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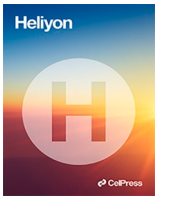

Adoption of on-farm feed safety practices among livestock farmers: Evidence from Saudi Arabia

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A B S T R A C T

Compliance with feed safety standards and practices on the farm promotes sustainable livestock production and can positively affect the environment and human health. This study aims to examine farmers' on-farm adoption of feed safety practices and determine the differences in adoption according to the socio-economic characteristics of farmers. An online survey was conducted to collect the study data. The study participants consisted of 442 livestock farmers in Riyadh region, Saudi Arabia. The study findings revealed that farmers highly adopted categories of feed purchasing (77.9 %) and feed mixing and distribution (75.05 %), whereas they were considered as a moderate level adoption regarding feed storing (70.9 %). The cluster analysis results showed two main patterns of adoption— "high adopters" and "moderate adopters"—based on the average level of adoption for 25 feed safety practices examined. The cluster of "high adopters" accounted for 59.9 % of the sample and had higher average adoption in all practices examined. The findings revealed that there are significant differences between the two segments of farmers, corresponding to gender, membership in livestock association, extension contact, raising sheep, and feeding system. This study proposes the regular monitoring of farms to ensure strict adherence to feed safety regulations, with the implementation of awareness and capacity development initiatives pertaining to feed safety concerns.

1. Introduction

Livestock plays a paramount role in food security and nutrition [1]. It represents a vital source of livelihood for value chain actors, and it is considered an essential source of nutrition for consumers [2]. According to the UN's Food and Agriculture Organization (FAO) [3], the significant contribution of livestock to food security and nutrition is connected to achieving two Sustainable Development Goals (SDGs); SDG2: zero hunger, and SDG3: good health and well-being. Livestock can support SDG2 by providing food (energy and high-value protein), traction and fertilizer for crop production, and generating an income [4]. Additionally, livestock can link to SDG3 by providing essential micronutrients, especially for children, women, and the elderly, and zoonotic diseases that could cause human pandemics [5].

Different types of meat (e.g., camel, cow, sheep, goat, and poultry) and eggs are produced in-house and open grazing farming in Saudi Arabia [6]. According to the Saudi's Agricultural Statistics report [7](GAS, 2023), the number of farm animals in 2022 reached

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about 21.4 million head of sheep, 6.7 million head of goats, 1.75 million head of camels, 336.000 head of cows, and around 5 million poultry and birds. Fresh dairy products came first in achieving self-sufficiency at 121 % in 2021, followed by table eggs and fish with rates of 112 % and 40 %, respectively. According to FAO's annual statistical report 2021 [8], grain crops represent 42.5 % of the total agricultural imports, while dairy products and eggs represent 23.5 % of agricultural exports. Moreover, Saudi Arabia ranked 10th in the livestock production index with an average index score of 142.8 in 2020. In the study area (Riyadh region), sheep represent approximately 43.5 % of the total livestock sector in the region in 2022, followed by goats (29.7 %), camels (21.3 %), and cows 5.5 %. Under the Saudi Arabian 2030 vision, the country aims to achieve sustainable protein production by overcoming water and feed availability challenges. The strategic objectives of the vision aim to transform the economy by using local investment power through improved management practices and apply technological developments to create a more sustainable domestic food supply in the country [9].

Based on livestock's social and economic values, access to sufficient, safe, and nutritious animal-source products that meet people's preferences and dietary needs is a major determinant for an active and healthy life [10]. Nevertheless, ensuring animal-source safety is a key component of food security [11,12]. Unsafe food impairs socioeconomic development by straining healthcare systems, harms national economies, tourism, and trade, and creates a vicious cycle of disease and malnutrition [12]. Therefore, actors in the livestock production chain have been increasingly adopting various food safety and quality assurance systems and standards to improve food control and traceability [13].

Animal feed is an essential component in the livestock production chain that affects the supply of livestock input and output [14]. Over the past decades, governments have regularly sought to implement and develop a diverse set of analytical and operational technologies through the feed supply chain to measure, maintain, and preserve feed from the presence of physical, chemical, or biological contaminants that have adverse effects on animal and human health [15–17]. Physical hazards include extraneous matter (hair, husk, bolts, stones, nuts, etc.), insect infestation, rodent excreta, and weeds [18,19]. Chemical hazards involve persistent organic pollutants (POPs), plant toxins, pesticide residues, organochlorine (OCs) residues, veterinary drug residues, and potentially toxic elements (PTEs) [19,20]. Also, biological hazards consist of mycotoxins, pathogenic microorganisms, hormones, and allergens) [19, 21].

To prevent or control conditions or factors leading to contamination, a holistic approach to animal feed safety management should be applied effectively [22,23]. International organizations have been developing feed hygiene regulations to ensure feed safety along the farm-to-fork continuum [24]. For instance, the Codex Alimentarius Code of Practice on Good Animal Feeding is an important regulation developed by FAO and the International Feed Industry Federation (IFIF) [19]. All stakeholders in the feed supply chain are required to comply with these guidelines. To control feed safety among the stakeholders along the feed supply chain at the local level, Saudi Food and Drugs Authority (SFDA) issued the feed act and regulations in 2017 [25]. According to these regulations, inspection campaigns are frequently organized to evaluate the compliance of feed operation and animal firms with the technical regulations or standards specifications. Furthermore, these regulations are used for registration of new feed products and obtaining approval for importing feed products. However, this study deals with feed safety at the farm level, and the farmers' compliance with these regulations.

Farmers' adoption of feed safety is a determinant to ensure they comply with feed safety guidelines [26]. Such practices involved various aspects, including feed purchasing, storing, record keeping, mixing, and distribution [19,25]. The adoption rate is affected by a variety of factors, including personal, cultural, social, and economic characteristics, and characteristics of feed safety practices [27, 28]. In this regard, Korale-Gedara et al. [29] claimed that exploring farmers' adoption of food safety practices is useful for designing extension strategies to prevent food contamination.

Even though several studies have been conducted to examine animal feed's biological, chemical, and physical hazards, very few studies have empirically assessed the adoption of feed safety practices and determine the differences in adoption according to the socio-economic profile of farmers, particularly in the context of Saudi Arabia. With this study, we have developed the first comprehensive assessment of feed safety practices at the farm level in Saudi Arabia. This method is based on measuring the extent to which farmers use practices in the local context concerning three components: feed purchasing, feed storing, and feed mixing and distribution. While the feed safety adoption rates in Saudi Arabia have not previously been documented, the findings are consistent with the strategic objectives of Saudi Vision 2030, which considers food safety and quality in the animal production sector as a national security issue. This strategy aims to ensure that all stakeholders in the feed supply chain commit to standard specifications and quality standards issued by international and national authorities. Concerning the limited research available in this area, this study aims to fill this gap by achieving the following objectives: (i) analyzing the actual adoption rates of feed safety practices and (ii) determining the differences in adoption based on farmers' socioeconomic profile and farm characteristics. The results of the current study can contribute toward improving extension services in the field of feed safety in accordance with the current situation of adoption and farming systems in the study area.

2. Methodology

2.1. Survey design

The research strategy adopted by this study is a quantitative research methodology using a survey design. A cross-sectional survey design was used to collect data at one point in time and examine the patterns of relationship between various variables at a particular time [30].

