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Editors

Prof. İsmet Daşdemir, Ph.D.
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CHAPTER 1

Statistical Analysis of the Socio-Economic Characteristics of Sheep Farming Enterprises Based on Business Types Formed According to Climate Change Perception Levels, Case of Konya Province

Cennet Oğuz[1] & Aykut Örs[2] & Aysun Yener Ögür[3] & Yusuf Çelik[4]

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1. Introduction

Climate change represents one of the most pressing environmental challenges confronting humanity today, with its effects observable on a global scale. Türkiye resides within a semi-arid climate zone, and the Konya region, ranked 20th in terms of provincial development, is acknowledged as one of the driest provinces in the country. A project supported by the Scientific Research Council of Türkiye (Tübitak) indicated that 69.54% of sheep farming enterprises in the Konya region are familiar with the concept of climate change (Oğuz et al., 2024). Nevertheless, the implementation of climate change adaptation strategies in this area faces significant barriers. The research examined farmers' perceptions and attitudes regarding climate change, utilizing Principal Component Analysis to inform this assessment. Subsequently, cluster analysis was employed to classify farmers based on their responses. The analysis identified four distinct farmer categories: environmentalist and climate-friendly smart innovators (ÇİDAY), reserved (A), concerned (E), and unconcerned (K). It is recommended that the ÇİDAY group be prioritized in farmer training initiatives and presented as exemplary models through practical applications. The study additionally investigated the statistical relationships among farmer types, their utilization of climate-friendly innovative technologies, and their perceptions and adaptation strategies regarding climate change. This analysis encompassed demographic characteristics, socioeconomic status and resource utilization activities. 21 hypotheses were tested, with results for 7 significant hypotheses detailed in this report. The hypothesis analysis has indicated that an increase in the education level of sheep farming enterprises correlates with a heightened utilization of innovative technology. Farmers have identified several barriers to adapting to climate change, including limited farm sizes, insufficient cash financing, and elevated input costs. Additionally, the analysis has established that the perceptions of climate change and the adaptation levels among sheep farming enterprises exhibit statistically significant variations based on land size and the number of animals owned. Farmers with an environmentalist and climate-friendly orientation demonstrate a high level of awareness concerning the effects of climate change on the environment. They possess a moderate level of understanding regarding the impacts of climate change on both plant and animal production. Conversely, concerned farmers, while exhibiting diminished awareness of environmental issues, display the highest level of awareness specifically related to the effects of climate change on plant production and animal husbandry. Despite the existence of current legal regulations in Türkiye aimed at combating global climate change, empirical observations suggest that adherence to these regulations is often lacking. Examples of this non-compliance include the continued practice of stubble burning, the intensive conduct of cattle farming in the absence of adequate forage crops, the provision of support without considering climate change implications, and the inclusion of water-intensive products in production patterns by farmers in arid regions. If the current legal frameworks are enforced rigorously and awareness training initiatives are enhanced, it is anticipated that positive outcomes may ensue. Although the Ministry of Environment, Urbanization and Climate Change was established in 2011, the lack of a dedicated organization to directly address climate change represents a significant shortcoming. Nonetheless, the establishment of the Climate Change Research Institute in Konya province in 2023 and the formation of a climate change department within the metropolitan municipality are promising developments. It is expected that these institutions will collaborate effectively with the ministry, universities, non-governmental organizations, and various stakeholders to address climate change challenges and manage soil and water resources more efficiently.

2. Material and Method

The study was conducted in Konya province, recognized for having the second-largest sheep population and being the driest region in Türkiye (TURKSTAT, 2023; Meteorology, 2023). The primary data for this research were obtained through surveys distributed to sheep farming enterprises within the province between December 2021 and April 2022. Additionally, records from the Konya Province Sheep and Goat Breeders Association provided the foundational framework for the study. The sample size was calculated to be 151, employing the Neyman Method, a type of Stratified Random Sampling Method, which included a 5% margin of error at a 95% confidence interval, as per the formula established by Yamane (1967).

$$n = \frac{\sum (Nh.Sh)^2}{N^2.D^2 + \sum Nh\,.(Sh)^2} \qquad D^2 = (\frac{d}{t})^2$$

In the formula

n: number of samples,

N: number of enterprises in the main audience,

Nh: the number of enterprises in the h^{th} layer (frequency)

Sh: standard deviation of the h^{th} layer,

d: allowable margin of error from the population means, t: the t table value corresponding to the 95% confidence interval predicted in the study.

The sample size was divided into three strata based on the coefficient of variation. The survey included a total of 151 enterprises, categorized as follows: the first stratum comprised 22 enterprises with 1 to 100 head of sheep; the second stratum included 79 enterprises with 101 to 250 head of sheep; and the third stratum contained 50 enterprises with more than 251 head of sheep (Oğuz et al., 2024).

The normality test conducted in the study indicated that the dependent variables associated with the hypotheses displayed a non-normal distribution. As a result, non-parametric tests were employed to assess the hypotheses. Specifically, the Kruskal-Wallis test was utilized to compare means across more than two groups, while the Chi-Square test was employed to examine the relationship between two qualitative (categorical) variables. In instances where the Kruskal-Wallis test revealed a statistically significant difference, the Mann-Whitney U test was utilized as a post-hoc analysis to ascertain the source of the difference (Can, 2018). The Mann-Whitney U test is recognized as a significant non-parametric statistical tool for evaluating differences between two independent groups (McKnight and Najab, 2010; MacFarland et al., 2016). Within this study, the Mann-Whitney U test served as the post-hoc analysis following a significant finding from the Kruskal-Wallis test. The effect size for the Mann-Whitney U test is represented by the *r* effect value, which corresponds to Pearson's correlation coefficient. The *r* value ranges from 0 (indicating no effect) to 1 (a perfect effect), and its evaluation is independent of the sign. In this study, *r* value of 0.1 was considered to indicate a small effect, 0.3 a medium effect, and 0.5 a large effect (Field, 2009).

The Kruskal-Wallis test is a statistical technique used to compare the means of three or more groups characterized by continuous variables that do not show a normal distribution. This test is recognized as a nonparametric alternative to one-way analysis of variance (ANOVA). In the context of this analysis, a *p*-value greater than 0.05 indicates the acceptance of the null hypothesis (H_0), whereas a *p*-value less than 0.05 leads to the rejection of the null hypothesis (Cevahir, 2020). The primary objective of the Kruskal-Wallis test is to ascertain whether there exists a statistically significant difference among the scores of the groups. The effect size associated with the Kruskal-Wallis test is indicated by the Eta squared (η^2) correlation coefficient. Eta squared quantifies the degree to which the independent variable influences the dependent variable, reflecting the proportion of total variance in the dependent variable that can be attributed to the independent variable (or factor). The values of Eta squared range between 0 and 1, with interpretations as follows: 0.01 is considered a small effect, 0.06 represents a medium effect, and 0.14 signifies a large effect (Cohen, 1992). Furthermore, a Chi-Square test was conducted to evaluate the potential rejection of the hypothesis regarding the lack of relationship between non-numerical variables (H_0 hypothesis), (Özmen et al., 2019). The Chi-Square test contains various applications, including tests for independence, homogeneity and goodness-of-fit. Within this study, the independence test was specifically utilized to explore the relationship between qualitative variables with two or more categories. To facilitate this analysis, two-way contingency tables, which comprise horizontal (row) and vertical (column) classifications, were created to represent the observed frequencies of the variables being examined (Özmen, 2009). Consistent with the Kruskal-Wallis test, a *p*-value exceeding 0.05 results in the acceptance of the null hypothesis, while a *p*-value below 0.05 results in its rejection (Cevahir, 2020).

Research Findings and Discussion

This study analyzes the statistical relationship among various farmer types, their utilization of climate-friendly innovative technologies, and their perceptions and adaptations regarding climate change, taking into account their socio-economic status. The farmers within the research area were classified into four distinct categories: environmentalist and climate-friendly smart innovators (ÇİDAY), reserved (A), concerned (E), and unconcerned (K) (Oğuz et al., 2024). Numerous studies have endeavored to identify farmer types as a means of assessing climate change adaptation at both national and regional levels (Barnes et al., 2012; Hyland et al., 2016; Arbuckle et al., 2017; Foguesatto, 2019; Shukla et al., 2019; Stringer, 2020; Islam et al., 2021). To analyze the climate change perceptions and adaptation strategies of sheep farming enterprises within the specified area, a total of 21 hypothesis tests were conducted to uncover any significant differences. For this report, only the statistically significant findings are presented. The null hypothesis (H_0) and the alternative hypothesis (H_1) were formulated as follows:

H_0: The perception of climate change and the adaptation levels among sheep farming enterprises remain constant regardless of land size.

H_1: The perception of climate change and the adaptation levels among sheep farming enterprises are influenced by land size.

To evaluate these hypotheses, the Kruskal-Wallis test was used to compare the means across multiple groups. The findings of the Kruskal-

Wallis test are detailed in Table 1. Upon examining Table 1, it becomes evident that the perceptions of climate change and the levels of adaptation among sheep farming enterprises differ significantly based on land size ($X^2 = 10.873$; $p < 0.05$).

Table 1. Comparison of land sizes with climate perception and adaptation levels

Climate perception and adaptation levels	N	Mean Rank	X^2 Chi-Square	p	Significant Difference
Low	23	103.30	10.873	0.004	Low→Medium
Medium	120	70.67			
High	8	77.50			

Consequently, H_0 is rejected. A Mann-Whitney U Test was conducted on paired groups to assess the differences in perceptions of climate change and adaptation levels among the enterprises. The analysis revealed that the land sizes of enterprises classified as low-level differed significantly from those categorized as medium level. This difference can be attributed to the variation in the mean ranks between the low and medium-level groups ($p < 0.05$).

H_0: The perception of climate change and the levels of adaptation among sheep farming enterprises remain constant regardless of the number of animals.

H_1: The perception of climate change and the levels of adaptation among sheep farming enterprises are influenced by the number of animals.

To evaluate these hypotheses, the Kruskal-Wallis test was utilized to compare the means across multiple groups. The findings from the Kruskal-Wallis test are presented in Table 2. The analysis revealed a significant difference in climate change perception and adaptation levels among sheep farming enterprises based on the number of animals they have (X2 = 7.413; $p < 0.05$), leading to the rejection of the H0. To further investigate the differences in these levels, a Mann-Whitney U Test was conducted in pairs.

Table 2. Comparison of the number of animals with the climate change perception and adaptation levels of enterprises

Climate perception and adaptation levels	N	Mean Rank	X^2 Chi-Square	p	Significant Difference
Low	23	96.26	7.413	0.025	Low→Medium
Medium	120	71.10			
High	8	91.19			

The results indicated that enterprises with a low perception of climate change showed a significant difference in animal numbers compared to those with a medium perception level (p<0,05).

H_0: There is no variation in the perception of climate change and adaptation levels among sheep farming enterprises based on their access to information scores.

H_1: There is a variation in the perception of climate change and adaptation levels among sheep farming enterprises based on their access to information scores.

To evaluate these hypotheses, the Kruskal-Wallis test was utilized to compare means across multiple groups. The results of the Kruskal-Wallis test are given in Table 3.

