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Construction of a Farm-Level Food Security Index: Case Study of Turkish Dairy Farms

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Abstract

Food security continues to be a global concern and its importance has recently increased for many reasons. Composite food security indices have been widely used to calculate and monitor food security, but farm-level studies are limited. Therefore, the main objective of this study is to construct a Farm-level Food Security Index (FFSI) for dairy farms to assess their contribution to food security, identify potential areas for improvement and guide policy makers. Data were collected from 126 farms in the Thrace Region of Turkey through face-to-face interviews. The FFSI was constructed with four dimensions, briefly called economic, quality, social and natural resources, containing twenty-three variables. Principal component analysis was used for the determination of variable weights, data envelopment analysis for calculating technical efficiency, and the Tobit model for examining the factors influencing FFSI scores. To assess the robustness of the FFSI, Monte Carlo simulations-based uncertainty and sensitivity analysis, dimension extraction approach and Shapley effects sensitivity analysis were performed. With an average score of 56.8, the key result of the FFSI is that dairy farms are using almost half of their potential to fully contribute to food security. Moreover, according to the Tobit model, FFSI scores are significantly affected by the farmer's age and education level, credit use, livestock unit, fodder crop area and milk marketing channel. The FFSI is robust to weights and sensitive to normalisation, and the social sustainability dimension can cause the largest shift in index scores. Based on these findings, numerous agricultural policy proposals have been developed in this study by identifying the priority areas that need to be addressed to guarantee food security.

Keywords Food security index · Composite indicator · Uncertainty and sensitivity analysis · Shapley effects

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1 Introduction

Food security continues to be a global concern and its importance has recently increased for many reasons, including population growth and demand for food, declining purchasing power due to inflation, degradation of natural resources, climate change, increasing political risks, conflict, and migration.

Food security exists "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2001). It is a multidimensional concept and has four main dimensions: availability, accessibility, utilisation, and stability. The availability dimension represents the supply side of food production and refers to the availability of sufficient food for all. Accessibility is a demand-side term, representing physical and economic access to available food. Utilisation means that the food that is available and accessible is nutrient adequate, safe, hygienic, and culturally acceptable. Stability refers to the stability of the other three dimensions (FAO, 2008). Recently, it has been suggested to include agency and sustainability dimensions in food security (Clapp et al., 2022; HLPE, 2020).

Measuring food security in the most appropriate way is crucial for designing agricultural and food policies, assessing nutrition and health situations, and developing the necessary strategies, programmes and policies. Because of its multidimensional nature, there are many different ways of calculating and monitoring food security. One of these is "composite indices", which are extremely useful tools for accurately analysing complex and elusive issues, illustrating key points, making comparisons, and thus helping policy makers to design result-oriented plans and policies and to identify effective and appropriate strategies (OECD and JRC, 2008; Greco et al., 2019). In this context, "composite food security indexes" have recently been frequently used to calculate and monitor food security (Caccavale & Giuffrida, 2020; EIU, 2021; Peng & Berry, 2018; WFP, 2020).

As the first and most important link in the food supply chain, farms and agricultural production make the greatest contribution to food security. However, there is a lack of farm-level food security indices that consider the unique challenges and opportunities faced by farmers in ensuring food security. In the literature, farm-level indicators have generally focused on sustainability (Zahm et al., 2008; Gaviglio et al., 2017; ul Haq and Boz, 2020; Attia et al., 2021). On the other hand, sustainability is only one of the dimensions of food security.

In this context, the first and main objective of this research is to establish a Farm-level Food Security Index (FFSI) for dairy farms to show their contribution to fully ensuring food security, to determine their potential to increase this contribution, to assess the problems encountered in production and to guide policy makers. There are also a number of other objectives: (2) to calculate technical efficiency at farm level and analyse the relationship between the index and efficiency scores; (3) to examine determinants of index scores by farmer and farm characteristics; (4) to check the robustness of the index to different methodological choices through uncertainty and sensitivity analyses; and (5) to make policy proposals.

1.1 Hypothesis

According to the conceptual framework and analyses, the study has three hypotheses:

H1 = Farms have the lowest scores in the economic dimension of the FFSI.

H2 = There is a positive relationship between farm scale, technical efficiency and FFSI scores.

H3 = Farmers' characteristics (age, education, family size, information channel, etc.) have a significant effect on farms' FFSI scores.

2 Literature Review

Food security indexes are typically used at macro levels such as national, international, and regional, their usage at the individual and household level is uncommon, and indices generated at the farm level are generally constructed within the framework of sustainability.

Macro-level indexes show the general situation of food security in the country and the most popular and comprehensive ones are Global Food Security Index (EIU, 2021), Proteus Global Food Security Index (WFP, 2020), and Global Hunger Index (Welthungerhilfe and Concern Worldwide, 2021). There are also varied indexes that combine different food security data, like Food Insecurity Multidimensional Index (Napoli, 2011), Global Nutritional Index (Peng & Berry, 2018), and the Regional Food Security Index (Mihoreanu et al., 2019).

Micro and farm-level studies to develop a food security index are limited. Various indexes have been developed to represent the food security status of farmers or farm families in countries where food insecurity remains a major concern (Abafita & Kim, 2014; Ibok et al., 2019). On the other hand, the economic, environmental, and social sustainability of farms is considered in industrialised and high-income countries, and indicators have been produced in this context (Dantsis et al., 2010; Elsaesser et al., 2015; Galdeano-Gómez et al., 2017; Gaviglio et al., 2017; Magrini & Giambona, 2022). Several methodologies have been developed to measure sustainability at the farm level, such as indicateurs de durabilité des exploitations agricoles (IDEA) (Zahm et al., 2008), a monitoring tool for integrated farm sustainability (MOTIFS) (Meul et al., 2008), sustainability assessment of farming and the environment (SAFE) (Van Cauwenbergh et al., 2007), response-inducing sustainability evaluation (RISE) (Häni et al., 2003), and framework for assessing the sustainability of natural resource management systems (MESMIS) (López-Ridaura et al., 2002). These micro-level studies aim to provide a clear and objective evaluation of sustainability in agriculture. The farm-level approaches' economy sub-dimension commonly employs variables such as production value, value added, productivity, and income diversity. The social dimension includes variables such as education, labour force, work conditions, farm continuity, and cooperation. The environmental sub-dimension includes variables such as water and soil quality, nutrient flow, fertilizer, pesticide use, and biodiversity (Robling et al., 2023). For example, the widely used IDEA methodology consists of three dimensions: economic, socio-territorial, and agroecological, each with 10 components and 41 indicators. It includes variables such as economic viability, independence, transferability, efficiency, product and land quality, organization, ethical and human development, diversity, and production methods. Several studies have employed the IDEA approach (Fadul-Pacheco et al., 2013; Gavrilescu et al., 2012; Ikhlef et al., 2015). These farm-level indexes are very useful in revealing three different dimensions of agricultural sustainability. Ensuring the sustainability of agricultural production is an important prerequisite for sustainable food security. However, their ability to provide a complete picture of food security is limited because they do not include variables that directly affect food security, such as food loss and waste, food safety, quality, capacity utilisation and climate change.

Numerous studies have been carried out for methodological purposes, such as reviewing and explaining the current and potential variables to be used in the indexes and determining their weights or importance levels (van Calker et al., 2005; Hayati et al., 2010; ul Haq and Boz, 2018). These studies aim to provide methodological guidance for future case study research. Generally, composite indexes are titled (Gómez-Limón & Sanchez-Fernandez, 2010; Galiè et al., 2018; ul Haq and Boz, 2020), even so, some researchers did not specify a name for their index and prefer to use general terms such as composite scoring, a composite indicator, and assessment tool (Dantsis et al., 2010; Dong et al., 2016). Although it is common practice to group variables under dimensions and use them to construct an index (Dantsis et al., 2010; Elsaesser et al., 2015; Galdeano-Gómez et al., 2017; Gaviglio et al., 2017), some researchers did not prefer sub-dimensions (Dong et al., 2016; Peng & Berry, 2018; Webb et al., 2015).

The common methods used in the weighting of the variables are Principal Components Analysis (PCA) or equal weighting (Gan et al., 2017). The most widely used method for normalisation is the min–max method (Napoli, 2011; ul Haq and Boz, 2020; EIU, 2021). After calculating the scores, correlation and regression analyses were used to investigate the relationship between the index scores and other factors (Garai et al., 2022; Ibok et al., 2019), while some studies applied grouping or cluster analysis (Gunduz et al., 2011; Webb et al., 2015). However, the lack of uncertainty and sensitivity analysis in most studies and the inadequacy of further analysis after index construction are notable.