2.2. Population and sample

The population of the study consisted of livestock farmers in Riyadh region, located in the center of Saudi Arabia. Their information was obtained from the Ministry of Environment, Water, and Agriculture (MEWA) database. As of December 31, 2021, the number of

Table 1
Socioeconomic profile of the respondents.

Farmers' Characteristics	Freq.	%	Mean	Std. Dev.	Min.	Max.
Gender (n = 440)						
Female	181	41.1	n.a	n.a	0	1
Male	259	58.9				
Age (n = 402)						
Less than 35 years	195	48.5	39.11	12.66	22	90
35–55 years	159	39.6				
More than 55 years	48	11.9				
Education (n = 442)						
Illiterate	61	13.8	9.8	4.9	0	17
Less than 7 years	84	19.0				
7–12 years	189	57.8				
More than 12 years	105	24.4				
Livestock farming as a main source of income (n = 442)						
Yes	367	83	0.83	0.37	0	1
No	75	17				
Livestock farming experience (n = 395)						
Less than 16 years	221	55.9	17.26	12.47	3	38
16–30 years	104	26.3				
More than 30 years	70	17.8				
Membership in livestock associations (n = 442)						
Yes	40	9.0	0.09	0.28	0	1
No	402	91.0				
Regular contact with extension workers (n = 442)						
Yes	170	32.5	0.38	0.48	0	1
No	272	61.5				
The main purpose of raising livestock (n = 442)						
Commercial (Meat production)	198	44.8	n.a	n.a	1	5
Commercial (Milk production)	12	2.7				
Commercial (Meat and milk production)	66	14.9				
Personal use (meat or milk)	49	11.2				
Hobby	116	26.2				
Competition in beauty contests	1	0.2				
Animals (n = 442)						
Camels	93	21.1	n.a	n.a	1	4
Cows	29	6.6				
Sheep	363	82.2				
Goats	280	63.3				
Number of camels (n = 93)						
Less than 21	52	55.9	33.22	31.66	10	120
21–40	33	35.5				
More than 40	8	8.6				
Number of cows (n = 29)						
Less than 16	15	51.7	23.0	26.41	5	100
16–30	9	31.1				
More than 30	5	17.2				
Number of sheep (n = 363)						
Less than 101	122	33.6	144.66	92.3	70	850
101–200	110	30.3				
More than 200	131	36.1				
Number of goats (n = 280)						
Less than 51	123	43.9	96.48	82.29	50	550
51–100	81	28.9				
More than 100	76	27.2				
Type of livestock operation (n = 442)						
On pasture	263	59.5	n.a	n.a	1	4
Farm complex	60	13.6				
Barns	8	1.8				
Sheds	111	25.1				
Feeding system (n = 442)						
Green fodder and grazing	89	20.1	n.a	n.a	1	4
Green fodder and barely	143	32.4				
Compound feed	89	20.1				
Compound feed, barely, and green fodder	121	27.4				

the registered livestock farmers in the database was 36,224 [31]. An online survey was developed to collect data from January to March 2022. The e-questionnaires were shared with all livestock farmers in the database through an e-mail and WhatsApp message. The researchers prepared an information sheet that included the purpose of the study and the researchers' contact information. Livestock farmers were given one month to fill in the e-questionnaire, and 281 questionnaires were delivered without any reminders. A reminder was then sent to all non-responding farmers after this period. After this reminder, two weeks were given to complete the e-questionnaire. During this period, another 131 questionnaires were collected. The researchers sent a final reminder to all non-responding farmers, giving them another two weeks to complete the e-questionnaires. In this period, 116 responses were collected. A total of 528 responses were returned to the researchers. Eighty-six questionnaires were excluded due to incomplete data. Accordingly, in the final analysis, the total sample consisted of 442 farmers.

2.3. Data collection instrument

The questionnaire consisted of two sections. Section one consisted of the following information about the profile of the livestock farmers: gender, age, education, the primary source of income, livestock farming experience, membership in livestock associations, extension contact, the primary purpose of raising livestock, number of farm animals, type of livestock operation, and feeding system. Farmers were asked to rate each practice's adoption level on a five-point Likert scale (always = 5, in most cases = 4, sometimes = 3, rarely = 2, none = 1). The feed safety practices index included 25 items divided into three components: feed purchasing (6 items), feed storing (11 items), and feed mixing and distribution (8 items). Each item on the scale represented a widely recommended practice at the farm level.

Each farmer was asked to rate the extent to which they implement these measures to determine how well they manage them. To understand the level of adoption in each of these practices, a total scale score was calculated by summing their ratings and converted into a percentage. The total scores for each practice and each category of the feed safety scale were divided into three groups based on the rate of total scores as follows: high level (>75 %), moderate level (50%–75 %), and low level (<50 %) [32]. To test the reliability of the feed safety scale, the internal consistency method was performed by calculating Cronbach's alpha coefficient. The Cronbach's alpha scores for the feed purchasing, feed store, feed mixing and distribution, and total scale were 0.87, 0.89, 0.84, 0.86, respectively. These values were over the acceptable internal consistency value (>0.7 %), indicating good internal consistency and high reliability for the scale and its sub-scales.

To ensure the content validity of the instrument, each item in the feed safety scale was operationalized and measured based on the definitions and explanations provided in feed legislation issued by the SFDA and the manual of the IFIF and the FAO on good practices in the feed sector. Moreover, each item was examined on the basis of its relevance to the study's purpose by five experts from the department of animal production, King Saud University.

Additionally, pre-testing the instrument with 15 livestock farmers before data collection ensured content validity. Six items were rephrased to reflect the local farming context in Saudi Arabia, according to the responses of farmers who participated in the pre-testing. Not all farmers participating in the pilot study were included in the sampling process. Accordingly, the proposed feed safety scale of the study reached the prescribed content validity and reliability standards. Ethics approval was obtained from the Human Ethics Committee of King Saud University (Ref# HEC 2021/758) to conduct this study.

2.4. Data analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS, ver. 28.0, IBM Corp, Armonk, NY, USA.). Responses were reported using descriptive statistics methods such as frequency distributions, percentages, and arithmetic mean. The similarities and differences among the examined practices with respect to the average adoption score were explored using agglomerative hierarchical cluster analysis [33]. The Euclidean distance was applied as a dissimilarity measure, and Ward's method was employed for the hierarchical clustering of feed safety practices under investigation.

The *Mann–Whitney* test is then performed to determine statistically significant differences between the two groups identified from the cluster analysis [34]. Moreover, the chi-square test of independence test was used to examine the differences between the two clusters regarding farmers' profiles and farm characteristics [35]. The results of cluster analysis were graphically presented; the heatmap and a dendrogram, using Origin (ver. 2; OriginLap Corp., Northampton, MA, USA).

3. Results

3.1. Socioeconomic characteristics of the respondents

Table 1 shows the socioeconomic profile of the surveyed livestock farmers. The findings reveal that more than half of the respondents (58.9 %) were male, whereas 41.1 % were female. The mean age of livestock farmers was 39.11 years. On average, the respondents had 9.8 years of education. Furthermore, livestock rearing was the main occupation of the majority of the farmers (83 %). Most farmers (55.9 %) had less than 16 years of livestock farming experience, with a mean of 17.26 years.