Table 3. Comparison of the climate change perception and adaptation levels of enterprises with their information access scores

Climate perception and adaptation levels	N	Mean Rank	X^2 Chi-Square	p	Significant Difference
Low	23	50.98	11.022	0.004	Low→Medium
Medium	120	81.85			
High	8	60.25			

Upon analysis of Table 3, a significant difference is observed in the climate change perception and adaptation levels of sheep farming enterprises based on their access to information scores (X2 = 11.022; p <0.05). Accordingly, H_0 is rejected. To further examine this difference, a Mann-Whitney U Test was conducted on paired groups to evaluate the variations in climate change perception and adaptation levels among the enterprises. The results indicate that the access to information scores of enterprises classified as low-level differ significantly from those in the medium-level category. This discrepancy can be attributed to the differences in mean ranks between the low and medium-level groups ($p < 0.05$).

H_0: The level of innovative technology utilization in sheep farming enterprises remains constant regardless of the farmers' educational attainment.

H_1: The level of innovative technology utilization in sheep farming enterprises varies in accordance with the educational attainment of the farmers.

To examine the relationship between these two variables, the Chi-Square Independence test was employed, given that both are categorical and consist of multiple classes. The results of the Chi-Square Independence test are detailed in Table 4.

Table 4. Comparison of innovative technology usage levels according to education level

Levels of innovative technology usage	Education Levels													
	Literacy		Primary School-Secondary School		High-School		College		Undergraduate		Other		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Low	0	0.0	7	77.8	2	22.2	0	0.0	0	0.0	0	0.0	9	100.0
Medium	1	0.8	105	79.5	15	11.4	7	5.3	4	3.0	0	0.0	132	100.0
High	0	0.0	4	40.0	2	20.0	1	10.0	2	20.0	1	10.0	10	100.0
Total	1	0.7	116	76.8	19	12.6	8	5.3	6	4.0	1	0.7	151	100.0
$\chi 2=25.406$ $p=0.005$														

The educational backgrounds of sheep farming business owners in the research area are primarily at the primary and secondary school levels. It was observed that 77.8% of enterprises characterized by low levels of innovative technology utilization were represented by individuals with these educational qualifications. Likewise, 79.5% of enterprises exhibiting medium levels of innovative technology use were owned by individuals with a primary and secondary school education level, while 40% of those with high levels of innovative technology adoption were also comprised of owners from this educational background. A statistically significant correlation was identified between the levels of innovative technology usage and the education levels of the business owners, as evidenced by a Chi-Square value of 25.406 ($p < 0.05$), resulting in the rejection of the null hypothesis (H_0). The analysis indicated that the education level had a weak effect on the use of innovative technology, with a Cramér's V value of 0.29. Furthermore, the post-hoc Z test revealed significant differences among certain groups ($p < 0.05$).

H_0: The types of farmers do not vary based on land size.

H_1: The types of farmers vary based on land size.

A Kruskal-Wallis test was conducted to compare the means across more than two groups in relation to these hypotheses. The results of the Kruskal-Wallis test are presented in Table 5.

Table 5. Comparison of farmer types and land sizes

Farmer Types	N	Mean Rank	X^2 Chi-Square	p	Significant Difference
Environmentalist and climate-friendly smart innovators (1)	51	85.45	9.469	0.024	1 → 2 2 → 4
Reserved (2)	43	59.51			
Concerned (3)	31	76.61			
Unconcerned (4)	26	84.00			

The data presented in the table indicate that there are significant differences among various types of sheep farming enterprises with regard to their land sizes ($X^2 = 9.469$; $p < 0.05$). Consequently, the null hypothesis (H_0) is rejected. The analysis illustrates the mean ranks for the different farmer categories as follows: environmentalist and climate-friendly smart innovators (mean rank = 85.45), reserved (mean rank = 59.51), concerned (mean rank = 76.61), and unconcerned (mean rank = 84.00). The analysis further reveals that the land sizes of environmentalist and climate-friendly smart innovators differ significantly from those of the reserved farmers, while the land sizes of reserved farmers also show a significant difference from those of the unconcerned farmers. This distinction can be attributed to the disparities in the mean ranks among these categories, specifically between environmentalist and climate-friendly smart innovators and reserved farmer types, as well as between reserved and unconcerned farmer types ($p < 0.05$).

H_0: Farmer types remain constant regardless of their agricultural income.

H_1: Farmer types vary based on their agricultural income.

To compare the means among more than two groups related to this hypothesis, a Kruskal-Wallis test was conducted. The results of the Kruskal-Wallis test are presented in Table 6.

Table 6. Comparison of farmer types and agricultural incomes

Farmer types	N	Mean Rank	X^2 Chi-Square	p	Significant Difference
Environmentalist and climate-friendly smart innovators (1)	51	75.57	8.593	0.035	2 → 4
Reserved (2)	43	65.86			
Concerned (3)	31	72.97			
Unconcerned (4)	26	97.23			

Analysis of the table shows that there are significant differences in agricultural incomes among various sheep farming enterprises, categorized by farmer types ($X^2 = 8.593$; $p < 0.05$). Consequently, the H_0 has been rejected. The results of the analysis indicate the following mean ranks for each farmer type: environmentalist and climate-friendly smart innovators (mean rank = 75.57), reserved farmers (mean rank= 65.86), concerned farmers (mean rank = 72.97), and unconcerned farmers (mean rank = 97.23). It is particularly noteworthy that there exists a significant difference in agricultural income between the reserved and unconcerned farmer types. This difference is attributed to the distinct ranks held by the reserved and unconcerned farmers ($p < 0.05$).

H_0: The types of farmers do not vary based on the levels of technology usage.

H_1: The types of farmers vary based on the levels of technology usage.

The Chi-Square Independence test was used to analyze both groups under comparison, as they represent multi-class qualitative variables. The findings of the Chi-Square Independence test are presented in Table 7. The results indicate that the innovative technology usage levels among the enterprise owners surveyed in this research predominantly fall within the medium range (Oğuz et al., 2024).

Table 7. Comparison of farmer types based on technology usage levels

Farmer Types	Levels of innovative technology use							
	Low		Medium		High		Total	
	n	%	n	%	n	%	n	%
Environmentalist and climate-friendly smart innovators	0	0.0	45	88.2	6	11.8	51	100.0
Reserved	9	20.9	34	79.1	0	0.0	43	100.0
Concerned	0	0.0	28	90.3	3	9.7	31	100.0
Unconcerned	0	0.0	25	96.2	1	3.8	26	100.0
Total	9	6.0	132	87.4	10	6.6	151	100.0
$\chi2$=28.832 p=0.000								

It can be seen that 11.8% of the farmer types of the enterprises were environmentalist and climate-friendly smart innovators at a high level, 9.7% of the concerned farmer types were at a high level and 3.8% of the unconcerned farmer types were at a high level. A statistically significant difference was found between the farmer types of the enterprises and their innovative technology usage levels (Chi-Square = 28.832; $p < 0.05$). H_0 hypothesis was rejected. Since the contingency table was greater than 2x2, Cramer's V value was taken as the effect size value. The effect size of this difference was V= 0.31, suggesting that the relationship had a weak effect. It was found that farmer types had a weak effect on the innovative technology usage levels (V=0.31). As a result of the post-hoc Z test, it was found that some groups differed from one another ($p<0.05$).

Conclusion and Recommendations

Based on the analysis of statistical relationships among the farmer types identified in this study, along with their demographic characteristics and socio-economic status:

- The research has established that the utilization of innovative technology in sheep farming enterprises correlates with the educational levels of farmers. Specifically, as education levels increase, there is a corresponding rise in the adoption of climate-friendly innovative technologies. Thus, it is imperative to enhance the educational infrastructure in rural areas and facilitate access to educational resources. Such initiatives will foster greater awareness and adaptation to climate change while promoting the increased implementation of climate-friendly technologies.

- Farmers identified several barriers to adapting to climate change, including limited farm sizes, insufficient cash financing, and elevated input costs. Furthermore, hypothesis analyses indicate that the perceptions and adaptation levels of sheep farming enterprises vary significantly based on land size and the number of animals owned. Therefore, increasing the capacities of small farms, providing financing for environmental and resource management, and offering targeted awareness training could lead to substantial advancements in the adaptation strategies by these enterprises in response to climate change.

- An analysis of information sources regarding climate change among farmers indicates that employees of the Ministry of Agriculture and Forestry, university representatives, and producer organizations are consulted at remarkably low rates. These three critical stakeholders face challenges in effectively reaching and engaging with farmers. Consequently, there is a pressing need to enhance the operations of these institutions and implement new communication strategies to improve accessibility for farmers.

- A significant majority of the farmers surveyed in this study expressed the necessity of establishing a dedicated center focused on drought and climate change. The creation of such a center, offering educational programs, publication services, and various support mechanisms, would greatly facilitate increased awareness and adaptation to climate-related issues.

- Environmentalist and climate-friendly innovative farmers exhibit a high level of awareness concerning the environmental impacts of climate change. They possess a moderate understanding of its implications for both plant and animal production. This group demonstrates a willingness to adopt methods for climate change adaptation and to assume leadership roles in implementing these practices. By providing targeted training, these individuals can serve as role models within their regions, educating fellow farmers about climate change's effects on agricultural production.

- Although concerned farmers generally possess low awareness of environmental matters, they show a heightened awareness of climate change's impact on both plant production and animal husbandry. Similar to their environmentalist counterparts, this group has the potential to enhance the awareness of other farmers and can function as leading figures in their communities.

Although it is assumed that current legal regulations in Türkiye are designed to address global climate change, empirical observations and practices reveal that the implementation of these regulations is insufficient. For instance, stubble burning continues among agricultural producers, intensive livestock farming is undertaken despite inadequate forage crop availability, and support initiatives are implemented without adequately considering climate change factors. Furthermore, producers in arid regions continue to cultivate crops that demand substantial water resources. If existing laws and regulations were enforced effectively and awareness training enhanced, positive outcomes would likely ensue. The establishment of the Ministry of Environment, Urbanization, and Climate Change in 2011 was a significant step toward addressing climate issues; however, the lack of an organization specifically dedicated to combating climate change represents a notable deficiency. The recent establishment of the Climate Change Research Institute in Konya in 2023 and the creation of a climate change department within the metropolitan municipality are promising developments. It is anticipated that these institutions will engage collaboratively with the ministry, academic institutions, non-governmental organizations, and various entities to enhance efforts related to climate change and soil-water resource management.