Within this framework, this research will make an important contribution to the literature as; (1) the new Farm-level Food Security Index (FFSI) has extended the current approaches used to measure sustainability at the farm level. (2) It is conducted in one of the most important regions in terms of food security and dairy farming in Turkey, the Thrace region. (3) FFSI allows the adaptation of macro indexes to the micro level both in the international literature and in Turkey. (4) FFSI will serve as a guide for future studies, can be used in different regions and will allow macro assessments to be made. (5) FFSI is methodologically different from most previous indexes; a notable feature of this study is a robustness check of the new index, which has not been done extensively in the literature.

3 Methodology

3.1 Study Area and Data Collection

The Thrace Region is in the European part of Turkey and consists of three provinces, namely Tekirdag, Edirne and Kirklareli. There are 287.7 thousand dairy cows, 132.9 thousand calves, 48.5 thousand bulls and bullocks in the region, and 68.6% of the area is used for agriculture (TurkStat, 2022). Total milk production in the region is 666.3 thousand tons. The average milk yield in the Thrace region is 3,740 kg, which is 18% higher than the Turkish average. In addition, the food industry is well-developed, and a significant part of Turkey's milk processing plants are located in this region (Ministry of Agriculture and Forestry, 2018). In this context, Thrace is a strategically important region for dairy farming in Turkey.

The sample size was calculated as 126 (95% confidence interval, 0.09 error margin, 0.046 variance σ_p) using the proportional sampling method (Newbold, 1995):

$$n = \frac{Np(1-p)}{(N-1)\sigma_{px}^2 + p(1-p)}$$

n is the sample size, N is population (31,833), p is the prediction rate (the assumed average FFSI score was 50, and *p* was taken as 0.50 in order to reach the maximum sample size).

Data were collected through face-to-face interviews. The interviews were conducted with farms that had five or more dairy cattle between December 2021 and February 2022. The farms were classified into five groups according to the generally accepted farm sizes in the region, based on the number of dairy cows: 5–9 (22.22%), 10–19 (20.63%), 20–49 (22.22%), 50–99 (17.46%), more than 100 (17.46%).

3.2 Methods of Data Analysis

There are ten basic steps in the construction of composite indexes, in accordance with the OECD and JRC (2008) handbook, which has been followed in this study; (1) theoretical framework, (2) data selection, (3) imputation of missing data, (4) multivariate analysis, (5) normalisation, (6) weighting and aggregation, (7) uncertainty and sensitivity analysis, (8) back to the real data, (9) links to other indicators, (10) visualisation of the results.

The theoretical and conceptual framework of the research is explained in the previous sections. SMART (specific, measurable, achievable, relevant, time-bound) criteria were used to select the index variables (Koç & Uzmay, 2019; Pérez-Escamilla et al., 2017; Santeramo, 2015). The dimensions and indicators selected for the FFSI based on these criteria are listed in Table 1 and explained in detail in the Appendix section.

The first dimension of the index is labelled "Economy, production and marketing" and is used to identify both the current contribution of farms to food security and the barriers to their potential to increase their production. The second dimension is "Quality and food safety" and is included in the index to determine whether farms are producing quality and safe food to ensure food security and to identify areas for improvement. The third dimension, "Social sustainability", aims to assess the current situation of farms and their expectations and aspirations for the future in terms of ensuring the continuity of agricultural production and thus the stability of national food security. The fourth and final dimension, "Natural resources and climate change", includes how agricultural production is affected by natural resource or climate change issues, and farmers' attitudes and practices towards these issues. Please refer to the Appendix for more detailed information.

As the material for the research was obtained through face-to-face interviews, there were no missing values. Indicators were normalised using the min–max method, which is compatible with various weighting and aggregation techniques.

Following the selection of dimensions and indicators, variable weights were calculated using Principal Component Analysis (PCA), a technique commonly used in index construction studies (Abafita & Kim, 2014; Gómez-Limón & Sanchez-Fernandez, 2010; Valizadeh & Hayati, 2021). Weights were obtained from the factor loading matrix (Gómez-Limón & Riesgo, 2008, 2009). In the use of PCA; components with (i) eigenvalues greater than 1, (ii) explain at least 10% of the variance alone, and (iii) contribute more than 60% of the total variance were taken (OECD and JRC, 2008). Variables with factor loadings greater than 0.40 and communities greater than 0.50 were included in the index (Hair et al., 2019; Ripoll-Bosch et al., 2014). In calculating the final FFSI score, equal weighting (25.00%) was given to each dimension, which represents the arithmetic mean of the four dimensions. The literature shows that the most used methods in indexes are equal weighting (46.88%)

Table 1 Dimensions, variables, and weights of FFSI

Indicator	1. Economy, production, and marketing	Weight (in dimension)	Weight (in index)
1.1 Production value	Total sales/Total livestock unit (LSU)	16.28	4.07
1.2 Self-sufficiency	Home-grown feed cost/Total feed cost	16.87	4.22
1.3 Capacity usage ratio	Current livestock assets/maximum capacity of the barn	12.07	3.02
1.4 Stability of yields	(0) decrease, (1) stabile, (2) increase	15.99	4.00
1.5 Dependency of subsidies	Would you be able to continue production without subsidies? (0) no (1) yes	13.11	3.28
1.6 Access to finance	(0) no, (1) partially, (2) yes	10.40	2.60
1.7 Input use	(0) decreased, (1) not decreased	15.28	3.82
2. Quality and food safety			
2.1 Milk loss	Milk loss ratio due to food safety issues (%)	32.50	8.13
2.2 Quality assessment	(0) no, (1) yes	18.53	4.63
2.3 Quality premium	(0) no, (1) yes	18.27	4.57
2.4 Milk cooling tank	(0) no (1) centrally/common (2) on the farm	19.08	4.77
2.5 Knowledge of food safety	(0) no (1) yes	11.61	2.90
3. Social sustainability			
3.1 Agricultural education	(0) no (1) yes	22.12	5.53
3.2 Access to extension	(0) no extension opportunities, (1) there is, but not participating, (2) partially participating, (3) full participation	21.49	5.37
3.3 Continuity of farm	(0) no (will not continue), (1) 1–5 years, (2) 6–10 years, (3) 11–15 years, (4) 15 years and more	15.23	3.81
3.4 Willingness to increase production	(0) no (1) yes	6.84	1.71
3.5 Residence	(0) no, (1) partially, (2) yes	16.29	4.07
3.6 Adaptability	(0) no, (1) followed but not comply with/not adapt, (2) followed and comply with/adapt	7.89	1.97
3.7 Membership	Participation to farmer organizations, score	10.15	2.54
4. Natural resources and climate change			
4.1 Insurance	Number of insured livestock / herd size	25.59	6.40
4.2 Early warning	(1) never, (2) rarely, (3) sometimes, (4) often, (5) very often	25.00	6.25
4.3 Adaptation to climate change	Number of relevant on-farm adaptation measures	16.96	4.24
4.4 Biodiversity	Number of different species	32.46	8.11

and PCA-based weighting (11.46%) (Gan et al., 2017). Many studies use PCA-based and equal weighting to determine the weights of variables (Meul et al., 2008; Gómez-Limón & Sanchez-Fernandez, 2010; Chand et al., 2015; Gaviglio et al., 2017; ul Haq and Boz, 2020). As a result, the following formula was used to calculate the FFSI scores;

$$FFSI_i = \sum_{j=1}^{j=4} a_j B_{ji}$$

where $FFSI_i$ is the index score of ith farm, a_j is the weight of jth dimension (0.25), and B_{ji} is the score of farm ith from dimension jth.

In addition, Data Envelopment Analysis (DEA) was used to measure the technical efficiency (TE) of farms to determine how efficiency relates to FFSI scores. TE was calculated in both input-oriented (IO) and output-oriented (OO) approaches using variable return to scale (VRS) and constant return to scale (CRS). The OO approach aims to assess the efficiency of a farm in producing outputs from a given set of inputs, while the IO approach aims to minimize the amount of inputs required to produce a given level of outputs (see Coelli, 1996; Coelli et al., 2005 for the details of DEA). The deaR (Coll-Serrano et al., 2022) R package was used to calculate efficiency.