Only a small proportion of the respondents (9.1 %) were members of the local livestock association, and approximately a third of them (32.5 %) had regular contact with extension workers. Additionally, commercial production was the main purpose for raising livestock for 62.4 % of the sample. Regarding the farm characteristics, Table 1 also shows that farmers owned and managed more than one type of animal.

As Table 1 shows, a clear majority of the respondents (82.2 %) owned sheep, followed by goats (63.3 %). In descending order, the average numbers of raising sheep, goats, camels, and cows were 144.66, 96.48, 33.22, and 23, respectively. Most farmers (59.5 %) raised livestock on pasture, while around a quarter (25.1 %) used sheds to raise their animals. Finally, 32.4 % of the respondents depended upon traditional feeding (green fodder and barely) as a main feeding system in their farms, while 27.4 % of them used compound feed, barely, and green fodder for feeding.

3.2. Adoption of feed safety practices

The overall adoption of feed safety practices is illustrated in Fig. 1. Farmers' adoption rate (%) of feed purchasing practices was 77.9 %, indicating that farmers had largely adopted such practices in their farming. Likewise, farmers considered feed mixing and distribution practices as being a high rate of adoption (75.05 %). However, farmers moderately adopted feed-storing practices (70.99 %). Overall, farmers had a high level of adoption (75.19 %). Details of each feed safety category are provided below.

3.2.1. Feed purchasing practices

The mean values of feed purchasing practices ranged from 3.35 to 4.14 (Table 2). Among six practices pertaining to feed purchasing, the respondents considered "purchasing feed that is not stored in open/uncovered areas" (mean = 3.35, SD = 1.29) as moderate adoption, while adopting other feed purchasing practices more often indicated a high rate of adoption.3.2.2. Feed storing practices.

For all eleven practices (Table 2), the level of adoption ranged from moderate to high. The farmers rated "storing feed under shade" as the highest level of adoption (mean = 4.13, SD = 1.16), while "keeping feed storage place away from livestock pens and their waste" had the lowest level of adoption (mean = 2.98, SD = 1.11).3.2.3. Feed mixing and distribution practices.

The assessment of the three statements about feed mixing and distribution (Table 2) demonstrates that respondents considered the adoption of ensuring the hygiene of troughs and feeders regularly, ensuring the hygiene of all equipment and machines used in feed mixing, and adhering to the optimum quantity of feed additives as being of a low level (mean > 3.75). Also, the rest practices had been adopted moderately by the respondents (2.5 > mean < 3.75).

To identify how changing production structure may affect the adoption of feed safety practices, the adoption rates of feed safety practices by feeding system, type of operation, and the number of farm animals raised are illustrated in Figs. 2–4, respectively. The adoption rate of feed safety practices varies slightly across the feeding systems (Fig. 2). Farmers using compound feed only as a primary feeding system adopted higher feed safety practices in all categories (Fig. 3). Farmers using green fodder barely ranked second on feed purchasing, feed storing, and feed mixing and distribution measures, with 79.94 %, 71.34 %, and 75.03 %, respectively.

Farmers keeping their animals in the complex adopted higher feed safety practices (Fig. 3). Furthermore, compared with pasture, barns, and sheds operation systems, farmers who raised their farm animals in complex systems adopted more feed safety measures in each category. Especially the adoption rate of farmers who raised livestock on pasture regarding feed purchasing components is less than 8 %. The adoption rate of feed-storing practices for complex farms ranged from 7 % to 8 %, higher than other operating systems. Meanwhile, the adoption rate of complex farms on the feed mixing and distribution component is higher than those who raised cows, with a minimum of 3 % for barns farms and a maximum of 10 % for farmers who grew their livestock on pasture.

The adoption rates also showed an increasing trend for each component of feed safety measures according to farmers who owned higher numbers of farm animals, regardless of the type of these animals (Fig. 4). Specifically, farmers who raised sheep in their farmers considered it a higher level of adoption compared to farmers who raised other farm animals. The overall adoption rate for sheep farmers who manage a higher number of sheep was 77 %, while it was 72.53 % for farmers who raised lower numbers of sheep.

3.3. Classification of farmers based on their adoption

The results show the feature of farmers' adoption structure, namely the combination of adoption levels of the 25 statements rather

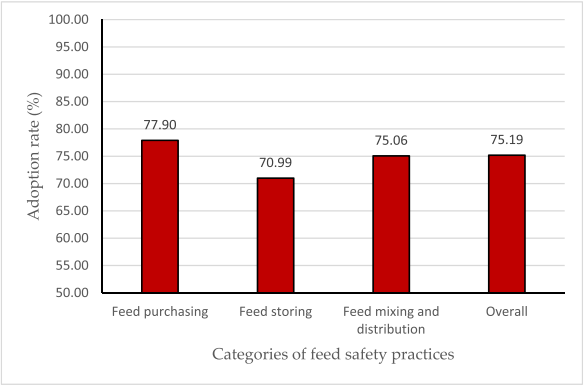

Fig. 1. Overall adoption of feed safety categories.

Table 2
Farmers' adoption of feed safety practices.

Practices	Adoption level		Rank	
	Mean	Std. Dev.	Within group	Overall
Feed purchasing				
P1- Purchasing feed that is not stored in open/uncovered areas.	3.35	1.29	6	19
P2- Ensuring feed is free from diverse contamination sources (plant residues, insects, rodents).	3.96	1.21	3	8
P3- Ensuring feed containers are intact and clean to prevent feed contamination.	4.14	1.16	1	4
P4- Ensuring feed has no bad odor or smell.	3.95	1.24	4	9
P5-Ensuring feed is free from mycotoxins and molds.	4.04	1.28	2	5
P6- Reading feed nutrition data labels carefully before buying.	3.93	1.22	5	10
Feed storing				
S1- Storing feed indoors/covered containers.	3.35	1.48	7	20
S2- Storing feed under shade.	4.13	1.16	1	3
S3- Avoid stacking feed directly onto the ground.	3.17	1.49	10	24
S4- Storing feed in a dedicated warehouse with temperature and humidity control.	3.20	1.55	9	23
S5- Reading storage methods on feed package labels carefully.	3.53	1.44	6	17
S6- Adhering to the validity period of the feed listed on the package under good storage conditions.	3.79	1.41	4	12
S7- Conducting the periodic cleaning of the feed storage place continuity.	4.02	1.26	2	6
S8- Conducting periodic control of rodents and insects.	3.92	1.29	3	11
S9- Avoid storing pesticides, fertilizers, disinfectants, etc., along with the feed.	3.74	1.53	5	13
S10- Keeping feed storage place away from livestock pens and their waste.	2.98	1.11	11	25
S11- Allocating cooled storage places for feed additives that need cooling so they are not affected by heat.	3.21	1.53	8	22
Feed mixing and distribution				
M1- Avoid mixing old feed with new feed.	3.42	1.37	7	18
M2- Separating feed that is supplied for each type of livestock.	3.66	1.40	4	14
M3- Ensuring the optimum quantity of daily feed.	3.56	1.45	6	16
M4- Ensuring the hygiene of troughs and feeders regularly.	4.35	1.07	1	1
M5- Ensuring the hygiene of all equipment and machines used in feed mixing.	4.16	1.21	2	2
M6- Adhering to the optimum quantity of feed additives (according to animal age, type of animal, type of feed, productive status, and physiological requirements).	4.01	1.25	3	7
M7- Using feed additives based on producers' recommendations (according to a percentage of mixing, type of animal, and mixing method).	3.62	1.44	5	15
M8- Handling Non-medicated feeds separately from medicated feeds.	3.25	1.44	8	21