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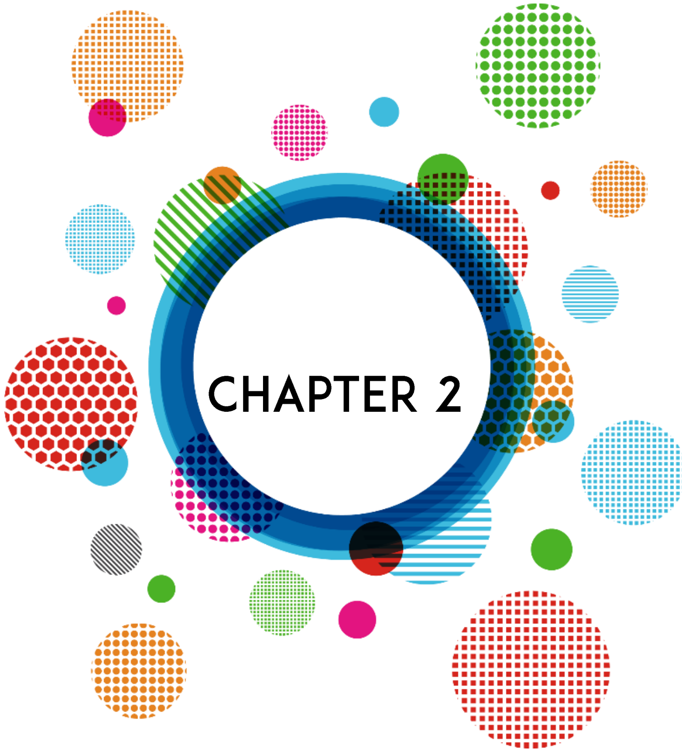

Pain Behavior in Small Ruminants and its Importance for Herd Management

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INTRODUCTION

Pain is a sensory experience that can significantly affect a ewe's welfare and quality of life. This approach can harm both sheep and lambs, resulting in poor nutrition and production economics through live weight gain or poor lactation (Gougoulis et al. 2008; Wassink et al. 2010). Pain in animals can also be defined as a defect in tissue integrity or a negative sensory experience (Ventura et al. 2014). According to Molony and Kent (1997), this phrase refers to any procedure that modifies an animal's physiology and behavior in order to minimize pain-related bodily harm, lessen the chance of recurrence, and promote healing. Anatomical location (superficial, deep, visceral, somatic, musculoskeletal), duration (acute, chronic), or underlying mechanism (nociceptive, inflammatory, neuropathic) can all be used to categorize pain (Guedes, 2017). Changing moral and ethical concerns worldwide also mean that society demands improved welfare through better breeding practices and food produced with attention to animal welfare. Appropriate pain management is fundamental to improving farm animal welfare in this context. Pain can lead to behavioural, autonomic and neuroendocrine changes as well as a negative emotional state. In other words, pain also means compromising animal welfare. Persistent discomfort can raise respiratory and pulse rates, lower rectal temperature, and decrease feed intake and average daily body weight growth in sheep (Silva et al. 2020).However, pain is still a neglected or under-emphasized issue in livestock, and sometimes it is neglected by the breeder, and its importance is not sufficiently recognised.

Assessing the level of pain that animals experience is crucial for determining their welfare and can provide valuable insights into the effectiveness of pain management interventions (Hunter et al. 2017). Determining whether farm animals are uncomfortable may be challenging. From an evolutionary perspective, it can sometimes be beneficial for sheep to avoid exhibiting pain-related indications of weakness because they are more susceptible to assaults by wild animals (Berckmans, 2017).This does not imply that sheep are painless. Both lame sheep and sheep with chronic mastitis have been shown to exhibit hyperalgesia, which is an enhanced response to a painful stimulus (Doughty et al. 2017). Pain management has not received the same attention as it has in other species, despite the fact that domestic sheep have been the focus of numerous pain studies. Sheep pain reduction is limited by several variables, including treatment costs, the availability of legal painkillers, and the absence of fundamental scientific data to evaluate animal responses both before and after therapy (Nieuwhof et al. 2005). Certain EU nations, like Norway, forbid the use of local anesthetics during husbandry procedures that result in severe pain, including castration or the docking of a male lamb's tail.But among many other things, sheep wellbeing may also be at danger from mild to severe pain brought on by clinical and subclinical illnesses and the activities that go along with them (Solveig et al. 2009). The increasing global demand for meat and dairy products is expected to cause a 25–70% increase in food production by 2050 (Clark et al. 2016). Intense production has increased as a result of the growing strain on breeders to provide big amounts of high-quality food. However, for technical or financial reasons, the share of breeders has significantly decreased in many nations. This change means that the daily needs of many animals are met by one person (Ventura et al. 2014). These adjustments have put breeders under a great deal of stress and added to their workload inside the organization.As a result, standards for health, safety, and welfare could decline (Kaler et al. 2010). Another aspect of the issue is the growing consumer concerns regarding the health and wellbeing of animals used for food under the existing management practices. Given all of these developments, any procedure or method that makes animals uncomfortable can cause humans to have grave worries. Diseases like mastitis and hoof rot, which are prevalent in small ruminant production, cause a great deal of misery and negatively impact the animals' well-being and productivity. Hoof rot is a highly contagious disease that causes lameness (Crook et al. 2014).

Pathogens such Staphylococcus aureus and Mannheimia hemolytica can cause mastitis, which can lead to painful sores in the udder duct and, in extreme situations, the sheep's mortality (Mavrogianni et al. 2004). Early identification and treatment of such health problems are essential to ensuring the animals' speedy recovery and preventing the sickness from spreading across the herd.Compared to other animals, it is more challenging to identify disease symptoms and potential pain early on. Consequently, the overall output and well-being of the herd are less impacted. According to Roberts et al. (2014), new technology must be developed to help farms satisfy these needs while maintaining high standards. Numerous animals are living closer to one another in pens due to the increasing housing density, necessitating the use of an integrated systems approach to detect and stop the spread of disease. This lessens the effect on the general health and productivity of the herd. New technology must be created to assist farms in meeting these demands while upholding high standards (Roberts et al. 2014).In this article, the concept of pain, how pain occurs in the body, the definition of pain in animal husbandry, what should be done to reduce it and some information about pain behaviours in animals were tried to be given.

CONCEPT of PAIN

The word "nociception," derived from the Latin nosera, which meaning "to harm," was used in the early 1900s to refer to nociceptive stimuli that could activate a range of sensory organs called nociceptors and jeopardize the body's or tissue's integrity (Rollin, 2011).It is thought that by inciting responses and activities, nociception acts as a warning system to safeguard the body. The purpose of this system is to reduce negative impacts. It makes it easier to dynamically maintain the general physiological balance. By inciting movements and reactions, nociception is regarded as a warning system that defends the body. This system aims to reduce negative consequences. It aids in dynamically preserving the general physiological balance. The terminals of nociceptor nerve fibers are not differentiated, and they are thin and unmyelinated. They are found at different densities depending on the nerve tissues. Examples of solid organ tissues devoid of nociceptor are the liver and brain.Polymodal nociceptors, which make up the bulk of nociceptors, are extremely sensitive to unpleasant stimuli. Without distinction, they respond to mechanical, thermal, or chemical stimuli (Steagall et al. 2021). Nociceptors provide data straight to the cranial nerve nucleus or spinal cord via sensory nerve bundles. The arrangement of afferents at the medulla network level, which is predicated on a spatially structured neuronal architecture, enables the localization of the information source. This construction, which also functions as the body base and substructure, forms the analytical component of sensation, the spatial localization of unpleasant stimuli carried by the body or originating from internal organs (INRA, 2009).

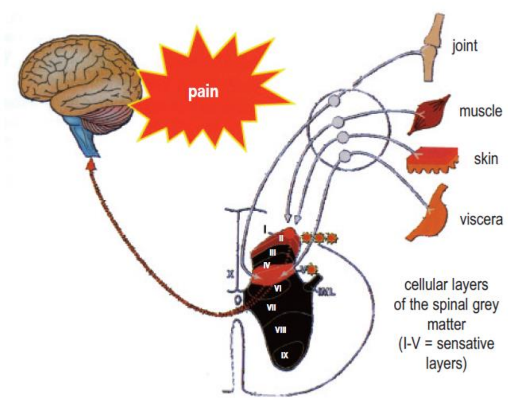


Figure 1. Human peripherally sensitive nociception afferents (Source: INRA, 2009)

Even bacteria have the basic sensory skill known as nociception, which is the ability to react to potentially harmful stimuli (Berg, 1975). Even though many nociceptors are multifunctional, it is frequently easy to determine whether animals can mount a response to noxious stimuli (Tsagareli, 2011). However, experts say that nociception and pain are different, or have a difference. Pain is a person's subjective perception of suffering, despair, and other unpleasant emotions, which explains why. It is difficult to demonstrate that animals feel pain in addition to nociception because other species may be able to detect negative internal mental states (Broom, 2001). The resemblance argument is based on the fact that the physiological and behavioral reactions of animals to nociception are comparable to those of humans to pain (Sherwin, 2001). Nevertheless, there are a number of problems with this concept. In other words, both the underlying neuroanatomy and the behavior of animals in response to pain are different from those of humans. It is important to know when these differences are important and when they are not. Understanding the biology of a particular species can help in this regard. Some specialists claim that although animals may behave as if they are in pain, this behavior may be a sign of nociception when pain is not there. Consequently, physiological and behavioral responses may not necessarily indicate the same mechanisms. Allen et al.. (2005) examined findings on pain in rodents and compared them with data from humans, concluding that the findings were not conclusive. However, Shriver (2006) looked at similar evidence and concluded that most animals feel pain "beyond reasonable doubt." The question of whether non-primate animals are capable of suffering has also been hotly debated due to the opposition to the notion that animals feel pain (Rose et al. 2014). It is impossible to demonstrate that animals do not feel pain, but it is equally impossible to demonstrate that they do.Animals' ability to feel pain must be proven beyond a reasonable doubt because it may negatively impact their general health and well-being.

PAIN FUNCTION

Nociception is a basic sensory system that alerts an animal or human body to potential damage. Animals are driven to avoid unpleasant stimuli and shield themselves from additional harm because nociceptive pathways link to brain areas crucial for motivation (Bateson, 1991).The emergence of such a system would therefore be adaptive as many species, like Drosophila melanogaster and Caenorhabditis elegans, have specialized receptors termed nociceptors that perceive painful stimuli (Im and Galko, 2012).However, different species have specific differences in how these nociceptors work. Animal groups are subjected to a wide range of nociceptive stimuli due to their evolutionary heritage and life history, including high pressure, harsh temperatures, hazardous substances, etc. Thus, in order to adapt to their surroundings, animals have developed nociceptive and potentially pain systems (Rutherford, 2002). While nociception has some advantages, in some animals, there is an excitatory motivational state similar to many aspects of pain in humans.It is undeniable that this stimuli-motivating state causes pain in at least some animals.It is necessary to consider the role of this stimulus-motivational condition. This is supported by the potential benefit of identifying the kinds of affects and manner in which different species can feel pain.Its main objective seems to be to give the animal a strong and enduring incentive to avoid a similar situation in the future. Stated differently, it helps the body defend against excessive harm, thereby gradually increasing resistance (Elwood, 2011). Consequently, nociception usually enables the quick reduction of tissue damage, while pain usually permits longer-term protection. But this characteristic by itself does not demonstrate that an animal feels pain.Nociception can also have long-lasting effects without activating higher-level neural processes (Smith and Lewin, 2009).

