiring a team of highly competent legal specialists [78].

Market and pricing strategies, economic crises (R7). To prevent this limitation (risk), three solutions were evaluated. According to experts, the best prevention of this risk is detailed and responsible budgeting and planning including financial contingency plans (mean rank—0.41). In order to avoid the consequences of a possible economic crisis, companies should plan their finances accordingly, i.e., create budgets including financial contingency plans (for example, an agreement to extend bill payment). This insight corresponds to Zavalko et al. [79] arguments about the importance and benefits of proper financial control in the enterprise. The second most effective solution method is horizontal cooperation in order to ensure market and price security (mean rank—0.37). Such methods can reduce costs and avoid alternative costs related to additional (individual) optimization; improve performance; share information with each other, making it possible to avoid unexpected changes and solve problems in time. Although there is a risk that if coordination of this method becomes too intense and comprehensive, some questions may arise about the compliance of these actions with the competition law [80]. Product price determination and value creation according to users of different segments (mean rank—0.22) are evaluated as the third or least effective of the examined solution methods. With price-insensitive consumers, the supply chain can focus on innovation because the buyer is more progress oriented and risk averse. Otherwise, with a more price-conscious consumer, the supply chain should be flexible, adapting to the consumer's expectations for quick delivery and response. By adopting such a preventive approach, the company could optimize its costs and better manage its available resources. This method of risk management also includes modifying products to better meet the needs of one or another group of users. Such an approach also helps to reduce food waste in the agri-food supply chains [81], thus should be also encouraged due to environmental and sustainability reasons.

5. Conclusions

Our research revealed seven root causes of the emergence of risks in agri-food supply chains. These seven root risks should be a main focus in designing a framework for achieving more sustainable and viable agri-food supply chains. This paper not only identifies these main root risks (natural disasters of a global or local scale; workers' strikes; change in government regulations or safety standards; rapid deterioration of raw materials (expiration) with seasonality; food safety incidents; fraud in the food sector; the market and pricing strategies with economic crises) but also proposes the best risk mitigation measures in order to avoid the manifestation of these root risks. It should be noted that most of the proposed and best-ranked measures (diversification of suppliers; optimization of stocks; attention to the welfare of the employees; maintaining clear and transparent communication between employees and the management; development of technological progress in the company, etc.) are of applied nature and can be easily implemented by the agri-food producers. What is more important, most of these measures, if implemented, will not only mitigate risks but will also significantly improve the economic performance of the agri-food enterprises.

Our research is, of course, not without limitations. We focused on the risks, which are relevant to all four stages of the agri-food supply chain because we investigated the agri-food supply chains which represent the centralized food production systems. One can easily presume a situation in which risks characteristic to only one or a few stages of agri-food supply chains are detrimental to one or another, specific agri-food supply chain. Such a situation could change the ranking of the most important risks or even the classification of the root risks. Thus, our findings are pertinent to agri-food supply chains covering all four stages. The study on a risk profile distinctive for shorter agri-food supply chains or for agri-food enterprises operating in some niche sector could be a prospective future research avenue.

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