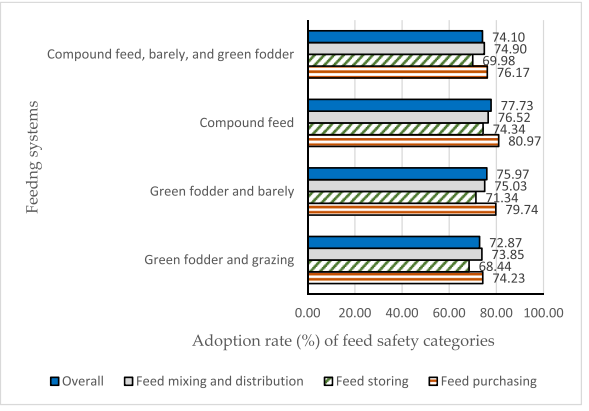

Fig. 2. Adoption of feed safety practices by feeding system.

than which statements are low or high. Two clusters were identified using hierarchical clustering analysis representing the most significant differences in adopting feed safety practices. As shown in Table 3, a Mann–Whitney *U* test was performed to examine the significant differences between the identified clusters.

The findings in Table 3 show that Cluster one: consists of the respondents who highly adopted the examined measures, accounting for 59.9 % of the respondents (265 observations). Also, cluster two: consisting of moderately adopted feed safety practices under investigation, this group represents 40.1 % of the surveyed farmers (177 observations). As shown in Table 3, the means of farmers' adoption in cluster two are less than in cluster 1 and significantly different ($p < 0.01$) for all practices examined, except for three practices (S9, S10, and M3).

The cluster analysis results of adoption data were visually illustrated in the heat map and the dendrogram (Fig. 5). This visual presentation is a valuable tool for exploring the similarities and differences among the examined practices. In this regard, high

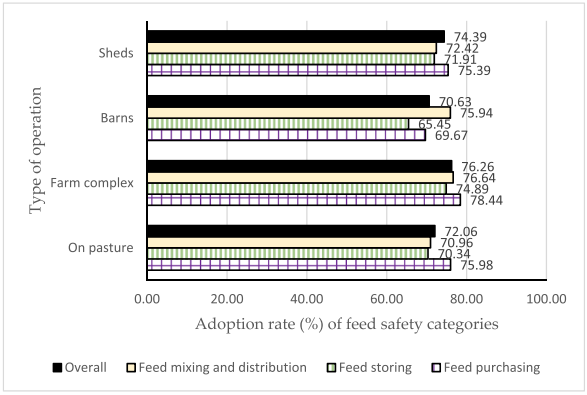

Fig. 3. Adoption of feed safety practices by type of operation.

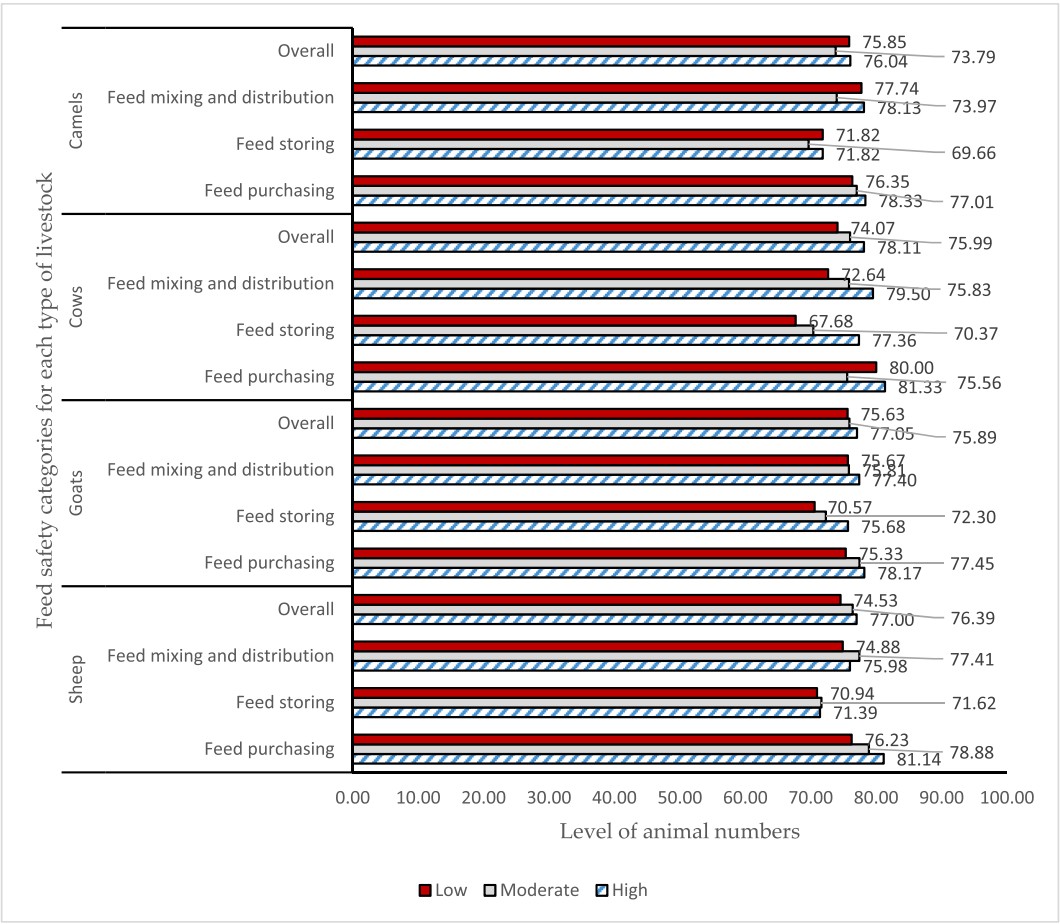

Fig. 4. Adoption of feed safety practices by animal numbers.

differences between the two clusters in the heat map (Fig. 5) regarding S6, S7, S8, P3, and S5 measures. This was verified by the standardized test statistic (Z-score) values for these measures, which gained higher mean differences (−16.267, −15.343, −14.524, −14.292, −14.253, respectively) between the two clusters of adoption as opposed to other measures.

3.4. Differences between adoption clusters according to farmers' profile

Farm characterizations and socioeconomic profile of the farmers were used to examine the differences between the identified

Table 3
Differences between clusters according to the adoption of feed safety practices.