The operational flow of dairy farms in the region mainly consists of herd management (reproduction, calf rearing and cattle purchase), feed supply (through home-grown and purchased feeds), labour supply (through family and hired labour), feeding and watering, animal health and welfare management, milking (through portable milking machines or milking parlours), manure management (use of manure as fertilizer or sale of manure), milk and meat marketing (cooperatives and modern dairies). In this context, the efficiency analysis used the following basic physical production inputs: (1) livestock unit (LSU), (2) area of forage crops (hectares), and (3) labour (man-hours). Additionally, the analysis considered the following inputs in monetary terms: (4) the cost of home-grown and purchased feed, (5) veterinary, medicine, and insemination costs, (6) electricity and water costs, and (7) other costs (equipment rental, fuel costs, cleaning, insurance, etc.). The study used sales of milk, livestock, carcass meat, and fertiliser as outputs. These outputs and inputs were identified through a review of the agricultural economics literature and have been widely used in previous studies to analyse technical efficiency of dairy farms (Cabrera et al., 2010; Gelan & Muriithi, 2012; Kelly et al., 2013; Koç & Uzmay, 2022a; Madau et al., 2017; Skevas & Cabrera, 2020).

Censored regression analysis, developed by Tobin (1958) and known as the Tobit model, was used to determine the factors influencing FFSI scores, i.e. the relationship between FFSI and general characteristics of the farmer and the farm. Tobit is the appropriate regression model to use when the dependent variable (FFSI) is continuous and varies within a certain range limited to the left or right, as in our study. Methodological details can be found in Greene (2018). Table 2 shows the descriptive statistics of the variables used in the model.

As explained above, the construction of an index involves a series of procedures involving a large number of analyses and calculations, as well as some methodological choices or assumptions. For such complex mathematical models to be used effectively and responsibly in decision-making, it is critical to demonstrate the impact of model uncertainties on the output. Sensitivity Analysis (SA) and Uncertainty Analysis (UA) are the two main tools for exploring this uncertainty (Saltelli et al., 2019), and are key building blocks in the decision-making process (Razavi et al., 2021). The combination of UA and SA enables for robustness checks on composite indexes and enhances their transparency (OECD and JRC,

Table 2 Descriptive statistics

Dependent variable	Min	Max	Mean	Std. Dev
Farm-level food security index	34.14	78.64	56.83	10.08
Independent variables	Min	Max	Mean	Std Dev
Age (years)	25.00	81.00	49.89	10.35
Education (years)	5.00	18.00	9.71	3.64
Family size	1.00	10.00	3.79	1.29
LSU	6.8	467.1	61.66	66.15
Fodder crops area (daa)	0.00	508.33	95.79	103.96
Technical efficiency	0.26	1.00	0.81	0.19
	Type of variable	Description	Frequency	%
Non-agricultural income	Dichotomous	0: No	61	48.41
		1: Yes	65	51.59
TV	Dichotomous	0: No	71	56.35
		1: Yes	55	43.65
Marketing channel for milk	Dichotomous	0: Private sector	76	60.32
		1: Agricultural cooperatives	50	39.68
Credit use	Dichotomous	0: No	62	49.21
		1: Yes	64	50.79
Knowledge of food security	Dichotomous	0: No	95	75.40
		1: Yes	31	24.60
Crop production	Dichotomous	0: No	32	25.40
		1: Yes	94	74.60

2008; Jiménez-Fernández et al., 2022). First, the UA describes the uncertainty in the model output, then the SA investigates components of this uncertainty by attributing them to their sources. In summary, SA leads to the conclusion that "factor x alone is responsible for y% of the uncertainty in the output" (Saltelli et al., 2019).

In this study, we performed four different methodologies under three approaches to check the robustness. In the first approach (methods i and ii), the calculation methods were changed while the other conditions (variables and dimensions) were kept constant. In the second approach (method iii), the conditions were altered but the computation methods remained the same. In the third approach (method iv), both the current conditions and the computation procedures were changed simultaneously.

i. UA based on Monte Carlo simulations,
ii. Variance-based global SA using quasi-random sampling of input factors and based on Monte Carlo simulations,
iii. Dimension and variable extraction approach,
iv. Sensitivity analysis based on Shapley effects.

First, the impact of the different sources of uncertainty on the FFSI ranking of the farms (shift in ranking, $\overline{R}_S$), was determined by the UA and the underlying reasons were addressed by the SA. There were two uncertainty factors in the UA and SA models: X_1 and X_2. X_1 represents two different normalisation methods; X_{11} is the min–max method and X_{12} is the alternative, z-score method. X_2 is the approach of weighting. To measure the robustness of the FFSI values to different weighting procedures, the reference weights of each variable and dimension were recalculated with a 25% increase or decrease in the weight. This means ± 25% variation of the weights around the original/reference values (Becker, 2021b; Thomas et al., 2017). We performed both analyses using Monte Carlo (MC) simulations, the number of simulations was 1000 and bootstrapping was performed 1000 times to calculate confidence intervals. In short, MC rescaled the weights (100% in total) and recalculated the FFSI scores a million times.

After calculating the main effects of the input factors (X_1 and X_2), the uncertainty from the interaction between the two is also revealed by the total effect sensitivity indices (S_{Ti}). The general formula for the two indices is given below. For procedures and details on UA and SA, see Saltelli (2002), Saisana et al. (2005), Saisana and Saltelli (2008), Saltelli et al. (2010) and Jaxa-Rozen et al. (2021).

$$S_i = \frac{V_{X_i}\left(E_{\mathbf{X}_{-i}}\left(Y \mid X_i\right)\right)}{V(Y)} = \frac{V_i}{V(Y)}$$

$$S_{Ti} = \frac{E\left[V\left(Y \mid X_{-i}\right)\right]}{V(Y)}$$

where V(Y) is the unconditional variance of y, obtained when all factors X_i are allowed to vary, $E_{\mathbf{X}_{-i}}\left(Y \mid X_i\right)$ is the mean of y when one factor is fixed (Saltelli et al., 2019).

The effect of excluding each dimension and each variable on the $\overline{R}_S$ was then analysed through iterations. Therefore, after four iterations for each dimension and 23 iterations for each indicator, the new FFSI scores of farms were calculated, and they were re-ranked. This method is an alternative and useful way of determining the impact or importance of the indicators in the index (Becker, 2021a).

Finally, the FFSI scores (outputs) were recalculated using different weighting, aggregation, and dimensioning approaches. In this analysis, seven different sources of uncertainty (X_{11}, X_{12},…., X_{nm}), grouped into three groups (X_1, X_2, X_3), are simultaneously included in the model. The first group of uncertainties (X_1) are alternatives to the arithmetic mean method used in equal weighting: geometric mean (X_{11}) and harmonic mean (X_{12}). The second (X_2) source of uncertainty is the equal weighting of all the variables instead of the PCA weighting. In the third group, each dimension was removed from the FFSI for recalculation; 4th dimension was removed for X_{31}, 3rd dimension was removed for X_{32}, and so on.

The original FFSI and these seven new scores were created by solving the "same multidimensional problem" with very similar, but theoretically "different" approaches. In this case, it is inevitable that output and inputs are highly correlated. Recent research has suggested using Shapley effects sensitivity analyses if there are correlated and dependent inputs, and there is increasing interest in this technique (Goda, 2021; Heredia et al., 2022; Idrissi et al., 2021; Owen & Prieur, 2017; Razavi et al., 2021; Song et al., 2016; Xiao & Duan, 2016). The Shapley effect, which is based on game theory, is a method of attributing the effect of a group of correlated inputs on output to each of the inputs (Iooss & Prieur, 2019), as our study.

There are two methods for calculating Shapley effects; MC simulations (Song et al., 2016) and K-Nearest Neighbours (KNN) procedure if there is "given-data" as in our study (X_{11}, X_{12},…., X_{nm}). Hence, we used KNN algorithm. Details of this methodology can be found in several studies (Broto et al., 2020; Iooss & Prieur, 2019; Iooss et al., 2021), particularly in Iooss and Prieur (2019) and Idrissi et al. (2021). COINr (Becker, 2021a) and sensitivity (Iooss et al., 2021) R packages were used for analysis.