DEFINITION and SOURCE of PAIN

An painful sensory experience that symbolizes the animal's awareness of danger or tissue damage is one way to characterize it. This leads to the teaching of avoidance and protective reactions (Flecknell, 2008). The intensity of the stimulation, the extent of tissue or nerve damage, and prior pain experiences all influence the complicated impression of pain. Acute, chronic, regional, widespread, physical, emotional, adaptive, and maladaptive pain are all possible.To put it another way, the animal might feel multiple kinds of pain simultaneously. It is frequently simpler to determine whether pain is there than how severe it is.agony can not only make individuals anxious and afraid, but it can also make them anticipate more agony.Using praise when putting animals into a car for handling or transportation is a good example (Lizarraga and Chambers, 2012). Since it encompasses both a physiological sensory component and a psychological or emotional component, pain is a challenging term to define. The subjective perception of nerve impulses triggered by stimuli that harm or threaten to harm tissue is known as pain. This sensation should trigger vegetative behaviors, such as the withdrawal and escape reflexes, and is a response to an unpleasant stimulus. Zimmerman (1986) suggested that a painful experience in animals should lead to learned avoidance and affect the animal's behaviour, including social behaviour. Therefore, we may assess if an acquired experience is dangerous to the animal using behavioral and physiological parameters. Because we can communicate our feelings to one another, assessing pain in people is simple. Because they think animals cannot have feelings akin to human beings, many people find it difficult to comprehend that animals may experience suffering. According to Bateson (1991), animal pain is "an unpleasant sensory and emotional experience" and is most likely distinct from human pain. Because of its links to anguish, suffering, and sorrow, the public's concern over how farmed animals are treated is growing. Since it encompasses both a psychological or emotional component and a physiological sensory component, it is a challenging topic to describe. Pain is the subjective experience of nerve impulses brought on by a stimuli that damages or threatens to damage tissue. This sensation should trigger vegetative behaviors, such as the withdrawal and escape reflexes, and is a response to an unpleasant stimulus. Here, "stress" is defined as an organism's generic, non-specific response to stressors, even though the term is frequently used to refer to both aggressive causes and the organism's response to them.The brain stem and hypothalamus are specific locations for stress-related reactions. When these structures are activated, the so-called stress response—a set of brain reactions aimed at the spine and endocrine glands—occurs.Both central and peripheral connections exist between the autonomic nervous system and the pain neural network. It is well established that elevated heart rate, blood pressure, and peripheral respiration are linked to acute pain. The body is asked to adjust to the hazardous circumstances by a complicated sequence of reactions, such as energy mobilization, glucocorticoid anti-inflammatory characteristics, cardiovascular regulation by the autonomic nervous system, and their effects on the central nervous system..It should be highlighted, though, that while pain contributes to stress, a stress reaction itself need not be painful. Although stress reactions are not a hallmark of pain, they can aid in determining the type of unpleasant stimuli. Along with associated notions that are not directly accounted for, Figure 2 describes the many factors that determine the pain generated in this assessment.

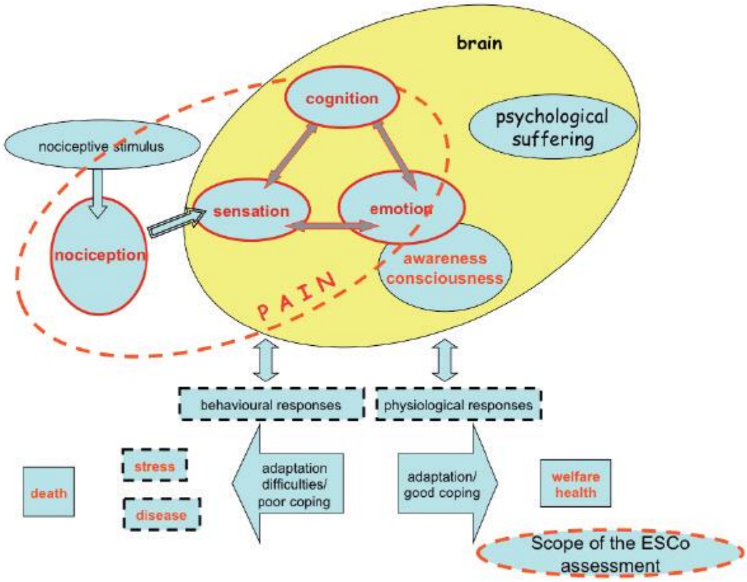


Figure 2. Basic concepts used in animal pain assessment

It's critical to differentiate between pain in humans and animals. However, applying human concepts of physical pain to understand animal discomfort is useful (Mahmoud et al. 2019). Animal pain serves the same purposes as human suffering and is at least as important to an animal as it is to a human. Pain in animals can change species-specific behavioural traits, such as prompting protective motor actions that result in learned avoidance and social behaviour, and human and animal perceptions of pain in response to the same stimuli may differ (BBSRC, 2016). An animal's awareness of damage or a danger to the integrity of its tissues is represented by pain, a negative sensory experience. To lessen damage, lower the chance of recurrence, and encourage recovery, it modifies the animal's physiology and behavior. According to Molony (1997), pain is considered dysfunctional (non-beneficial) when its length or intensity is inappropriate for the ongoing injury and when behavioral and physiological responses cannot lessen it.

Three subheadings can be used to classify the source of pain: neuropathic, visceral, and somatic. These are as follows:

- Somatic discomfort comes from the body's tissues, such as the skin, bones, muscles, and tendons.
- Visceral pain is caused by internal systems such as the heart, lungs, digestive tract, and reproductive system.

- Because of abnormal nerve activity processing, neuropathic pain originates in the brain, spinal cord, and nerves.

Table 1 lists the immediate and long-term consequences of a few unpopular farm animal husbandry techniques.

Table 1. Some breeding practices that should be done in the short and long term in farm

Process	**Short time**	**Long time**
Dehorning	Pain, bleeding	Infection
Castration	Pain, erythema	Infection, removal of internal organs
Foot trimming	Pain, bleeding	Infection
Milking	Pain	Mastitis
Docking	Pain, bleeding	Tetanus, Prolapse

Source: Sneddon et al.., 2000.

WHY IS IT IMPORTANT TO RECOGNIZE AND REDUCE PAIN IN ANIMALS?

Most scientific research using animals is of direct or indirect benefit to society. In other words, much of this research is directly or indirectly publicly funded in many countries (Youn et al. 2017). The public has a right and an obligation to discuss the methods used in animal research because of these two factors. People want animal experiments to be not only scientifically justified and valid but also humane, meaning that there should be minimal or no pain, stress, distress or other adverse effects on the welfare of experimental animals. When laboratory animals are exposed to conditions that cause pain or suffering, ethically, the benefits derived from the study should take precedence over the cost of the research (Prunier et al. 2013). This ethical justification depends on the difficult balance between benefits and costs to experimental animals in the form of pain, distress and euthanasia. Ethical expectations are embodied in the principles of the three R's**.** These are change, improvement and reduction (Russell and Burch 1959). They are also promoted by guidelines and supported by legislation.The 3Rs were first developed to safeguard the welfare of research animals, but they are now commonly recognized as global guidelines for the humane use of animals in studies or experiments. The three R's are defined as follows by the National Center for the Replacement, Improvement, and Reduction of Animals in Research (EFSA, 2023).

Replacement: Methods that change or eliminate the use of animals are referred to as replacement. Examples include using different techniques or substituting "lower" creatures for higher-level ones like mammals.

Remediation entails enhancing animal welfare in situations where using animals is not an option. These enhancements have an impact on the animal's lifetime and relate to husbandry or methods that enhance welfare and reduce suffering, agony, irreversible injury, or other welfare risks. Examples of improvements include training animals to cooperate in certain methods to reduce stress, meeting the needs of animals during housing, and using appropriate anaesthetic or analgesic drugs. The Committee also recommends the definition of humane endpoints for each experiment as an important improvement.

Reduction refers to methods that use fewer animals and enable researchers to obtain the same amount of information from fewer animals or more information from the same number of animals. These techniques involve the use of sophisticated noninvasive imaging techniques, statistical analysis, sample size determination, and suitable experimental design. Therefore, minimizing animal suffering whenever possible is crucial from an ethical and legal standpoint. For instance, newborn animals who experience pain early on may develop heightened pain sensitivity in damaged tissue in later life. All animals can recover more quickly if their discomfort is effectively managed.In other words, it can reduce mortality and minimize the potentially unexplained effects of untreated pain on many aspects of biological function.

HOW DOES PAIN OCCUR?

All vertebrates have a similar pain mechanism that uses local spinal reflexes to react to painful stimuli. Using a soft brush as a painless stimulus and a male lamb castrated with a rubber ring as an example of a painful stimulus can provide simplified perspectives on some of the peripheral effects of both painless and non-painful stimuli. Both central and peripheral pathways are crucial in the development of pain (Halachmi and Guarino, 2016). There are thousands of nerve terminals in a single millimetre in skin, muscle, bone, and other tissues when discussing peripheral systems. When activated, these nerves produce electrical impulses that go to the brain and spinal cord via nerve fibers at varying speeds. Signals can take anywhere from a few milliseconds [0.001s] to a few seconds [1.0s] to produce a "pain" impression or an appropriate physiological and behavioral response (Johnson et al. 2017). There are two significant quantitative forms of tissue stimulation. These fall into one of two categories: harmful and non-harmful stimulation.Non-noxious sensations, like touch, are frequently used by the animal to become conscious of its immediate environment and bodily state. Unless the thick, myelinated Aß nerve fibers are sensitized, as may occur with inflammation, this kind of stimulation rarely causes pain (Hewitt and Mahmoud, 2019). The time it takes for signals to result in a "pain" experience or a suitable physiological and/or behavioural response can range from a few milliseconds [0.001s] to a few seconds [1.0s] (Johnson et al. 2017). There are two significant quantitative forms of tissue stimulation. These can be divided into two groups: noxious and non-noxious stimulus. Non-noxious sensations, like touch, are frequently used by the animal to become conscious of its immediate environment and bodily state. This type of stimulation rarely results in pain unless the thick, myelinated Aß nerve fibres are sensitized, as could happen with inflammation (Hewitt and Mahmoud, 2019). The animal uses noxious stimulation to alert itself to stimuli that may or may not cause tissue damage. The "free" nerve ends of thin, myelinated (Aδ) and unmyelinated (C) nerve fibres in the tissues are called nociceptors, and they are responsible for detecting noxious stimuli.According to Guesgen et al. (2013), central mechanisms are changes that take place in the brain and spinal cord. The small nerve fibers from the nociceptors enter the grey matter of the spinal cord mostly through the dorsal roots of the spinal nerves. Nociceptive neurons are created when these nerve fibers come together.Nociceptive relay neurons in the spinal cord are involved in local spinal reflex responses, such as withdrawal from the stimulus, as well as complex defensive reflexes involving the brain and pain perception.Via channels like the spinothalamic tract, the spinal cord sends nociceptive impulses to the brain. The dorsal roots of the spinal nerves are the primary route by which the thin nerve fibers from nociceptors enter the grey matter of the spinal cord. Nociceptive neurons are formed when these nerve fibers combine.The spinal cord's nociceptive relay neurons play a role in both complicated defensive reactions involving the brain and the perception of pain, as well as local spinal reflex responses including withdrawal from the stimulus. The brain receives nociceptive signals from the spinal cord through pathways like the spinothalamic tract.

HOW CAN PAIN IN ANIMALS BE ASSESSED?