Practices	Cluster I (n = 265)		Cluster II (n = 177)		Mann–Whitney U	Z	*p*-value
	Mean	SD	Mean	SD			
P1	3.50	1.35	3.12	1.59	19118.500[a]	−3.391	0.002
P2	4.46	0.94	3.20	1.53	9535.500[a]	−11.344	<0.0001
P3	4.77	0.56	3.21	1.21	6588.500[a]	−14.292	<0.0001
P4	4.46	1.03	3.18	1.15	9406.000[a]	−11.503	<0.0001
P5	4.71	0.69	3.04	1.31	7128.000[a]	−13.822	<0.0001
P6	4.51	0.92	3.08	1.27	8961.500[a]	−11.879	<0.0001
S1	3.52	1.56	3.09	1.33	19297.000[a]	−3.270	0.003
S2	4.59	0.81	3.44	1.25	11039.500[a]	−10.478	<0.0001
S3	3.31	1.58	2.95	1.34	20176.000[a]	−2.557	0.01
S4	3.83	1.49	2.25	1.11	9877.500[a]	−10.628	<0.0001
S5	4.31	1.11	2.37	1.04	5504.500[a]	−14.253	<0.0001
S6	4.64	0.79	2.51	1.11	3410.000[a]	−16.267	<0.0001
S7	4.75	0.61	2.94	1.21	5061.500[a]	−15.343	<0.0001
S8	4.62	0.81	2.89	1.19	5715.500[a]	−14.524	<0.0001
S9	3.63	1.74	3.09	1.14	23208.000	−0.202	0.84
S10	2.97	1.08	2.98	1.16	23368.500	−11.691	0.94
S11	3.89	1.38	2.19	1.11	19299.500[a]	−.071	<0.0001
M1	3.56	1.47	3.20	1.17	7512.500[a]	−3.262	0.008
M2	4.34	1.05	2.64	1.25	23034.000[a]	−12.756	<0.0001
M3	3.52	1.61	3.61	1.18	10755.000	−0.332	0.74
M4	4.82	0.53	3.65	1.27	8965.500[a]	−11.673	<0.0001
M5	4.74	0.67	3.30	1.33	7455.500[a]	−12.550	<0.0001
M6	4.63	0.77	3.07	1.25	8069.000[a]	−13.302	<0.0001
M7	4.28	1.17	2.64	1.23	18967.500[a]	−12.297	<0.0001
M8	3.05	1.57	3.56	1.16	23368.500[a]	−3.521	<0.0001

[a] Denotes statistical significance at the 0.01 level.

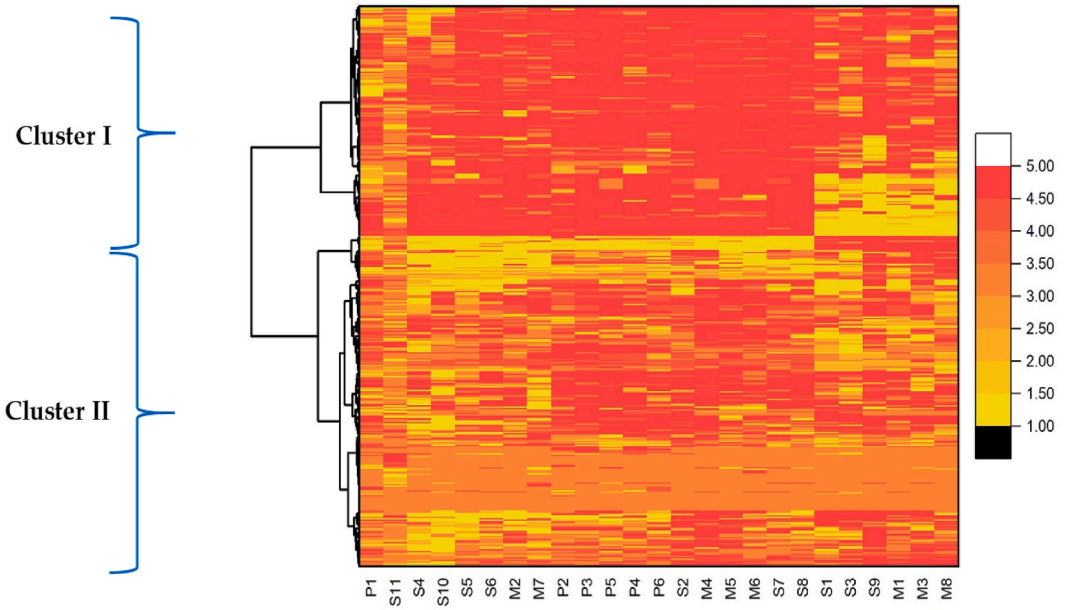

Fig. 5. Heat map and dendrogram of hierarchical cluster analysis for adoption of feed safety practices among farmers.

clusters (Table 4). The chi-square test results showed a significant difference at the 0.01 probability level between the "high adopters" cluster and the "moderate adopters" cluster for the variable of gender. Moreover, there were significant differences at the 0.05 probability level between the two clusters for membership in livestock association, extension contact, raising sheep, and feeding system. However, no significant difference ($p > 0.05$) were observed between the two adoption clusters for age, education, livestock as a main source of income, livestock farming experience, the primary purpose of raising livestock, raising camels, raising cows, raising goats, and type of livestock operation. Interestingly, the percentage of female farmers in the "high adopters" cluster was 47.1 %, while the percentage of male farmers in the same cluster was 32.2 %. The "high adopters" in the first cluster were usually members of

Table 4
Differences between adoption clusters according to farmers' socioeconomic attributes and farm characteristics.

Variable	Category	Cluster 1 (%)	Cluster 2 (%)	$\chi 2$	*p*-Value
Gender	Female	47.1	32.2	9.75 **	0.002
	Male	52.9	67.8		
Age	<35	52.1	56.3	0.95	0.81
	35–55	33.1	30.6		
	>55	14.8	13.1		
Education	Illiterate	14.3	13.0	6.84	0.23
	Less than 7 years	19.6	18.1		
	7–12 years	43.7	41.3		
	More than 12 years	22.4	27.6		
Livestock farming as a main source of income	Yes	84.9	80.2	1.64	0.12
	No	15.1	19.8		
Livestock farming experience	<16	57.8	52.7	3.2	0.2
	16–30	34.5	34.2		
	>30	7.6	13.0		
Membership in livestock associations	Yes	11.3	5.6	4.14[a]	0.04
	No	88.7	94.4		
Regular contact with extension workers	Yes	42.3	32.8	4.04[a]	0.05
	No	57.7	67.2		
The primary purpose of raising livestock	Commercial	75.8	86.2	3.46	0.07
	Personal use	24.2	13.8		
Raising camels	Yes	22.0	22.2	0.02	0.96
	No	78.0	77.8		
Raising cows	Yes	5.5	9.0	1.9	0.17
	No	94.5	91.0		
Raising sheep	Yes	88.6	82.0	3.91[a]	0.05
	No	11.4	18.0		
Raising goats	Yes	65.9	67.1	0.06	0.83
	No	34.1	32.9		
Type of livestock operation	On pasture	58.1	61.6	2.37	0.31
	Farm complex	12.5	15.2		
	Barns or sheds	29.4	23.2		
Feeding system	Green fodder and grazing	17.0	24.9	7.53[a]	0.05
	Green fodder and barely	33.6	30.5		
	Compound feed	23.0	15.8		
	Compound feed, barely, and green fodder	26.4	28.8		

[a] Denotes statistical significance at the 0.05 level; denotes statistical significance at the 0.01 level.

livestock associations than "moderate adopters" in the second. The ratio of members in the "high adopters" cluster (11.3 %) was two times higher than the "moderate adopters" (5.6 %). In the same line, the "high adopters" cluster has more increased contact with extension than the "moderate adopters."