The limitations of the study can be divided into three aspects. Firstly, the interviews were conducted during the COVID-19 pandemic, which limited data collection. Secondly, FFSI was calculated using cross-sectional data and only provides a snapshot of dairy farms at a specific point in time. More comprehensive farm-level indices such as the FFSI have not yet been constructed, so the literature for discussing the results was limited. Secondly, constructing such a comprehensive indicator required the use of various techniques, including regression analysis, mathematical programming, and factor analysis. It is important to note that each method has its own limitations, which could affect the validity of the results.

4 Results and Discussions

4.1 Characteristics of Farmers and Farms

Table 2 shows the general characteristics of farmers and farms. The farms are classified into five different groups based on the number of dairy cows they have. The first group includes farms with 5–9 cows, the second group includes farms with 10–19 cows, the third group includes farms with 20–49 cows, the fourth group includes farms with 50–99 cows, and the largest group includes farms with more than 100 cows.

The average age, farming experience and school year are 49.9, 26.6 and 9.7 years, respectively. The level of education tends to increase with the scale of the farm. The average years of education for the five farm scale groups are 8.5, 8.7, 9.2, 10.5, and 12.2, respectively (Kruskal–Wallis, p 0.001 < 0.01). The average family size is 3.8 and 58.7% live in villages; 63.5% are members of the Agricultural Development Cooperative and 75.4% are members of the Cattle Breeders' Association of Turkey. Farmers are on average members of 2 farmer organisations, 1.8 in the smallest group (5–9 cows), 2.1–2.5 in the medium groups (10–99 cows) and 1.6 in the largest group (more than 100 cows) (Kruskal–Wallis, p 0.018 < 0.05).

The primary sources of information are people in one's own social circle, such as family, friends, and other farmers (68.3%), followed by television (43.7%) and the internet (27.8%). Younger and more educated farmers prefer to use the internet as a source of information, while farmers of middle age tend to use television. Only 20.6% are aware of the concepts of food security and 46.0% of food safety. Only 20.6% of farmers have an agricultural advisor and 45.2% keep records of agricultural production. The average number of dairy cattle is 56.5 for those who keep agricultural records and 33.7 for those who do not ($p = 0.042 < 0.05$). In other words, while between 27.3% and 32.1% of the first three groups keep records, 53.6% of the fourth group and 77.3% of the largest group do so (χ^2 15.185, p 0.004 < 0.01).

In the short term, only 20.6% have plans to increase the number of animals. 50.8% of farmers have used livestock credit in the last year and 57.9% have full access to financial resources. Only 21.4% of the smallest group have full access to finance, with just 10.7% having used credit. In contrast, a much larger proportion of the largest group, 68.5%, have full access to finance and all have used credit. There is a significant difference in access to finance and credit between the farm scale groups (credit use, χ^2 54.574, p 0.000 < 0.001, financial resources χ^2 36,326, p 0.000 < 0.001).

Overall, 85.7% of farmers perceive cost rises to be the most significant and pressing issue to solve. All of them are having financial difficulty buying basic inputs, particularly feed. For this reason, 40.7% of them have reduced the use of factory feed, 18.6% of them have reduced the use of meal, 24.4% of them have reduced the use of both factory feed and meal and 16.3% of them have reduced the amount of all feed. The main problem with sales and marketing is the low price and the lack of an effective farmer organisation.

The size of the herd on farms ranges from a minimum of 10 to a maximum of 665 head, with an average of 78.14 head. The average LSU is 61.7, the average number of dairy cattle is 44.0 and 79.3% of LSU are dairy cattle. The average barn capacity is 98.13 head, and the average capacity utilisation is 77.0%. The average daily milk yield is 20.7 L, and the lactation yield is 5,841 L. The milk yield consistently increases with scale, with values of 19.0, 20.1, 19.9, 21.0, and 24.1 L per day, respectively (p 0.000 < 0.001). The farms also grow fodder crops on an average area of 9.58 ha, with the most popular crops being wheat, barley, and maize.

In Turkey's dairy farming, various support instruments are implemented, including those based on output and input (e.g., calf support, fodder crop support, milk premiums, and support for disease-free and certified farms). Financial and investment support is also provided. However, studies on the effects of policies on farms indicate that the impact is positive but minimal (Koç & Uzmay, 2022a, 2022b; Uzmay & Çınar, 2016). This situation can be explained by several factors, including delayed payment, non-utilisation of subsidy payments on farms due to economic or other problems, and inadequate follow-up. This study asked farmers if they would continue production without subsidies. About 30% of farmers said they would not continue without support. The highest rate of farmers who would not continue without subsidies was found in Group 4, with 46%.

The average technical efficiency scores are 0.812 CRS, 0.867 output-oriented and 0.889 input oriented VRS. The average technical efficiency scores are 0.812 CRS, 0.867 output-oriented and 0.889 input oriented VRS. The efficiency scores increase as the size of the farm increases and difference between the groups is significant (Kruskal–Wallis, CRS p 0.013 < 0.05, VRS-OO p 0.041 < 0.05, VRS-IO p 0.027 < 0.05). The mean TE scores for the smallest to largest groups in the CRS model were 0.74, 0.75, 0.82, 0.86, and 0.92, respectively. The minimum efficiency scores in the first four scale groups (99 heads and below) decreased to 0.262. Notably, the lowest efficiency score in the largest group (100 heads and above) was 0.734. To put it differently, while half of the farms in the largest group (100 or more heads) are fully efficient, this proportion decreases to between 18.2 and 32.1% for smaller farms.

Milk is mainly sold to cooperatives (39.7%) and modern dairies (33.3%). On average, only 38.1% of farms have a built-in milk cooling tank. The majority of these farms (40 out of 48) are in the two largest farm scale groups. Regular veterinary controls are carried out on 56.3% of the farms. It is important to note that the regular control rate for the small and medium-sized groups is 30.8–50.0%, while for the two largest groups it is 78.6–95.5% (χ^2 33.247, p 0.000 < 0.001). Furthermore, 27.8% of farms have milk loss owing to mastitis, 24.6% due to antibiotic use, 18.3% due to various incidents, and 10.30% while milking.

At high temperatures, 90.5% of farmers reported that dairy cattle were affected by climate change and suffered from heat stress, 80.2% reported reduced feed intake and 84.9% reported reduced milk yield. During the hot summer months, daily milk production decreases by 3.6 L per cow. To mitigate these effects, 88.9% of farmers have at least one climate change adaptation measure. The most common adaptation methods are seasonal change of feed ration (68.3%) and the use of supplementary feed additives (78.6%). The proportion of farms with air conditioning is 43.7% and the proportion with livestock insurance is 47.6%. The rate of adaptation generally increases with the scale of the farm, and these results support the literature (Koç & Uzmay, 2022b; Opiyo et al., 2016). For example, 50.00% of farmers in the smallest group, 57.69% in the second, 60.71% in the third, 86.36% in the fourth, and 86.36% in the largest group adjust their feed ration seasonally (χ^2 20.180, p 0.000 < 0.001). Likewise, cooling systems were present in 17.86% of farms in the smallest group, 19.23% in the second, 31.14% in the third, 81.82% in the fourth, and 95.45% in the largest group (χ^2 51.611, p 0.000 < 0.001).

4.2 Results of Farm-Level Food Security Index

Table 1 shows the weights for the FFSI indicators. The production value and self-sufficiency are the indicators with the highest weight on the first dimension, milk losses on the second, education and extension on the third and biodiversity and insurance on the last.

Although prior studies differ in terms of the products and locations covered, the number of factors included in the index, as well as the goal and methodology, some basic comparisons and discussions may be made. In the Dairyman sustainability index for north-west Europe, for example, equal weighting was used between dimensions and differential weighting within dimensions, as in this study (Elsaesser et al., 2015). In the economic dimension of the study, production value and dependency on subsidies had a weight of 22% and 10%, respectively, among the five variables. In our study, the economic dimension consists of seven variables, the weight of the production value is 16.3% and the weight of the dependency on subsidies is 13.1%. Moreover, the weight of the education variable in this research (22%) is the same as in aforementioned, and the weight of the willingness to continue production is quite similar. In a monitoring tool for integrated farm sustainability (MOTIFS) developed by Meul et al. (2008) in Belgium, both dimensions and variables are weighted equally. The weight of the production value was calculated as 12.5%, which is lower than our study. Biodiversity has a weight of 33.3% within the environment dimension, similar to this study (32.5%). According to the Indicateurs de Durabilité des Exploitations Agricoles (IDEA) method, which was designed with 41 indicators to demonstrate the sustainability of agribusiness, the food safety variable is included in the socio-regional dimension and has a weight of 12%, while the biodiversity variable has a weight of 13% in the agroecology dimension (Zahm et al., 2008). Several studies have adapted the IDEA approach and its weights to animal production; dairy in Algeria, Tunisia and Mexico (Attia et al., 2021; Bir et al., 2019; Fadul-Pacheco et al., 2013; Ikhlef et al., 2015), sheep in Morocco (Araba & Boughalmi, 2016), and livestock in Romania (Gavrilescu et al., 2012).