Methods that are objective, systematic, or easy to apply are used to measure animal discomfort. However, every evaluation method's validity, sensitivity, and reliability must be taken into account (Wathes, 2007). Since an animal's subjective perception of pain cannot yet be measured directly, the evaluation of animal pain is a value judgment based on the monitoring of behavioural and physiological changes. For this, a variety of indicators should be employed, and training and experience can enhance their evaluation.The judges with the most expertise will know the breed, species, and specific animal. However, it should be recognized that no one person is likely to be an expert on every species, and if possible, advice should be sought from individuals who are knowledgeable about the species in question, especially those who would normally care for the animal or species being studied.It should be appropriate for skilled assessors to determine that an animal is not experiencing severe discomfort.In the event that this assessment is not possible, pain should be considered and appropriate action should be done (McLennan, 2024). By doing this, it would be feasible to treat certain animals that are not in pain at a fair price without having to treat animals that are in excruciating pain.It is important to distinguish between the pain that the human evaluator experiences and the pain that the animal may experience. The assessor's emotional state should ideally have no bearing on the judgment of pain. Most people have a well-developed capacity to appreciate and share the emotions of others. In addition to being used appropriately to respect people's feelings, this skill is also used to animals and inanimate objects when it may not be appropriate. To prevent pain, it must be identified and, if feasible, quantified. People are usually able to identify, evaluate, and express their discomfort. It is impossible to evaluate this suffering in the absence of written or spoken communication; therefore, behavioral or physiological traits must be employed. The problem is really complex because animals cannot assess their level of discomfort.In several scholarly articles and reviews, the assessment of pain has been discussed. The majority of the examples utilized in these research are from animals, and the criteria used to evaluate human pain closely resemble the chosen traits.In addition to this similarity, rats and mice are often used in drug experiments to alleviate pain in humans. Because it preserves life, the discomfort brought on by pain has a great biological value. In other words, it sometimes warns us about tissue damage that has occurred or is about to occur, allowing the individual to take steps to prevent, minimize, or prevent the potential injury that could endanger their lives. The majority of characteristics taken into account when evaluating pain relate to behavioural or physiological alterations, and their purpose is to prevent or lessen the consequences of harmful stimuli that endanger the person's bodily integrity (Table 2). It might be challenging to identify the characteristics that explicitly point to the existence of pain because similar changes can also occur in stress, anxiety, or discomfort circumstances that do not necessarily entail a nociceptive component.The aforementioned changes may also lead to decreased performance qualities in animals.Another option is to use a tissue damage-based method to evaluate pain in both physiological and behavioral contexts. Put another way, it is logical to assume that negative outcomes will ensue once tissue damage has been detected.

Table 2. Physiological and behavioural parameters that pain can alter in mammals

Physiological criteria	Behavioural criteria
Hormone concentrations (in blood, urine or saliva) HPA axis: ACTH, glucocorticoids Sympathetic system: adrenaline, noradrenaline **Blood metabolites** Glucose, lactate Free Fatty Acids **Autonomic responses** Heart rate Respiratory rate Blood Pressure Skin, eye or internal body temperature Dilatation of the pupil Sweating **Inflammatory response (blood)** Haptoglobin, fibrinogen ... **Brain Activity** Electroencephalogram (EEG)	**Vocalizations** Number and duration Intensity Spectral components **Postures, movements** Reflex withdrawal Analgesic posture Licking, scratching, rubbing Tonic immobility Excessive or lack of locomotion Escape and avoidance **General Behaviour** Loss of appetite Agitation Prostration Isolation Aggressiveness

Source: Mellor et al. 2000.

Monitoring physiological indicators, observing behavioral changes, clinically evaluating tissue damage, or searching for declines in animal performance are all required to identify and quantify animal suffering. It should be mentioned, therefore, that a "pain score" cannot be obtained from a straightforward chemical or electrophysiological test; rather, a combination of multiple features is required. With an emphasis on ruminants, pigs, fish, and birds, the standards for assessing pain are described for each species.Despite the widespread belief that both birds and mammals are capable of feeling pain, the emotional component of pain varies depending on the species under study. Since the emotional component of general anesthesia causes the animal to become conscious, it is considered that pain is not experienced at this time. Since it is unclear whether or not this class of vertebrates experiences pain, fish are referred to as possessing nociception.The characteristics used to measure pain are typically stated in situations where standard husbandry procedures, such as the castration of males, cause discomfort. Depending on the stage of the entire slaughter process, different methods are used to quantify pain. This is particularly true during slaughter, when animals are typically stunned before being exsanguinated, and suffering may be severe. Therefore, before slaughter, it is helpful to understand the circumstances or activities that may cause pain. The potential bleeding stage is differentiated from the use of electroshock during slaughter. The assessment of pain is predicated on the animal's state of consciousness, which determines its capacity for pain perception, as well as behavior that enables the identification of preexisting pain cues. The carcass should be examined for wounds and lesions that can cause pain prior to death after it has been slaughtered.

DURATION of PAIN and CHANGES in BODY

There are two aspects of pain: its length and severity. If at least one additional evaluation method supports the length of pain, then a pain-related behaviour can be utilized to ascertain that duration (Stafford and Mellor, 2002). Therefore, if the behavior happens during a plasma cortisol pain response but not before or after, it might be permissible to use it to measure the duration of acute pain. However, a lot of behaviours, such as escape behaviours, only happen during the treatment itself and don't happen when you're in pain. These behaviors may indicate a specific type of acute pain that is hard for cortisol responses to appropriately communicate (Mellor et al., 2000). When cortisol is released, certain behaviors occur.For instance, following surgical castration and tailing, a period of cortisol secretion results in statue posture and other aberrant standing and movement behaviors (Lester et al., 1996).However, the early, middle, and late stages are characterized by restlessness, side-lying while awake, and normal laying while sleeping with a rubber ring (elastrator) secreting cortisol hormone levels (Mellor and Murray, 1989; Mellor et al., 1991; Molony et al., 1993). After an accident, there is acute discomfort that goes away as the body heals.

It is frequently intimately linked to quantifiable modifications in the mechanisms that shield the body from harm (AWIN, 2015). Although chronic pain lasts a long time, there is disagreement over whether recurrent episodes of acute pain turn into chronic pain or how long the pain must last to qualify as such. It's possible that there won't be any discernible alterations in how the defensive body functions. Two subcategories of chronic pain can be distinguished in this context: neuropathic and inflammatory. When infection or other inflammatory processes cause healing to take longer than anticipated, chronic inflammatory pain results. Lame sheep that suffer from foot rot, a chronic inflammatory illness, graze at their knees. Chronic neuropathic pain may also have an unclear onset and may not respond to treatments for acute or chronic inflammatory pain. One way to describe this illness is as "persistent" pain. A number of medical conditions can cause discomfort for sheep, which is a major welfare problem. Hoof injury and mastitis are the most common conditions.In many nations, certain husbandry procedures, such as castration and tail docking, are also typically painful (Langford et al. 2010). Australian Merino sheep also often shed their unwanted genital wool to deter dung flies. Sheep often receive inadequate pain management, and doctors do not always administer analgesics to sheep experiencing discomfort since it can be difficult to identify and assess pain in this species. Therefore, having accurate, dependable, and useful markers of sheep pain will greatly improve pain management and raise awareness among producers and vets that pain is a serious welfare concern. Additionally, behavioural and physiological signs can be used to measure pain (McLennan et al. 2016). Physiological signs include hyperalgesia plasma cortisol hormone levels and acute phase proteins. Hyperalgesia, or an increased pain response to unpleasant stimuli, can be measured by applying a mechanical stimulation that gradually rises in pressure until the animal moves in reaction. Although blood-based physiological markers are commonly used in research, they are not appropriate for use in outdoor environments. Since general behavioural changes are sensitive and noninvasive markers of pain, they serve as the foundation for most pain evaluation instruments. Animals have recently benefited greatly from modifications in facial expressions (Fitzpatrick et al. 2006). Sheep can also be scored for mastitis and lameness using existing techniques. Examining general behavioral alterations brought on by pain, it has been noted that castrated or tail-docked lambs exhibit aberrant postures, lip curling, shaking, and vocalization. Reluctance to move, licking, rubbing, or scratching of painful areas, grinding of teeth, pursing of the lips, altered social interactions, and changes in posture to avoid moving or touching a painful body part are some of the symptoms that sheep may exhibit when they are in pain from practical rearing procedures (NRC, 2009).

BEHAVIORS SHOWN by ANIMALS in PAIN

Normal Posture

According to Molony et al. (2002) and Manteca et al. (2017), lambs and calves typically lie on their stomach or back with their head up (V2) or down (V1) and both of their fore and rear legs bent upwards (Figure 3). Animals occasionally lie on their sides, although typically only for brief periods and mostly in warm weather (Stafford and Mellor, 2002).

Figure 3. Sleeping position of sheep in pain: belly down, head down and belly up, head up

Abnormal postures

Abnormal poses are those that are rarely adopted by "normal" animals. Pain from many body parts and species can accompany abnormal postures (Fogarty et al. 2020). Lambs suffering from unpleasant situations may assume the following postures:

1. Lying in side/horizontal position	**2. Lying down with the hind legs extended**
 	 The lamb on the left has its legs tucked in and is positioned in a typical, comfortable ventral (sternal) posture (V2). The lamb on the right has its hind legs fully extended and is resting ventrally. Keep in mind that, unlike when lateral lying, the undershoulder is not on the ground.
3. Lying down with only the hind legs partially extended	
 Only when laying in a ventral position with the hind legs slightly extended (V3) can mild pain occur, but it may be accompanied with restlessness, relaxed quarters, or an increased frequency of tremors.	**4. Normal V2 lying down shaking**  
5. Doing a dog sit, trying to keep the affected area off the ground (Vg).	**6. Abnormal standing/walking**
	 Swaying, leaning against fences/walls, repetitive stamping, kicking and tail wagging, falling, yawning, and abnormal walking patterns (e.g. sideways, backwards, circling).

7. 'Statue' pose  	Constantly standing still, often associated with other postures such as trembling, yawning, hunched back, tucked-in tail, and pulled-in abdomen

Piglets, lambs, and calves observed following castration are examples of these positions. Depending on the species, the impact or violence experienced by the body, and the location and source of the pain, changes in everyday activities might range from complete immobility to manic hyperactivity. Significant motions may result from pain in particular locations. For instance, when an animal has pain in the head region, it may twitch its ears, shake its head, or grind its teeth (Graf and Senn 1999; Faulkner et al. 2000). When they experience pain in the tail region, they may move their head in the direction of their tail or rub their tail against the ground or fences (Hay et al. 2003).

FACIAL CHANGES DURING PAIN

Facial expression grading systems have been established to evaluate pain in a variety of animal species, such as lab animals, horses, and rabbits. These methods are efficient, precise, and trustworthy for determining how much pain an animal is experiencing. A more recent development is the Sheep Facial Expression Scoring System (SFES) (McLennan, 2024).It has been demonstrated that the SFES can detect sheep that are experiencing pain from foot rot or mastitis. Very little training is needed, and interobserver reliability is very high. According to the researchers' findings over a short training period, "the SFES provides a reliable and effective method for assessing pain in sheep." The SFES can accurately distinguish between healthy sheep and sheep suffering from severe diseases. This grading system has been depended upon and accurately used by trained observers to evaluate sheep pain. Adult sheep's overall face pain score decreased as a result of illness treatment. Overall pain levels were found to positively correlate with lesion and lameness scores.As shown in Figures 4 and 5-6, the five SFES components are rated as 0 (not present), 1 (partially present), or 2 (present).