The percentage of farmers having regular contact with extension was 42.3 % in the "high adopters," while the value was 32.8 % in the "moderate adopters." Likewise, significant differences were observed for the "high adopters" cluster concerning raising sheep, while both clusters showed similarities to remaining farm animals. Lastly, the percentage of farmers using the compound feed was 23 % in the "high adopters," while it was 15.8 % in the "moderate adopters" group.

4. Discussion

The findings in this section have been discussed based on three sides: the farmers' actual adoption rate of 25 practices examined, how the adoption cluster differentiates according to the average adoption of each practice, and the differences between the two clusters regarding personal attributes and farm characteristics.

4.1. Adoption rate of feed safety practices

Assessment of average index scores for each feed safety practices component shows that the livestock farmers have adopted the feed purchasing component extensively. This result may be attributed to farmers purchasing feeds from feed markets, which are regularly inspected by national authorities to ensure their compliance of sale points with quality and safety standards. This result is consistent with the Codex Alimentarius Code of practice on good animal feeding that the livestock farmer should purchase feed and feed ingredients from reliable sources and not use the feed unless it is healthy, and the feed should be in good condition and meet acceptable quality and safety standards.

Likewise, a high adoption rate was observed in adopting the majority of practices of mixing and distribution component among farmers. Studies show that there is a direct relationship between keeping animal health and compliance with feed hygiene practices [15,21,22,36]. With more awareness of this connection among farmers, more commitment to applying the best practices when handling feeds can be observed. These results are inconsistent with the finding of the Ministry of National Economy in Palestine [37],

where livestock farmers did not highly adopt feed-handling practices. Lower adoption rates were observed regarding the feed-storing component. This may be because most farmers rely on grazing as a primary operation type for their animals (Table 1). These farmers do not have proper storage facilities to preserve their animal feeds to meet requirements to comply with a given standard. In contrast, the findings revealed that farmers who keep their farm animals on the complex farms adopted higher feed string practices. In this sense, Yang et al. [38] and Zhong et al. [39] agreed that feed storing compliance costs may negatively impact the adoption of milk safety behavior among livestock farmers. Future research should therefore focus on examining why livestock farmers struggle to find adequate alternatives to establishing costly feed storages and develop such alternatives.

4.2. Differences between the clusters regarding the adoption of feed safety practices

The findings revealed that, among practices of feed purchasing component, high differences were found between the two clusters regarding the adoption of "ensuring feed containers are intact and clean to prevent feed contamination." Within the scope of this study, this practice has a two-fold picture in terms of packaging and transportation. While all feed products and ingredients, including green fodder, are targeted in this study, some are not sold in packages. Furthermore, some farmers may purchase green fodder from the farms directly, and therefore neglect the cleanliness of the containers. Meanwhile, some farmers may neglect to clean and disinfect transport containers before use and reuse to control and minimize the risk of contamination. Such behavior interprets the differences between adoption clusters regarding this practice. According to Codex standards [19], transport of both feed and feed ingredients should be adequately protected and cleaned during transport. Consequently, this study recommended paying attention to this practice by extension services to raise awareness about risks associated with incompliance and by regulatory authorities to monitor this requirement at all times.

The findings also highlighted the high differences between adoption clusters according to the adoption of four practices in the feed-storing component. Among these practices, two practices were found relating to reading the recommendations on feed packages in terms of storage methods and validity period. This result might be as high "high adopters" clusters rely more on compound feed as a main feeding system. Compound feeds are sold with package labels identifying their storage methods and validity period. Farmers purchasing compound feed may read this label carefully to preserve animal health and increase profit. On the contrary, farmers who depend upon grazing or buying green fodder are used to recalling their endogenous knowledge in feed storing, which may not always be accurate. In this regard, Yang, Chen and Kong [38] show that the type of operation is an important determinant for adopting hygiene practices by dairy farmers in China. The results of the study confirmed that milk storage hygiene adoption was higher among scale dairy farmers than farmers who manage complex farms or family backyards.

Likewise, there are high differences between "high adopters" and "moderate adopters" clusters in their practices of periodic cleaning of feed storage places and regular control of rodents and insects. This may be due to the fact that farmers do not have sufficient information about the risks associated with incompliance, or it may be due to the fact that some farmers do not have the financial capability to establish feed storage facilities on their farms. Lack of availability and access to proper feed storage facilities have been reported to be the most important limitation to implementing contamination control interventions [27,40,41].

4.3. Differences between the clusters according to socioeconomic profile of the respondents

Livestock farmers' socioeconomic attributes and farm-specific characteristics considerably impact outcomes such as adoption of innovations, productivity, and economic performance [27,42].

The findings revealed that the "high adopters" segment profile differed significantly from the "moderate adopters" segment in terms of gender. The results showed that the adoption rate of feed safety practices by female farmers is higher than that of male farmers. This may be due to the fact that male farmers in Saudi Arabia are more experienced in raising and feeding livestock and handling fodder, starting from purchasing, transporting, and storing, but performing these practices in a primitive way stemming from experience, and do not pay attention to safety requirements and standards. Also, although women in many developing countries are primarily responsible for keeping and caring for livestock, they have recently been involved in Saudi Arabia, starting from launching Saudi Vision 2030 in 2016. Many initiatives have targeted women empowerment in the agricultural sector and strengthen women-led entrepreneurship for livestock sector development. Such initiatives have provided various incentives, including financial aid, loans, and technical and extension assistance for intensifying productivity, product aggregation, processing, value addition, and marketing across the small ruminant sector [43]. Such experiences may motivate women to apply feed safety standards to protect animal health and enhance income levels. Similar findings were found in Ethiopia, where women play a pivotal role in adopting milk hygiene practices [44]. In the same context, Beharielal et al. [45] confirmed that the number of women in South Africa are considerably higher than men in applying farm hygiene practices.

The findings also revealed that there was a significant difference between the two clusters with regard to membership of livestock cooperatives. Higher adoption rates were observed among farmers who are members in livestock cooperatives compared to non-members. A possible explanation of this result is that cooperatives provide more support activities to their members regarding high-quality animal feeds and organizing capacity-building programs on feed issues. Imami et al. [46] claimed that development gaps in food safety require strong cooperatives to strengthen vertical coordination within the agri-food value chains. In this regard, Kirezieva et al. [47] argued that cooperatives promote the adoption of food safety standards among farmers by making tactical decisions about coordination of quality and safety activities between cooperative, farmers, and customers (e.g., hazard monitoring, providing logistics, sorting and packaging of the products, and training and advice to the members to implement quality assurance standards), making strategic decisions about the governance of transactions in the supply chain, and sell the products of their members. This result

is in line with Mwambi et al. [48], who found that membership in farmer organizations positively and significantly affects Kenyan farmers in adopting milk safety measures.

Raising sheep plays a precarious role in compliance with feed safety measures. Significant difference was found between the two clusters in terms of raising sheep. In the context of the current study, the findings depicted that "high adopters" cluster keep a higher number of sheep than "moderate adopters" cluster. A possible explanation for this result is that sheep meat is the most preferred meat among Saudi customers. Therefore, they may follow the best practices in feed safety to maintain sheep health and keep their profitability.