The FFSI scores of the farms are a minimum of 34.1, a maximum of 78.6 and an average of 56.8 ± 10.1. As the farm scale increases, so do the index scores, with an average of 51.2 in the smallest group and 63.7 in the largest (Kruskal–Wallis, p 0.000 < 0.05). The FFSI scores were 49.3 for the first dimension, 61.5 for the second dimension, 61.8 for the third dimension and 54.7 for the fourth dimension (Table 3). Self-sufficiency, reduced input consumption, and decreased yields are the factors that lowered the FFSI scores in the first dimension. The low rate of carrying out quality analyses and consequently getting the quality premium decreased the scores in the second dimension. The farmers' willingness to increase milk production and their technological adaptability, as well as the low insurance rate, are also the most important variables that negatively affect the index scores.

Small-scale farms (5–9 head and 10–19 head) received high self-sufficiency scores in the first dimension, while a higher capacity utilisation increased scores in medium-sized farms (20–49 head and 50–99 head). Large-scale farms (100 head and above) have high

Table 3 FFSI scores by dimensions and farm scale

Farm-scale	1. Economy, production and marketing	2. Quality and food safety	3. Social sustainability	4. Natural resources and climate change	FFSI
5–9 head	47.85	47.65	56.34	52.96	51.20
10–19 head	50.43	50.57	60.88	57.21	54.77
20–49 head	47.86	55.85	65.41	60.56	57.42
50–99 head	45.15	74.97	63.16	51.94	58.80
100+head	55.61	85.90	64.03	49.26	63.70
General	49.27	61.52	61.83	54.70	56.83
p	0.076***	0.000*	0.478	0.005*	0.000*

Kruskal–Wallis, *$p<0.01$, **$p<0.05$, ***$p<0.1$

production values and complete access to financing sources, but their self-sufficiency scores and capacity utilisation rates are lower than others. In the second dimension, the scores of farms in groups 4 and 5, which have a milk cooling tank and receive a quality premium by producing higher quality and using marketing advantages, are quite high compared to others. In the third dimension, the scores for the variables residence, membership, willingness to continue and increase the production are higher in small and medium-sized farms, while the scores for the variables education, extension and adaptability are higher in large farms. In the fourth dimension, scores are lower in large farms with less biodiversity and no crop production, resulting in less frequent following of meteorological warning systems.

Farms' economic sustainability scores range from 0.51 to 0.82 on a four-dimension index for four different dairy systems in the Netherlands, while internal and external social sustainability scores range from 0.35 to 0.86 and environmental sustainability scores range from 0.60 to 0.74. In contrast to our findings, it was discovered in the Netherlands that small family farms (low-cost) have higher scores than large farms (high-tech) (van Calker et al., 2006). In an Italian study, where most of the sample consisted of livestock farms, the average scores for the economic dimension were 56.6 (141.5 out of 250), the social was 42.8 (107 out of 250), and the environmental was 38.0 (95.1 out of 250) (Gaviglio et al., 2017). In Poland, livestock farms had Synthetic Farm Sustainability Index scores of 0.60 in the economic, 0.51 in the social, 0.54 in the ecological dimensions, and 0.49 overall (Majewski, 2013). Our study is also comparable to the average sustainability index score of 62 for livestock farms in Spain (Franco et al., 2012) and 58 for extensive cattle and sheep farms in southern Chile (Avilez et al., 2021).

Tunisian livestock farms scored 63.5 in the agro-ecological, 54.2 in the socio-regional, and 63.6 in the economic dimension, according to the index scores determined using the IDEA approach (Attia et al., 2021). A similar study carried out in Mexico using an IDEA method revealed that the farms obtained 59 points in the agro-ecological, 53 points in the socio-regional, and 43 points in the economic dimensions (Fadul-Pacheco et al., 2013), and also the average sustainability score of the ten small dairy farms studied in the same country was found to be 55.3 (Torres-Lemus et al., 2021). In dual-purpose livestock farms in Mexico, the scores according to the IDEA approach are 60 in the economic, 73 in the socio-regional, 87 in the agro-ecological dimension and 73 overall (Salas-Reyes et al., 2015). In organic and conventional dairy farms in Mexico, the sustainability index scores range between 45.2 and 61.7 (Nahed et al., 2019).

It is noteworthy that the results of the farm-level index can differ significantly between studies carried out in the same country and using similar methodologies.

In Algeria, Bir et al. (2019) reported that the average agricultural sustainability score of dairy farms was 47, with the highest scores in the agro-ecological (56) and the lowest in the economic dimension (54). Ikhlef et al. (2015) calculated 46 for the agro-ecological dimension for the same country, using a similar methodology. In Peru, in the index designed for small livestock farms, farms had an average score of 40.5 (1.62/4.00) in the economic, 35.3 (1.41/4.00) in the environmental, 54.0 (2.16/4.00) in the social dimension and 43.0 in general (Heurck et al., 2020). Integrated dairy and horticultural farms in Indonesia have 29.5 for the economic, 27.4 for the social and 28.1 for the environmental dimension (Rosmiati et al., 2020). These results are lower than the scores calculated in our study as well as in other countries.

4.3 Results of Tobit model

According to the results of the Tobit model, the age and years of education of the farmer, credit usage, the LSU, the area under forage crops and the milk sales channel have a significant effect on the index scores (Table 4).

A one-year increase in the farmer's age lowers the index score by 0.17 point, while an increase in education raises the index score by 0.51 point. In fact, farmers with a primary education have an average score of 50.6, while those with a secondary education have a score of 60.5, and those with a university education have a score of 63.6 (Kruskal–Wallis, p 0.000 < 0.001). These findings are consistent with the literature (Gunduz et al., 2011; ul Haq and Boz, 2020).

The use of livestock loans improves the FFSI score, increasing it by 3.51 points when compared to non-users. The average score for loan users is 60.30, while non-users have a

Table 4 Results of tobit model

	Marginal affects	Standard error	t	*p*
Age	− 0.17273569	0.095601	− 1.811	0.070***
Education	0.51364259	0.254664	2.021	0.043**
Family size	− 0.45723407	0.566329	− 0.809	0.418
Non-agricultural income	− 1.39194707	1.534817	− 0.909	0.363
LSU	0.02445684	0.013699	1.789	0.074***
Fodder crops area (daa)	0.02398719	0.007638	3.147	0.002*
TV	1.50197103	1.517181	0.992	0.321
Credit use	3.51076911	1.661605	2.117	0.034**
Technical efficiency	2.29592517	1.556872	1.478	0.139
Knowledge of food security	1.92732440	1.776465	1.087	0.277
Crop production	2.96098466	2.213295	1.341	0.180
Marketing channel	− 3.30707200	1.471212	− 2.253	0.024**
Constant	–	6.510778	8.268	0.000*

Log-likelihood: −423.566, Wald-statistic: 122.9, 12 df, p: 0.000*, AIC = 875.1319, BIC = 914.8399, *$p < 0.01$, **$p < 0.05$, ***$p < 0.1$

score of 53.25 (Mann–Whitney U, p 0.000 < 0.001). This is because the FFSI scores are higher in farms that have easier access to financing. Additionally, farmers who receive information from television (57.70) and those who do not (56.49) have remarkably similar FFSI scores. This situation shows that visual media alone are insufficient to motivate farmers to improve their production, economic situation, quality, etc.

Farms marketing milk through cooperatives have an index score that is 3.31 points lower than the private sector. In fact, there is a statistically significant difference between those selling to cooperatives (52.89) and private sector (59.42) (p 0.000 < 0.001). This is related to the age and education level of farmers and the size of the farm. For example, while the average age of those marketing milk through cooperatives is 51.54 years and the number of dairy cows is 22.02, the average age of those selling milk to the private sector is 48.80 and the number of dairy cows is 58.50.

Each 10-unit increase in LSU and each 10 decares increase in forage area increases the index score by 0.24. The results are in line with the literature (Chand et al., 2015; Gaviglio et al., 2017; Gavrilescu et al., 2012). For example, for Indian dairy farms, the scores of the economic dimension are 21.7 for small and 36.7 for large farms (Chand et al., 2015).