• Orbital constriction: In this condition, the eyelids close the palpebral fissure, and the eye aperture narrows.

• Cheek constriction: The masseter muscle area of the cheek has a more convex shape.

• The ears are turned caudally and ventrally, which is considered abnormal ear posture.
• A flat or concave chin profile is an example of an abnormal lip and chin profile.
• Abnormal philtrum and nostril shape: There is a "V" formed between the nostril apertures.

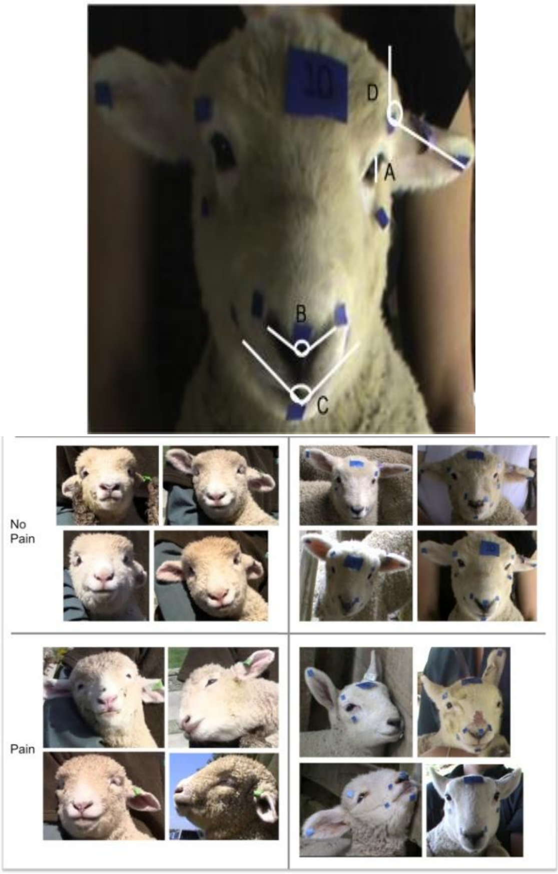


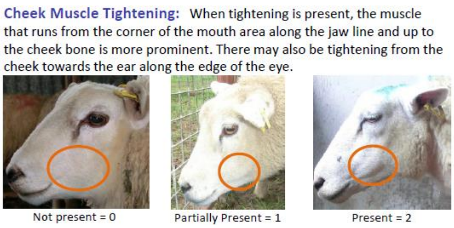
Figure 4. Fields used in the Facial Expression Scoring System in Sheep (SFES)

Source:Noor et al. 2020, https://www.cl.cam.ac.uk/~pr10/publications/fg17.pdf

Figure 5. Normal and abnormal sheep face images.

The first row is for normal and the second row is for abnormal sheep faces using SFES.

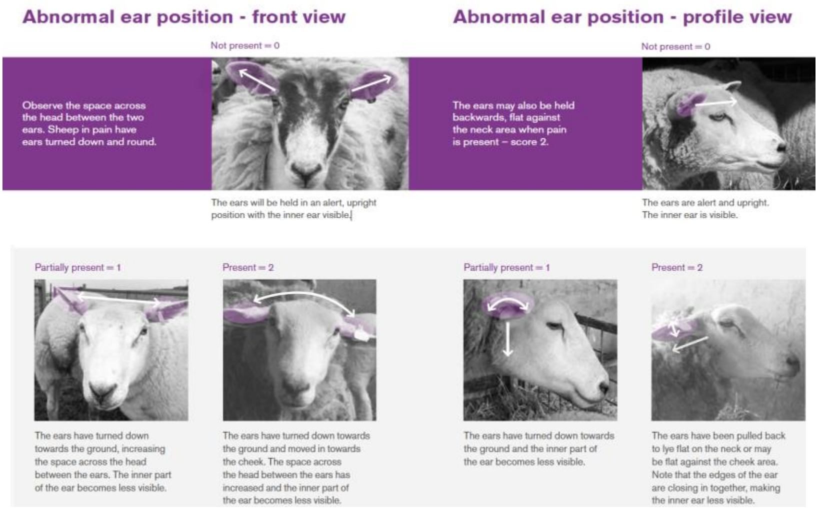
Eyes - Degree of Eyelid Closure **Cheek - Tightening Degree**



Shape of Ear and Head

Abnormal Ear Position: Normally, ears are held erect and the inner part of the ear is visible when viewed from the front. As the position becomes abnormal, the ears drop and turn towards the face, so the inner part of the ear is not visible. The ear may be held in a backwards position. Normal ear position will differ depending on breed type; however, the changes that occur are the same for all breeds.

Not present = 0 | Partially Present = 1 | Present = 2



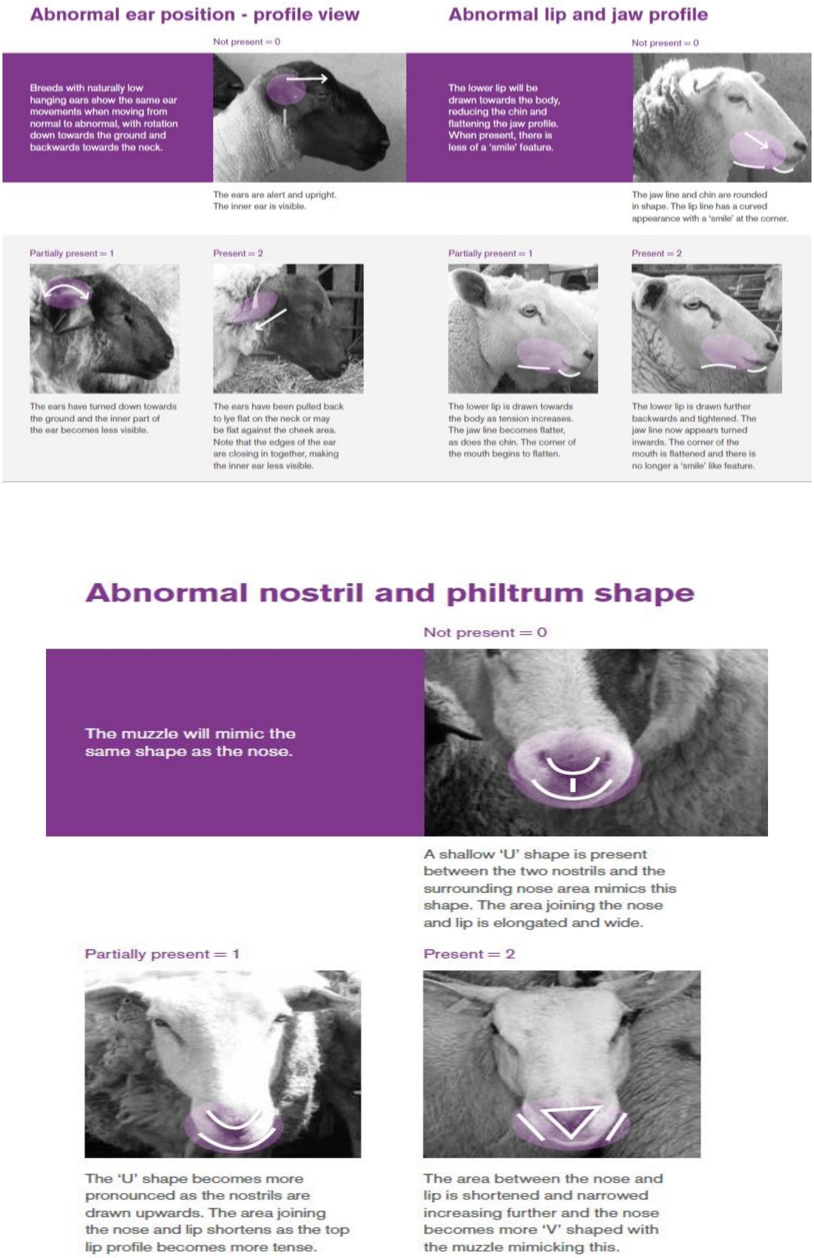


Figure 6. Abnormal ear, lip, jaw, nostril and philtrum shapes in sheep

A METHOD for DEFINING PAIN in SHEEP: FACIAL EXPRESSION

According to McLennan et al. (2016), the Sheep Facial Expression Scale (SFES) is a useful instrument for assisting producers and veterinarians in identifying and evaluating sheep suffering.Facial expression is a measurement of how the face or "action units" of muscles change in response to emotional inputs (Larochette et al., 2006). When an animal feels pain, this is most likely its automatic response. It is believed that facial expressions directly convey the level of discomfort (Figure 7).

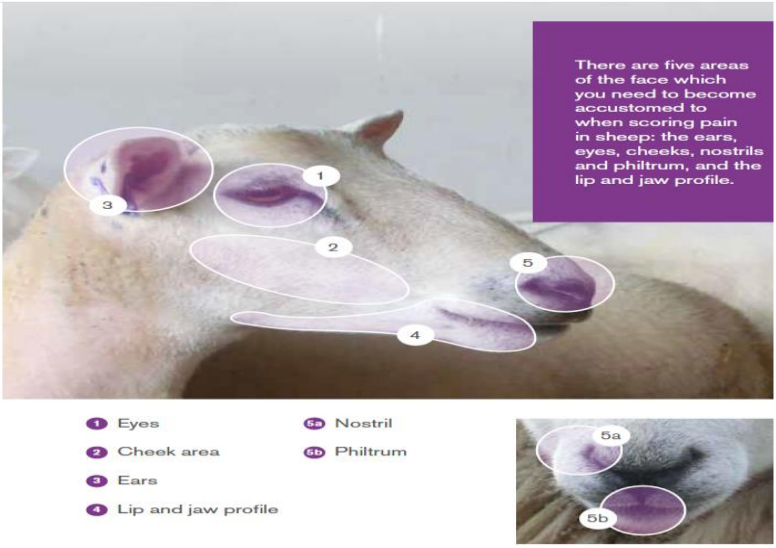


Figure 7. A Sheep Facial Expression of Pain Scale

This is because human facial expressions of pain are becoming harder to "hide", and pseudo pain is readily identifiable. Facial expressions can reveal the temporal nature of pain. It may identify whether pain is constant or might be changing by continuously examining facial expressions.Better pain management techniques may result from observers' increased understanding of the frequency and duration of pain as a result of ongoing assessment and thorough research on the subject. To score pain facial expressions in real-time, a human being with the ability to influence pain expression must be present (Kunz et al. 2011). Improving the screening process requires an automated system that can learn individual facial expressions and then recognize when those expressions change, suggesting the existence of a potential disease. Any subjectivity in the evaluation is eliminated by a well-integrated automated system that guarantees consistency in pain estimation (Porter et al. 2012). Because an observer does not need to be present all the time to evaluate these changes before and after therapy, it improves the efficacy of care. It creates a new application for the technique of measuring sheep discomfort by fusing automated facial expression analysis with SPFES ideas.