Feeding animals with compound feeds is highlighted in the literature as a significant source of nutrients for growth, reproductive health, and milk production [14]. In this sense, the results indicated that the "high adopters" segment profile differed significantly from the "moderate adopters" segment in terms of using compound feed as a main feeding system. The results showed that the adoption rate of feed safety practices by farmers who depend upon compound feed as a main feeding system on their farms is higher than others who do not. This may due to the fact that the compound feed is sold with package labels, describing each product's use and storage method. Farmers may carefully follow such recommendations to keep healthy conditions for their animals. Also, farmers using green fodder or grazing depend upon their indigenous knowledge of storing and handling livestock feed.

Even though a limited number of the sample had regular contact with extension services, the results showed that there was a significant difference in the adoption rates between the two clusters in terms of extension contact. The results showed that the "high adopter" cluster relies on extension services to make feed safety adoption decisions higher than the "moderate adopter" cluster. Extension services are a key input component in the feed supply chain besides technology, resources, and financial services that directly affect other actors (production, processing, packaging, transporting, marketing, and utilization). Because strong extension services accelerate the adoption of best practices in the feed sector by providing essential services such as technical training, technology adoption, awareness creation, capacity building, and market information [27]. This result is in line with the study results of Kebebe [49], who found that weak extension services are one of the main constraints limiting feed innovations' adoption among farmers. In this context, several international case studies prove the importance of Farmer Field Schools (FFS) as one of the most successful extension approaches for promoting safety and quality standards among livestock farmers in different contexts and environments. Over the years, FFS has been applied to many livestock production systems based on the "learning by doing" methodology to facilitate farmers' critical analysis, decision-making, and communication skills [50]. In this context, regarding the context of this study, adopting the FFS methodology may help promote active learning, acquire positive attitudes, and increase feed safety measures' adoption rate.

5. Conclusions

As this topic has rarely been discussed in the previous studies in the context of Saudi Arabia, this study contributes to the existing literature by emphasizing the actual adoption rates of feed safety practices at the farm level, as well as how adoption segments differ according to farmers' socioeconomic profile and farm characteristics.

It was found that the level of farmers' adoption of feed safety categories (i.e., feed purchasing, feed storing, and feed mixing and distribution) ranged between medium and high rates for all practices. Our results confirmed that feed storing requires attention from livestock farmers, specifically storing feed in a dedicated warehouse with temperature and humidity control, avoiding stacking feed directly onto the ground, and keeping feed storage places away from livestock pens and their waste. However, significant differences in adoption rates of feed safety practices were noted between "high adopters" and "moderate adopters" clusters according to gender, members of livestock associations, extension contact, raising sheep, and use compound feeds as a main feeding system. This study suggests useful implications for both theory and practice.

The feed safety practices index developed in this study provides a relatively objective picture of farm level adoption patterns. Practically speaking, this scale also provides a reliable guide to assist future researchers who want to examine the adoption gaps that need to be filled by livestock farmers. Based on the findings, this study provides valuable implications for policymakers. Overall, the feed safety adoption rate needs to be increased substantially. Training and awareness programs related to feed safety issues should be increased at the farm level. Moreover, farms should be monitored frequently to enforce the code of feed safety practices strictly. As the adoption level of feed-storing practices was moderate among farmers, this study recommends that the Saudi government assist farmers by providing loans for establishing stores to avoid feed contamination. Additionally, the findings of this study indicate that farmers who are members of livestock associations exhibit a higher adoption rate of feed safety measures compared to non-members. Accordingly, this study recommends that the government support these cooperatives financially to sustain their services to the community, as well as implement joint programs with the cooperatives to monitor the application of feed safety measures.

There are some limitations in this study that require acknowledgment. The data were collected from one region. Thus, we cannot generalize the results to include other regions within Saudi Arabia or other countries. The assessment of adoption rates of feed safety practices has depended on the self-report of the livestock farmers, indicating that this method relies on what the farmers believe to be accurate, biasing the findings of the assessment of adoption. Furthermore, collecting data using online survey does not allow us to collect qualitative data on the adoption obstacles of the best practices at the farm level.

Future research focusing on covering the compliance level of feed safety adoption along the feed value chain (production, processing, marketing, and consumption). Such a focus could further suggest long-term activities that should be undertaken to ensure a sustainable feed safety management system. Additionally, examining how the cost of feed safety practices can affect adoption among livestock farmers would also be interesting.