The TE score has a positive but insignificant impact on the index score. There is a positive but very weak correlation (0.14). This is because some of the fully efficient farms have an index score as low as 35, while some of the less efficient farms have index scores above 70 (Fig. 1). The correlation coefficients between CRS TE and FFSI vary depending on the scale size. The correlation coefficient is -0.085 in the smallest group, −0.002 in the second group, −0.022 in the third group, -0.180 in the fourth group, and 0.359 in the largest group. These results indicate that the low correlation in the overall scores (0.14) is due to the small and medium-sized (less than 49 head) farms. Small and medium farms, even if they score well on the FFSI, may experience inefficiencies in input utilisation and management. On the other hand, farms that have succeeded in achieving technical efficiency may fail in social and environmental aspects. Larger farms (with 50 or more head) tend to perform better in terms of efficiency and FFSI scores. Enhancing TE is a crucial element that needs to be considered for improving farm performance to contribute to food security, as it reflects farmers' ability to generate maximum food production by utilising minimum inputs. Boosting TE is essential for increasing availability at both micro (farm) and macro (regional) levels. Nonetheless, it is worth noting that achieving full efficiency (DEA score of 1) does not provide a comprehensive measure of other significant aspects of food security.

4.4 Results of Uncertainty and Sensitivity Analysis

According to the UA results (Fig. 2), the shift in the ranking ($\overline{R}_S$) is less apparent for the farms with the highest (top ranking) and lowest (bottom ranking) scores and more pronounced for farms with intermediate scores. The results are consistent with prior research (OECD and JRC, 2008; Thomas et al., 2017; Diebold, 2022).

The results of the SA carried out to investigate the sources of this uncertainty in the FFSI are given in Table 5. The first order sensitivity indices (S_i) are 0.73 for normalisation and 0.05 for weighting. Total effect sensitivity indices (S_{Ti}) are 0.89 for normalisation, and 0.17 for weighting.

Normalisation alone accounts for 73.33% ($S_i = 0.73$) of the total uncertainty in the index, while weighting accounts for 5.28% (Fig. 3). The difference between S_i and S_{Ti}

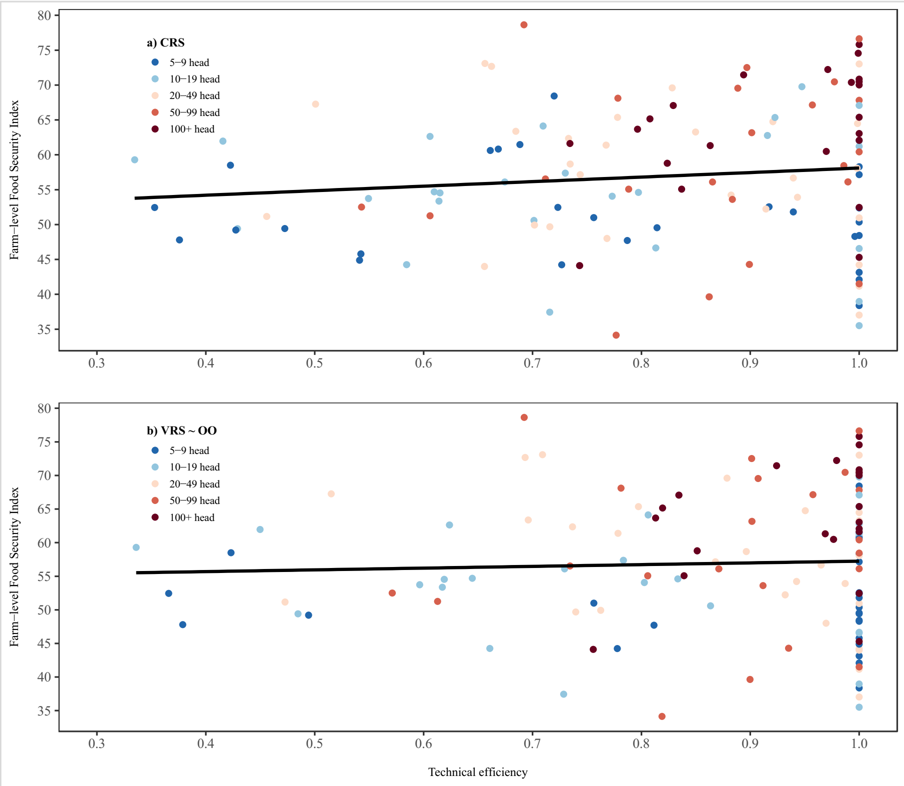

Fig. 1 Relationship between TE and FFSI scores

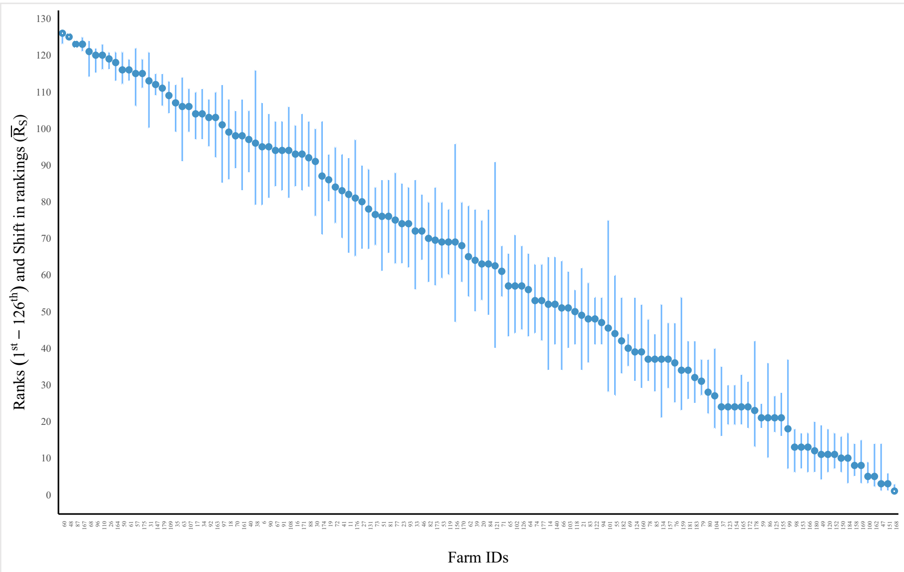

Fig. 2 Results of Uncertainty Analysis

Table 5 Results of Sensitivity Analysis: S_i and S_{Ti}

	S_i	S_{Ti}	$S_{i\_}Q5$	$S_{i\_}Q95$	$S_{Ti\_}Q5$	$S_{Ti\_}Q95$
Normalisation	0.73	0.89	0.56	0.90	0.82	0.95
Weighting	0.05	0.17	0.01	0.12	0.16	0.18

gives the effect of the interaction of the two inputs on the uncertainty. For example, the total effect of normalisation is 88.85% ($S_{Ti}=0.89$), of which 73.33% is the main effect and 15.52% (S_i–$S_{Ti}=0.16$) is the effect of the interaction of the two factors. In short, 21.39% of the uncertainty is due to the interaction between normalisation and weighting (Fig. 3).

The correlation coefficient between the original and seven alternatives (based on uncertainty groups X_1, X_2, X_3) is high, 0.90 and more. Even so, according to the Shapley effects sensitivity indices (Sh_i), the methodological choice that most affects the FFSI scores is to aggregate the dimensions using the geometric mean ($Sh_i=0.165\pm0.002$) rather than the arithmetic mean, or to weight each variable equally ($Sh_i=0.156\pm0.002$) (Fig. 4).

Furthermore, the results of the dimension extraction approach show that the removal of the social sustainability dimension from the index can lead to a shift of 17.9 in the $\overline{R}_S$. The $\overline{R}_S$ for the other dimensions are as follows; 12.2 for the first, 16.8 for the second and 16.4 for the fourth. In the variable extraction approach, the variables that could cause the largest shifts in the ranking were found to be biodiversity and farmers' knowledge of food safety.