Sheep are at the vanguard of this technology and have amazing breeding potential as a result. Recognizing pain Because of their ability to read facial expressions, humans can roughly identify the appearance of someone who is experiencing pain. According to research, humans can tell when an animal is obviously in pain because we are drawn to their expressions when evaluating suffering. But it's crucial to pay attention to more subliminal clues or know when to give painkillers. Sheep do indeed show signs of distress on their faces. Five parts of the face need to be evaluated. Sheep's facial expressions during painful illness have been uncovered by recent research in this field. To assist breeders and veterinarians in recognizing and measuring pain in sheep, a Sheep Facial Expression of Pain Scale was created (Lu et al. 2017). Scientists have evaluated the scale's accuracy and dependability, and with little instruction, others can correctly determine whether or not sheep are in pain. When evaluating sheep's pain, one should be aware of five facial features: the ear, eye, cheek, nose, and the profile of the chin, lip, and philtrum. To properly evaluate each area of a sheep's face, it will be required to observe it from both a frontal and lateral perspective. Never score an animal while it is chewing or has food in its mouth.It is advised that pain medication be taken into consideration if a sheep's overall pain score is greater than 5. A veterinarian may need to be consulted about this. After a day, the animal's expression should be evaluated again, and if pain medication is given, the animal should be monitored for a few hours to determine how well it works.

LAMENESS SCORING

Lameness is the term for aberrant mobility, which is most obvious when the animal is in motion (FAWC, 2011). Sheep frequently suffer from lameness, which is mostly brought on by foot infections. A sheep that is lame is in pain, and numerous investigations have demonstrated that lameness results in hyperalgesia (Figure 8). A 4-point scale that considers factors such as stride length, head nodding, smoothness of movement, whether weight is distributed evenly across all four feet, and reluctance to stand or move can be used to evaluate lameness (AHDB, 2020).

Topallık yok(0 puan)		Hareketlerde sorun yok, vücut ağırlığı eşit bir şekilde dağılmış, Ayaklar arasındaki mesafeler eşit. Yürürken baş çok az aşağıda, duruşta bir sorun yok
Az topallık durumu (1 puan)		Yürürken başın sallanmasıyla birlikte kısa adımların atılması çok belirgin, Etkilenen ayağa bağlı olarak yerle temasın daha az olması söz konusu
Topallık var (2 puan)		Başın sallanması çok belirgin, yürürken etkilenen vücut ağırlığı diğer tarafa verilmiş, otlama ya da hareket ettiğinde dizler üzerinde durmaya çalışma
Şiddetli topallık durumu (3)		Ayakta durma ya da hareket edemediği için uzanma/yatma davranışı çok belirgin

Figure 8. Lameness scoring in sheep

Kaynak:chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://toolkit.bii.co.uk/wp-content/uploads/2021/10/5.9-Sheep-Resources.pdf www.fas.scot/downloads/five-point-plan-tackling-lameness-sheep/

MASTITIS SCORING

Mastitis is an infection that causes pain and hyperalgesia in dairy sheep's udders, according to Pegreffi (2019). Mastitis can be assessed using a 3-point rating system that takes into account the udder's redness or hardness, as well as the existence of lumps and lesions (Figure 9).

Figure 9. Example of mastitis scoring card in sheep

Kaynak:chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://toolkit.bii.co.uk/wp-content/uploads/2021/10/5.9-Sheep-Resources.pdf https://www.izs-sardegna.it/quaderni/Mastitis%20in%20small%20ruminant.pdf

DOCKING, CASTRATION and PAIN MANAGEMENT in SHEEP

For the purpose of the sheep's health and wellbeing, any method that could result in pain and suffering must be evaluated against the procedure's necessity. Despite being occasionally popular husbandry practices, castration and tail docking should be done less frequently due to their discomfort, particularly if there are alternative management choices available (Guesgen et al. 2016). In cases when castration and/or tail docking are deemed necessary, the farm health and welfare strategy should include veterinary practice.Ideally, local anesthesia and appropriate analgesics should reduce related pain; however, the lack of approved medications for use in sheep makes this more challenging. When possible, management strategies that aim to achieve slaughter weight prior to sexual maturity should be employed as long as welfare is preserved (Molony et al. 1993). The ram lambs should be physically and visually separated from the female lambs to prevent the commencement of breeding activity when sexual maturity is attained before slaughter.The management of the farm as a whole should only consider castration as a last resort. Ideally, local anesthesia and appropriate analgesics should reduce pain because there aren't many approved products. Breeders and veterinarians should collaborate to make sure that prevention is a crucial component of the farm health and welfare plan since the health and welfare effects of dung flies should not be understated (Lomax et al. 2010). Whenever possible, specific management techniques that are appropriate for the climate, location, and flock should be employed to reduce the need for docking. Castration should only be performed after consulting a veterinary surgeon and as part of a farm animal health and welfare plan.Only a qualified person who abides by the law should perform this task. Given the lack of approved medications, local anesthesia and appropriate analgesics should be utilized whenever possible to reduce pain (Small et al. 2020). Until the ewe/lamb relationship is solidified and adequate colostrum intake is attained, lambs should not be castrated. Male lambs will need extra attention because their tails can be severed at the same time. Only a veterinary surgeon should conduct surgical castration at any age, utilizing local anaesthesia and, if feasible, suitable analgesics. Tail docking should only be carried out as part of a farm animal health and welfare plan after consulting with a veterinary surgeon. By law, care should be taken to guarantee that this treatment is carried out by a qualified and capable individual. Due to the lack of approved products, local anesthesia and appropriate analgesics should be used whenever possible to alleviate discomfort (Hemsworth et al. 2009). It is not advisable to dock a lamb's tail until the bond between the ewe and the lamb has formed. At any age, surgical docking should only be performed by a veterinary surgeon who is properly anesthetized and analgesic.

SUGGESTIONS

Both physiological and behavioural signs can be used to evaluate pain. Acute phase proteins and hyperalgesia plasma cortisol levels are examples of physiological markers. Applying a mechanical stimulus that progressively increases in pressure until the animal responds by moving is one way to quantify hyperalgesia, which is an enhanced pain response to noxious stimuli. Physiological markers recorded in blood are not useful in the field while being commonly employed in research. Since general behavioural changes are sensitive and non-invasive markers of pain, they serve as the foundation for most pain assessment instruments. Changes in facial expressions have been quite helpful recently. Sheep can be scored for mastitis and lameness using several methods. Sheep are said to have trouble recognizing pain, which contributes to the fact that pain management in this species is frequently insufficient. Since behavioural changes are sensitive and non-invasive markers of pain, they serve as the foundation for most pain assessment instruments. Sheep's facial expression changes are a great way to gauge their level of distress. There are also scoring systems for sheep lameness and mastitis. Decisions on sheep management depend on accurate and efficient pain assessment. Rapid disease detection and treatment by committed and knowledgeable animal caregivers is crucial to minimizing farm animals' suffering. It is important to not undervalue the nursing care that can be given by providing a comfortable setting with convenient access to food and water. Preventive measures, such as increased vaccination use, should be considered when making decisions on herd/flock health issues. On the farm, comparative improvements can be a strong motivator. In conclusion, sheep's welfare and production are negatively impacted by pain. Knowing when pain is present enables you to take early action to stop additional suffering. The general health and welfare of the herd will improve if pain is effectively managed by keeping an eye on changes in the animal's facial expression.

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CHAPTER 3

Critical Control Points and Their Importance to Reduce Postpartum Lamb Mortality

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INTRODUCTION

For a sheep farm to be deemed typical, what lamb mortality rate is necessary? Many breeders often pose this question (Binns et al. 2002). However, the answer to this issue is not simple because it depends on several factors, such as the lambing rate, flock management strategies, and the production method. Although sheep breeders occasionally ask questions to determine the problem of lamb mortality, it is not a very accurate approach to look at the general lamb mortality rate without considering the production figures of the farm and specific causes of mortality (Hinch and Brien, 2014). Determining the kind and extent of lamb mortality is a better strategy. To identify the farm-specific causes of lamb mortality, a strategy must be developed, even if this approach may vary from year to year. While some methods for reducing lamb mortality can significantly lower the likelihood of an issue, others are more challenging to implement. Once the problem-solving solutions have been identified, it would be more accurate to concentrate on the methods that have the most impact. A key factor in sheep flock productivity is lamb survival. This topic has been one of the highest priorities in recent years, and many studies have been done on it. Recent studies on the prevalence and variety of lamb mortality in countries such as Australia and New Zealand have also been carried out in light of this (Campbell et al. 2009, 2014). Prominent among these causes are dystocia, cold shock, starvation, failure to find the dam and wild animal attacks. Similarly, the importance of birth weight in contributing to such lamb losses and strategies to increase lamb survival are being developed and discussed. Strategies examined include improving sheep nutrition, providing appropriate housing and selection to build resistance to cold shock and improving dam-offspring behaviour.

In extensive sheep farming, the source of the problems is the low survival rate of lambs depending on weaning age and low fertility (Fowler, 2007). The majority of research concentrates on the possibility of genetic gain, even though feeding and herd management strategies have been thoroughly investigated and shown to improve lamb survival rates. For example, it helps determine selection strategies to increase these advantages and improve fertility in sheep farming in Australia in general. Using threshold models indicates that heritability may be higher than the low heritability estimate for lamb survival obtained from linear model analysis (Forrest et al. 2007). The substantial genetic gains found in long-term selection experiments could be explained if this method is accurate. Because epigenetic mechanisms can obscure and/or confuse genetic variation and covariance, they may make it more difficult to select for and identify quantitative trait loci. By identifying elements that are subject to selection, these impacts can be considered in genetic studies if enough information is available. Finding effective criteria to improve lamb survival in indirect selection has been difficult (Oldham et al. 2011). Temperament, dystocia, and dam-offspring behavior are among the traits that have been researched, and there is only a weak genetic association between these traits and lamb survival. Among the investigated lamb behaviours and thermogenic indicators, delayed bleating or neonatal rectal temperature are moderately genetically related to lamb survival without human intervention. The more promising of these methods should be further studied for use in industry. Lastly, it would be more acceptable to take into account other selection factors connected to lamb survival rather than using direct selection for it. This article will provide brief information on how to evaluate the causes of lamb mortality and how to implement approaches to increase productivity on the farm while maintaining animal welfare standards.

ANALYSIS OF LAMB DEATH CAUSES

Most of the lamb deaths occur within the first twenty-four hours of the lamb's birth. When lamb deaths are especially severe, it is helpful to keep an eye on things (Ehrhardt, 2020). The main causes of lamb mortality are effectively identified by this method (Thompson et al. 2011a, 2011b). Obtaining a basic information note for the evaluation of possible lamb deaths due to the identified reason will be beneficial in this regard. These observations can be utilized to differentiate between the primary causes of death using a sharp knife or scalpel, basic anatomical features, and the approximate age of the lamb's death. The following factors are the main causes of lamb loss: a) stillbirth; b) hunger or cold shock; c) embryo deaths and related problems, and d) respiratory diseases (for example, pneumonia). One crucial characteristic to differentiate among them is the age of the lamb at death (Palmer, 2010).