Data availability

The authors do not have permission to share data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] M.C. Appleby, L.A. Mitchell, Understanding human and other animal behaviour: ethology, welfare and food policy, Appl. Anim. Behav. Sci. 205 (2018) 126–131.
[2] S. Nyokabi, R. Birner, B. Bett, L. Isuyi, D. Grace, D. Güttler, J. Lindahl, Informal value chain actors' knowledge and perceptions about zoonotic diseases and biosecurity in Kenya and the importance for food safety and public health, Trop. Anim. Health Prod. 50 (2018) 509–518.
[3] F.A.O. Livestock, Contribution to Food Security in the Near East and North Africa, FAO, Rome, Italy, 2016.
[4] B. Molina-Flores, P. Manzano-Baena, M.D. Coulibaly, The Role of Livestock in Food Security, Poverty Reduction and Wealth Creation in West Africa, FAO, Rome, 2020.
[5] S. Alonso, P. Dominguez-Salas, D. Grace, The role of livestock products for nutrition in the first 1,000 days of life, Animal Frontiers 9 (2019) 24–31.
[6] S. Chowdhury, O.K. Ouda, M.P. Papadopoulou, Meat and egg production in Saudi Arabia: an analysis on vrtual water content for livestock farming, Int. J. Water Resour. Arid Environ. 9 (2020) 94–106.
[7] GAS. General Authority for Statistics (GAS): Riyadh, Saudi Arabia, 2020.
[8] F.A.O. Annual, Agricultural Imports and Exports in Saudi Arabia, FAO, Rome, Italy, 2021.
[9] Government of Saudi Arabia, Saudi Vision 2030, Government of Saudi Arabia, Riyadh, Saudi Arabia, 2016.
[10] Y. Mayett-Moreno, J.M. López Oglesby, Beyond food security: challenges in food safety policies and governance along a heterogeneous agri-food chain and its effects on health measures and sustainable development in Mexico, Sustainability 10 (2018) 4755.
[11] U. Sekaran, L. Lai, D.A. Ussiri, S. Kumar, S. Clay, Role of integrated crop-livestock systems in improving agriculture production and addressing food security–A review, J. Agric. Food Res. 5 (2021), 100190.
[12] A. Kumar, A.K. Mishra, S. Saroj, V.K. Sonkar, G. Thapa, P.K. Joshi, Food safety measures and food security of smallholder dairy farmers: empirical evidence from Bihar, India, Agribusiness 36 (2020) 363–384.
[13] E.K. Ling, S.N. Wahab, Integrity of food supply chain: going beyond food safety and food quality, Int. J. Prod. Qual. Manag. 29 (2020) 216–232.
[14] T. Yosef, N. Demise, T. Tadesse, T. Daniel, Study on the animal feed ingredients and livestock product supply, price and market-related constraints in Ethiopia, Int. J. Agric. Res. 17 (2022) 102–115.
[15] P. Schrögel, W. Wätjen, Insects for food and feed-safety aspects related to mycotoxins and metals, Foods 8 (2019) 288.
[16] E.L. Stevens, H.A. Carleton, J. Beal, G.E. Tillman, R.L. Lindsey, A. Lauer, A. Pightling, K.G. Jarvis, A. Ottesen, P. Ramachandran, Use of whole genome sequencing by the federal interagency collaboration for genomics for food and feed safety in the United States, J. Food Protect. 85 (2022) 755–772.
[17] J.D. Wolt, Current risk assessment approaches for environmental and food and feed safety assessment, Transgenic Res. 28 (2019) 111–117.
[18] M. Petersen, Z. Yu, X. Lu, Application of Raman spectroscopic methods in food safety: a review, Biosensors 11 (2021) 187.
[19] FAO, IFIF. Good Practices for the Feed Sector Implementing the Codex Alimentarius Code of Practice on Good Animal Feeding, FAO, International Feed Industry Federation (IFIF), Rome, Italy, 2020.
[20] L.A. Thompson, W.S. Darwish, Environmental chemical contaminants in food: review of a global problem, J. Toxicol. 2019 (2019) 1–14.
[21] A. Huss, R. Cochrane, M. Muckey, C. Jones, Animal feed mill biosecurity: prevention of biological hazards, in: Food and Feed Safety Systems and Analysis, Elsevier, 2018, pp. 63–81.
[22] V. Sharma, S. Sharma, C. Datt, Potential hazards in animal feeds: safety and regulation, Indian J. Anim. Nutr. 32 (2015) 242–262.
[23] J.N. Ssemanda, M. Reij, M.C. Bagabe, C.M. Muvunyi, H. Joosten, M.H. Zwietering, Indicator microorganisms in fresh vegetables from "farm to fork" in Rwanda, Food Control 75 (2017) 126–133.
[24] F. Cheli, R. Gallo, D. Battaglia, V. Dell'Orto, EU legislation on feed related issues: an update, Ital. J. Anim. Sci. 12 (2013) e48.
[25] SFDA, *Feed Act &Regulations*; Saudi Food and Drugs Authority (SFDA) Riyadh, Saudi Arabia, 2017.
[26] J. Chen, C. Qin, J. Trienekens, H.-t. Wang, Determinants of cooperative pig farmers' safe production behaviour in China—evidences from perspective of cooperatives' services, J. Integr. Agric. 17 (2018) 2345–2355.
[27] M. Balehegn, A. Duncan, A. Tolera, A.A. Ayantunde, S. Issa, M. Karimou, N. Zampaligré, K. André, I. Gnanda, P. Varijakshapanicker, Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low-and middle-income countries, Global Food Secur. 26 (2020), 100372.
[28] R. Rezaei, S. Mianaji, A. Ganjloo, Factors affecting farmers' intention to engage in on-farm food safety practices in Iran: extending the theory of planned behavior, J. Rural Stud. 60 (2018) 152–166.
[29] P. Korale-Gedara, J. Weerahewa, D. Roy, Food safety in milk: adoption of food safety practices by small-scale dairy farmers in Sri Lanka and their determinants, Food Control 143 (2023), 109274.
[30] A. Bryman, Social Research Methods, fifth ed., Oxford University Press, New York, NY, USA, 2016.
[31] MHRSD. Civil Organizations Manual, 2020.
[32] D. De Vaus, Surveys in Social Research, fifth ed., Routledge, London, 2002.
[33] H.F. Köhn, L.J. Hubert, Hierarchical Cluster Analysis, Wiley StatsRef: Statistics Reference Online, 2014, pp. 1–13.
[34] T.W. MacFarland, J.M. Yates, Mann–whitney u test, in: Introduction to Nonparametric Statistics for the Biological Sciences Using R, Springer, 2016, pp. 103–132.
[35] M.F. Zibran, Chi-squared Test of Independence, vol. 1, Department of Computer Science, University of Calgary, Alberta, Canada, 2007, pp. 1–7.
[36] Negash, D. Animal feed safety: cases and approaches to identify the contaminants and toxins. Saf. Now. 4, 8..
[37] Ministry of National Economy, A Study of Animal Feed Market in Phalestine, Ministry of National Economy: Ramallah, Phalestine, 2015.
[38] X.-R. Yang, K.Z. Chen, X.-Z. Kong, Factors affecting the adoption of on-farm milk safety measures in Northern China—an examination from the perspective of farm size and production type, J. Integr. Agric. 18 (2019) 471–481.
[39] Y. Zhong, Z. Huang, L. Wu, Identifying critical factors influencing the safety and quality related behaviors of pig farmers in China, Food Control 73 (2017) 1532–1540.

[40] S.K. Mutiga, A.A. Mushongi, E.K. Kangéthe, Enhancing food safety through adoption of long-term technical advisory, financial, and storage support services in maize growing areas of East Africa, Sustainability 11 (2019) 2827.
[41] F. Xu, R. Baker, T. Whitaker, H. Luo, Y. Zhao, A. Stevenson, C. Boesch, G. Zhang, Review of good agricultural practices for smallholder maize farmers to minimise aflatoxin contamination, World Mycotoxin J. 15 (2022) 171–186.
[42] C. Rojo-Gimeno, M. van der Voort, J.K. Niemi, L. Lauwers, A.R. Kristensen, E. Wauters, Assessment of the value of information of precision livestock farming: a conceptual framework, NJAS - Wageningen J. Life Sci. 90 (2019), 100311.
[43] FAO, MEWA. *Initiatives Of Women-Led Entrepreneurship in Saudi Arabia*; FAO and Ministry of Environment, Water, and Agriculture (MEWA), Riyadh, Saudi Arabia, 2022.
[44] A.V. Garsow, M.R. Biondi, B.B. Kowalcyk, J.L. Vipham, J. Kovac, K. Amenu, A. Zewdu, K.E. Colverson, Exploring the relationship between gender and food safety risks in the dairy value chain in Ethiopia, Int. Dairy J. 124 (2022), 105173.
[45] T. Beharielal, J. Thamaga-Chitja, S. Schmidt, Socioeconomic characteristics associated with farming practices, food safety and security in the production of fresh produce—a case study including small-scale farmers in KwaZulu-natal (South Africa), Sustainability 14 (2022), 10590.
[46] D. Imami, V. Valentinov, E. Skreli, Food safety and value chain coordination in the context of a transition economy: the role of agricultural cooperatives, Int. J. Commons (2021) 15.
[47] K. Kirezieva, J. Bijman, L. Jacxsens, P.A. Luning, The role of cooperatives in food safety management of fresh produce chains: case studies in four strawberry cooperatives, Food Control 62 (2016) 299–308.
[48] M. Mwambi, J. Bijman, P. Mshenga, S. Oosting, Adoption of food safety measures: the role of bargaining and processing producer organizations, NJAS - Wageningen J. Life Sci. 92 (2020), 100337.
[49] E. Kebebe, Bridging technology adoption gaps in livestock sector in Ethiopia: a innovation system perspective, Technol. Soc. 57 (2019) 30–37.
[50] F.A.O. Farmer, Field Schools for Small-Scale Livestock Producers: A Guide for Decision Makers on Improving Livelihoods, FAO, Rome, Italy, 2018.