As a result, when the weight of each variable or dimension in the index is randomly reduced or increased by 25%, there is no significant effect on the index scores and farm ranking. In this context, FFSI can be said to be resistant to the established weights. Ibok et al. (2019) reported that using equal weights across dimensions produces unbiased results by ensuring consistent scores and rankings in their analyses for the Vulnerability to Food Insecurity Index, which supports the findings of our study. However, using z-score normalisation instead of min–max has a stronger effect. The normalisation method was discovered to be the second most important source of uncertainty after missing data imputation in the

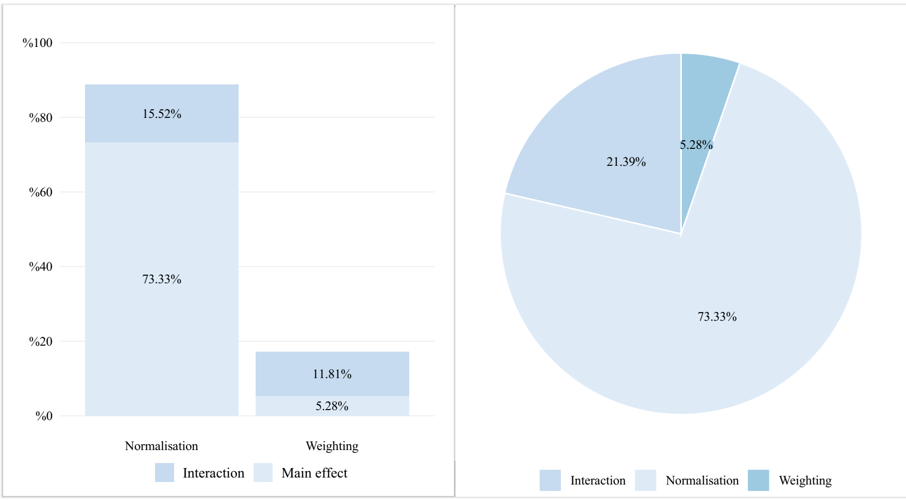

Fig. 3 Results of sensitivity analysis

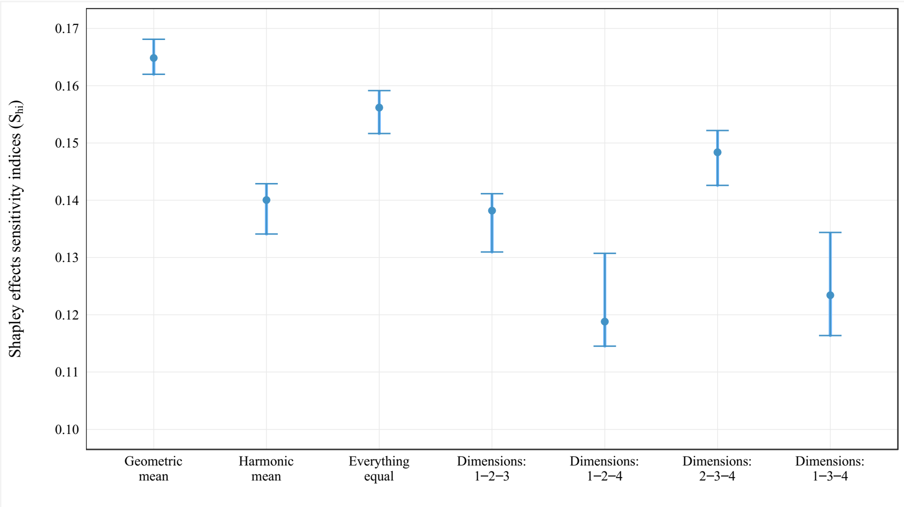

Fig. 4 Shapley effects sensitivity indices

SA conducted by Caccavale and Giuffrida (2020) for the Proteus Global Food Security Index. Weighting is one of the least important factors, and the findings are similar to those of this study. Moreover, the factor with the highest S_i in the European Commission ASEM Connectivity Index results is also the normalisation method (Becker, 2021b).

5 Conclusions

The developed FFSI is a comprehensive composite indicator that combines a variety of data points to provide a comprehensive approach to food security at the farm level, the first and most important link in the food supply chain. It can also be used as a reference tool for future research and can be applied in various regions and for variety of products. Each dimension of the FFSI can be used to identify priority areas for attention and improvement in agricultural policy development.

The main finding of the FFSI is that dairy farms in Thrace are not using 43.2% of their potential to contribute fully to food security. Farms scored lowest in economy, production and marketing dimension (first dimension), and this result confirms the first hypothesis of the study (H_1). The variables with a high share in FFSI weighting in this dimension are self-sufficiency, production value, yield stability, and input use. The results obtained for these variables differ according to the farm scales. Farms with 20–99 cows (3rd and 4th groups) experienced a significant decrease in input use, resulting in a negative impact on their production levels. Furthermore, almost half of the farmers belonging to group 4 (which have 50–99 cows) stated that they would be unable to sustain production without subsidies. The group with the lowest self-sufficiency score was the large-scale farms in group 5, which had a low rate of forage crop cultivation. In this context, it is evident that agricultural policies should vary based on the scale of the farm. Increasing support for farms that reduce inputs and facilitating diversified access to finance for these farms is important. Encouraging the development of a risk management plan to prepare for potential unexpected situations is also recommended. Efforts should be made to implement policies that incentivise or require the largest farms, which generally have no forage area of their own but score high on all other FFSI indicators, to grow a certain proportion of forage crops. In Turkey, past incorrect policies allowed non-agricultural individuals to exploit credit policies, including zero-interest credit schemes, to establish large-scale farms. However, they later abandoned agriculture. In this context, it is crucial to support small and medium-sized farms that have been engaged in farming activities for years and are able to grow their own fodder crops in sufficient quantities, in order to enable these farms to increase in scale. Organising seminars and workshops to improve their financial literacy and management skills could be beneficial. These activities should cover topics such as budgeting, income and expenditure analysis, profitability, cost–benefit analysis, and return on investment to optimize resource allocation.

In the quality and food safety dimension, farms in the first three groups (5–49 heads) had a negative impact on the FFSI score. One of the primary issues on these farms is a lack of awareness of food safety, coupled with a widespread lack of availability of cooling tanks and quality analysis. Although analyses have been carried out, farmers often do not follow-up on the results. In this context, it is important to increase inspections, particularly for the farms in the first three groups, and to provide milk premium support primarily based on quality. To reduce yield loss and food waste caused by animal diseases and antibiotic use, farmers should receive regular information and support on preventive health practices. Additionally, early warning systems should be developed to identify potential animal health risks in the region.

It is important to note that the farms have a low level of adaptation to technology in social sustainability (the third dimension). Additionally, specialised co-operatives for milk marketing are ineffective in the market. To address this issue, it is recommended that specialised co-operatives related to dairy farming are developed in the region and that incentives are provided for these co-operatives to set up their own processing facilities and enter the market.

Improving on-farm adaptation and promoting climate-smart dairy farming practices can enhance both yield and quality, thereby increasing availability. One of the most crucial practices is to modernise existing barns to provide a more comfortable environment for cattle in hot conditions. This can be achieved through the installation of climate-controlled ventilation systems, insulation, and cooling mechanisms. To implement these practices, farms should be provided with technical support for project designs, investment loans for suitable projects, and machinery loans for modernising barns and providing suitable environmental conditions. Furthermore, it is essential to improve existing early-warning systems to include livestock production. Clear and practical warnings must be provided to farmers, especially during hot or extreme weather, to enable them to make informed management decisions regarding feeding, milking, and animal health.

The Tobit model results reveal the importance of education and youth involvement in agriculture. Uncertainty and Sensitivity Analysis results show that social sustainability dimension leads to the highest shift in rankings. These results from different analyses are consistent, demonstrating that, even if farms produce the highest quality products by utilising economic opportunities and natural resources in the best way, their contribution to food security will be limited if their production is not continuous, lacks progressiveness, or is socially unsustainable. Thus, policies in the region should focus not only on economic aspects but also on social sustainability. Ensuring that young people in the region participate in agricultural production or continue to work on family farms is crucial for stability of food security. To this end, rural development policies should support youth participation in agriculture and increase support specifically targeted at youth. Grant programmes, such as grants for agricultural equipment or livestock, are a type of support that can incentivise young people. One-to-one mentoring and peer support are other methods of encouraging young people. These methods are useful for young farmers to acquire skills in technical issues (animal health, food safety, etc.), better management, marketing, etc.

Furthermore, both the Tobit and correlation analysis results show a positive but insignificant relationship between technical efficiency and FFSI scores. The research hypothesis (H_2) was confirmed by this result. The FFSI, in contrast to the efficiency analysis, is a much broader indicator that includes not only the potential of farms to increase output with available inputs, but also the quality of production, the efficient use of natural resources, and the farm's sustainability. In this context, farms with low efficiency scores should first achieve full efficiency. Farmers should be able to benefit effectively from financial resources, training and extension, insurance, and organisations on farms that are fully efficient but have low FFSI scores.

The results of the robustness tests indicate that the weighting method has no significant effect on the index scores or farm rankings. However, the normalisation method has a notable impact on farm rankings. Therefore, it can be concluded that the FFSI is resistant to established weights but sensitive to normalisation methods.

For future research, it is suggested that FFSI scores should be assessed in different regions and for different agricultural products at certain periods of time. This will enable inter-regional comparisons in dairy cattle farming, systematic follow-up of farm-level developments, and the generation of alternative policies. As long as the overall structure of the FFSI is maintained, new studies may include regional or product-specific variables and reassess the importance of existing variables. It is important to consider that the FFSI results are influenced by external factors such as the environment, natural resources, market fluctuations, and the political atmosphere, in addition to farmers' own decisions and circumstances.

Appendix

This appendix provides a full description of the FFSI variables mentioned in Sect. 3.2 and Table 1. It describes their sources, usage in the literature, and relevance to our research.

The first variable in the first dimension is the ***production value***, which is frequently used in farm-level indexes (Franco et al., 2012; Paracchini et al., 2015; Ryan et al., 2016). This variable is included in the FFSI to represent the productivity of the inputs (livestock) used to produce the economic output (Paracchini et al., 2015; Ripoll-Bosch et al., 2012). The production value per livestock unit (LSU) was calculated by dividing the total income of the farms by the LSU. ***Self-sufficiency*** is a measure of the capacity of farms to be self-sufficient, their ability to meet their basic input needs from their own resources rather than from purchased inputs and is a variable that has been included in previous studies (Nahed et al., 2019; Ripoll-Bosch et al., 2012, 2014; Roy & Chan, 2012). In the context of FFSI, self-sufficiency refers to the level of dependency of farms on external feed sources, as described in Ripoll-Bosch et al. (2012), Nahed et al. (2019) and Paraskevopoulou et al. (2020). A farm's dependence on external feed affects its sensitivity to input availability and price fluctuations (Latruffe et al., 2016). ***Capacity usage ratio*:** ensuring that farms operate at full capacity, have no idle capacity and maximise food supply by using all means of production is very important for ensuring food security. Ceyhan (2010) used a ratio measuring the amount of unused land on crop farms. This study used the ratio of current animal assets to the maximum barn capacity as a measure of capacity utilisation rate. ***Yield stability*** is an important indicator of the stability of farms' ability to contribute to food security; maximising productivity and minimising yield variability is a prerequisite for ensuring income stability and thus enabling farms to continue agricultural production. Yield stability is used as a measure of economic viability (Rasul & Thapa, 2004) and income fluctuation (ul Haq and Boz, 2020) in the literature. In addition, this study also considers it as representative of the stability dimension of food security. ***Subsidy dependency*** or independence is a variable that may lead to a reduction (or abandonment) of production in a situation that is potentially undesirable in relation to subsidies, with a consequent negative impact on food security. In short, if farms rely heavily on public support, decreased subsidies may jeopardise production (Latruffe et al., 2016). This variable is also included in the previous indices (Elsaesser et al., 2015; Galdeano-Gómez et al., 2017; Gavrilescu et al., 2012; Ripoll-Bosch et al., 2012, 2014). ***Access to finance***; the availability of different financial resources is crucial for farmers to improve their existing production capabilities or to adopt new practices (Dantsis et al., 2010) and has been included in previous studies (Allahyari et al., 2016; Bosshaq et al., 2012; Galiè et al., 2018). As timely credit support supports farmers in meeting their overall credit needs throughout production (Suresh et al., 2022), this study used existing financial services as described in Galdeano-Gómez et al. (2017) as a proxy for financial security (Sharma & Shardendu, 2011). ***Input use;*** one of the main obstacles to achieving maximum efficiency in production is the fact that farmers have problems in accessing basic inputs and therefore have to limit their input use or stop using some inputs (factory feed, meal, etc.).

The assurance of the safety and quality of raw milk is critical to the achievement of the utilisation dimension of food security. This reduces food losses, increases food supply, and contributes to food security (Demirbaş et al., 2009; Vipham et al., 2020). As the safety and quality of milk products depend on various production processes at the farm level, the second dimension of the FFSI focuses on five key variables that represent or influence milk safety and quality. ***Milk loss*** variable calculates the loss of milk production caused by non-compliance with food safety regulations, such as udder infections and other diseases, use of antibiotics, high somatic cell count, or spoilage of milk. The ***quality assessment*** shows whether farmers carry out the necessary analyses relating to the nutrient composition and quality of the milk, such as fat, protein and bacterial counts, and whether they follow up these analyses regularly, as in Paraskevopoulou et al. (2020). The ***quality premium*** is included in the index to measure whether producers receive additional payments or premiums from sales channels according to the quality values of their products. These two quality related variables are incentives for producers to produce higher quality agricultural products, also contribute positively to agricultural income, the economic situation of the farm and the availability dimension of food security. The presence of a **milk cooling tank** is another crucial indicator of quality protection, as it ensures that transporting the milk to the processing plant without breaking the cold chain is essential for food safety (Kazancoglu et al., 2018). Finally, the ***knowledge*** variable was added to this dimension because farmers' awareness of food safety plays a crucial role in ensuring milk safety (Demirbaş et al., 2009; Ledo et al., 2021).

The third dimension, that farmers have access to technical ***training*** on agricultural production, such as courses, certificates, etc., as well as access to and participation in ***extension*** activities, such as meetings, seminars, etc., is extremely important for the improvement of all dimensions of food security. These two variables have been widely used in previous studies (Kelly et al., 2015; Nave et al., 2013; Ryan et al., 2016; Valizadeh & Hayati, 2021;

Westers et al., 2017). Farmers' intentions to ***continue production*** in the future and their investment plans to ***increase production*** are important for both social sustainability and the stability of food security. A large body of literature has also included these variables (Bosshaq et al., 2012; Ripoll-Bosch et al., 2014; Elsaesser et al., 2015; Kelly et al., 2015; Lenerts et al., 2017; ul Haq and Boz, 2020). Farmers' ***adaptability*** refers to their ability to adopt and implement technical changes and improvements. Earlier indices also included the acts of technical capacity building and the adoption of new technological alternatives (Lenerts et al., 2017; Malak-Rawlikowska et al., 2021; Nave et al., 2013; van Calker et al., 2005; Westers et al., 2017). The continuity of farms and stability of food security are facing challenges due to the aging of farmers and the lack of interest among the younger generation in continuing farming (Bernues et al., 2011). In addition, the urbanization of the younger generation makes it harder to stay up with technology and innovation, threatening farms' sustainability and food security. To address this issue, the ***residency*** variable tracks whether the farmer and their family members remain in the village or migrate to the city, which is necessary for farm succession. ***Membership*** or participation in farmer organizations enables improvements in agricultural production, exchange of information, and collaboration along the supply chain, and has been widely used in various studies (Roy & Chan, 2012; Allahyari et al., 2016; Westers et al., 2017; Gaviglio et al., 2017; Heurck et al., 2020).

In the fourth dimension, natural disasters and risk ***insurance*** are included in the index. A high level of insurance is a variable that has been widely used in previous studies and is extremely important in minimising farmers' income losses due to unexpected external factors (Abdar et al., 2022; Allahyari et al., 2016; Nave et al., 2013). The FFSI also includes two variables, early warning systems and adaptation, which are used to evaluate farmers' responses to changing environmental conditions in order to minimize their impact on food security. ***Early warning systems*** measure whether farmers follow and comply with agrometeorological warnings issued by institutions and organisations. ***Adaptation*** measures the methods used on farms to adapt to climate change. Farmers were asked about various adaptation methods that can be applied, such as having an air conditioning system, changing ration seasonally, using additional nutrients or supplements, and the adaptation score was calculated by giving points for each item applied. Finally, ***biodiversity***, or food diversity as it is used in FFSI, was included in the index by calculating the number of agricultural products produced. Diversity is extremely important for the improvement of human health and food security, and has been used in many studies (Meul et al., 2008; Zahm et al., 2008; Gavrilescu et al., 2012; Roy & Chan, 2012).

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Declarations

Conflict of interest There is no conflict of interest.

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