Premature loss. Premature lambs do not have enough lung surfactant[1] to survive. Therefore, premature lambs are often stillborn or live only a few minutes after birth. These lambs have a low hair cover and a relatively small body size (Refshauge et al. 2011). Less than 2% premature loss is considered "normal," but higher lamb deaths warrant more research. If there is a persistent stillbirth and these deaths take place within the first three days of life, the rate may be higher than anticipated, even if the flock's incidence of premature birth is low.

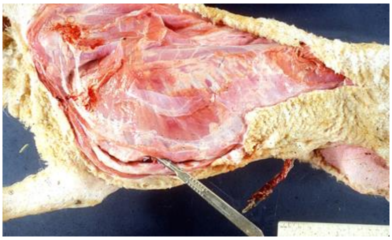

Figure 1. The anterior shoulder is removed to reveal the brown fat beneath the scapula. The chest cavity should be opened by making an incision. https://www.canr.msu.edu/news/critical-control-points-for-lamb-survival

the first 24 hours of loss. Distinguishing stillborn lambs from those who pass away during the first day due to other causes is crucial (Brown et al. 2014). Stillborn lambs have uninflated lungs, abundant brown fat reserves, and intact soft tissue covering the hooves. A simple incision to expose the rib cage, followed by two more incisions to open the thoracic and abdominal cavities (Figure 1), will reveal whether the lungs are inflated (Figure 2) and whether brown fat is depleted at the time of death (Figures 3a, 3b). Brown fat surrounds the kidneys at birth, and the depleted reserves are dark red. The lungs of fasting lambs are inflated, but the rate of brown fat depletion varies depending on the rate of heat loss. Lambs can easily deplete their fat stores within 12 hours in cold climates, whereas it may take several days in temperate conditions. Lambs born in extreme cold die before their brown fat stores are depleted because they lose body heat rapidly. More obvious are swollen lungs and depleted brown fat reserves (Holst, 2004).

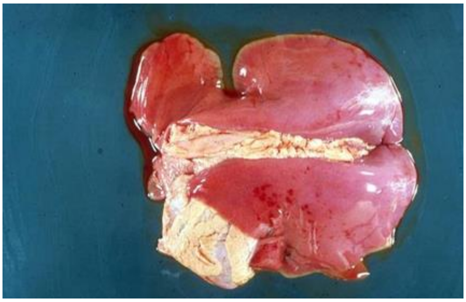

Figure 2a. Uninflated lungs of a stillborn lamb

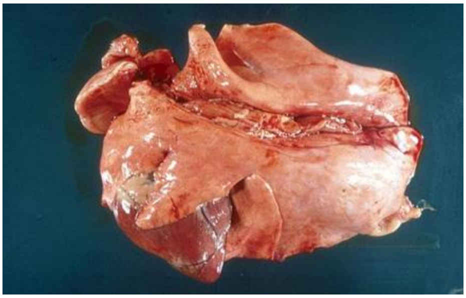

Figure 2b. Inflated lungs (plus heart) of a lamb that died of starvation on day 1.

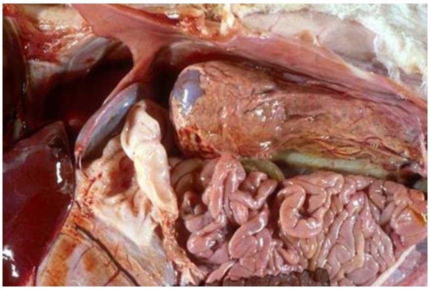

Figure 3a. Abdominal cavity of stillborn lamb. Note the large amount of brown fat covering the kidney and the lack of digestive material in the intestine.

Figure 3b. The abdominal cavity of the lamb starved on day 3.

Loss of days 2-7. Lambs that die due to starvation or adverse environmental conditions below 0°C for more than 36 hours usually suckle but cannot consume enough colostrum to maintain heat production. Lambs are more likely to die from pneumonia during their first week of life than during subsequent weeks (Blumer et al. 2013). Lesions in the lung region surrounding the heart are the most common indicator of these deaths (Figure 4). Since pneumonia spreads quickly in newborn lambs, the first indication could be death. Other significant but less frequent causes of death include diarrhea and enterotoxemia. A milk-filled stomach, minor intestinal hemorrhage, and abrupt death are all clear signs of enterotoxemia in the first week following delivery. E. coli- caused diarrhea, which includes watery diarrhea, increased salivation, and a chilly mouth, are additional significant symptoms (Hocking-Erwards et al. 2011).

Figure 4. Internal organs of a lamb that passed away on the third day due to pneumonia.

Lamb Mortality Patterns

It is crucial to realize that while some patterns of lamb mortality are easier to control, others are more challenging. Lamb mortality rates are displayed in Table 1 according to fertility, or the quantity of lambs born. Since the majority of lamb deaths happen in the first few hours after birth, abortion is not included in this table. As previously noted, early lamb mortality of more than 2% may be a starting point to investigate possible abortion (Kenyon et al. 2014). These lamb mortality rates are derived from the farmer's field experience and an analysis of numerous field research on first-week lamb loss in pen and pasture lambing scenarios. Nonetheless, the figures in the table are approximations and must be assessed appropriately.

Table 1. Lamb mortality in the first week following birth and lambing percentage

Characteristics	Kuzulama Yüzdesi			Effect level
	Low	**Orta**	**High**	
Death	Average=%130	Average=%165	Average=%200	
Still-birth(all time)	1-8	2-12	4-18	Low
Starvation/Cold stress	1-10	2-15	3-20	Medium
Respiration diseases	0-10	0-15	0-20	High

Explanation: The range of losses that could occur under various farm conditions is used to determine lamb loss ([dead lambs/total live and dead lamb births] times 100).

Lambing percentage = total full-term lambs born dead or alive/several ewes with full-term pregnancies*100. Potential impact: Low=0-30%, Medium=30-60%, High=60-100% reduction in death loss.

An example of a difficult loss to affect is non-disease-related stillbirth loss in high-yielding sheep breeds. A flock with a lambing rate of 225% may find it difficult to reduce overall loss to less than 15%, even while "acceptable" lamb mortality rates may seem suitable, even with excellent preventive measures and ideal lambing time management (Robertson et al. 2011). The higher rates of stillbirth loss (5–8% of lambs may be lost) in high-yielding ewes (lambing rates > 200%) are partly caused by "placental insufficiency" and dystocia. While it is difficult to prevent such lamb losses, preventive actions can change or reduce other forms of mortality in flocks (possibly genetically). The preventative steps on this list can significantly reduce loss in post-natal lambs during the first week of life, either by themselves or in combination.

WHAT CAUSES LAMB DEATHS?

Some insights into the causes of lamb deaths can be gained by documenting individual births both before and during lambing. Put differently, five fundamental metrics that should be taken on this topic indicate the potential trouble spots on the farm (Paganoni et al. 2014a, 2014b). These are;

a. Empty Ewes (not pregnant) during pregnancy control with ultrasound - Number of ewes that are not pregnant during pregnancy control / Total number of ewes/lambs given to the ram x 100

b Number of lambs detected during pregnancy – calculated from pregnancy control results. Control percentage = (Number of lambs detected in pregnant ewes/Number of ewes given to rams) x 100

c Lambing percentage (live-born lambs) – When comparing the number of lambs controlled during pregnancy with the lambs after birth, this shows how many lambs died during pregnancy due to abortion. It should not be disregarded since a lot of stillborn lambs could be the result of medical issues, including infectious infections, miscarriage, or nutrition issues.

d Number of lambs that died at birth (Lambs out): This illustrates the ratio of lambs born to those that perished on the farm in their first few days of life. A decrease in numbers may indicate underlying health problems, hygiene issues or problems with colostrum intake

e. Rearing percentage: Mortality during the first several months of lambing is shown by the ratio of lambs sold to lambs at weaning. These are more likely to be linked to health issues, including infectious illnesses and inadequate parasite management. Rearing percentage = (Lambs at weaning/ewes given to rams) x 100

HOW TO PREPARE FOR THE BIRTH SEASON?

The lambing season is quickly approaching if births are scheduled for the spring. To optimize the lamb survival rate and create a stress-free environment for you and your animals, it is crucial to prepare the farm for lambing (Kelly et al. 2014). It is helpful to focus on a few of the headings below because of this. These are;

Attention Should Be Given to the Body Condition and Nutrition of Pregnant Sheep: Approximately 70% of the fetus's growth takes place during the final six weeks of pregnancy. For a pregnant sheep, this is one of the most taxing periods in terms of energy. More attention must be paid to the physical state of the sheep. A Body Condition Score (BCS) of 3 to 3.5 is ideal. Sheep that are very fat are more likely to have difficult births and pregnancy toxaemia because too much fat in the body cavity makes it difficult to accommodate a full rumen and growing lambs. Sheep cannot consume enough Tylenol to meet their energy needs. Supplemental feed should be administered to ensure that the calves are born with enough size and vitality, as a very thin sheep may also suffer from pregnancy toxaemia, in contrast to overfeeding (Hocking-Edwards et al. 2008). The nutrient needs of a pregnant sheep vary depending on its live weight and age. The need for nutrients will be proportionately higher than in sterile animals, depending on the number of offspring, whether single or many. In some cases, high-energy feed may be necessary, but overfeeding should be prevented. It is crucial to keep in mind that pregnant sheep need energy as well as certain vitamins and minerals (calcium, selenium, vitamin E, etc.).

Calcium requirements: Calcium requirements in sheep approximately double in late pregnancy. Low calcium levels in the diet can cause milk fever, and very high calcium intake can cause urinary tract obstruction. In general, cereals are a poor source of calcium, and forages, especially legume hay, tend to be much better. However, calcium can also be supplemented with dicalcium phosphate, bone meal or limestone mixed into the diet.

Selenium and Vitamin E: In late pregnancy, vitamin E and selenium are transferred straight from the placenta to the fetus. Lambs with low levels of both may develop muscular dystrophy or white muscle disease, which can result in issues like inadequate placenta expulsion and poor reproductive success. Adequate mineral-vitamin blocks or their correct addition to the diet will minimize potential problems.

b. Herd Health-Protection Plan Should Be Controlled: Making plans for herd health and safety should be a continuous activity. Records from prior years should be reviewed to identify key control points on the farm and to pinpoint places where issues have previously arisen (Ipsen, 2014). Although it is good to have general protective protocols for problems such as diarrhoea, the main areas to consider when evaluating the health-protection plan for pregnant sheep should be the vaccination plan and parasite and antibiotic applications.

c. Vaccination Plan for Pregnant Sheep: Ewes should receive vaccinations against tetanus, pasteurellosis, and clostridial illness at least four to six weeks before to lambing. But it's important to keep in mind that ewes who have never received a vaccination or whose status regarding immunizations is unclear should get two shots in late pregnancy, separated by four weeks (Kopp et al. 2014). After vaccination, ewes will be able to transfer antibodies to their lambs via colostrum, which can help increase the survival of lambs.

d. Parasite Control in Pregnant Sheep[3]: d. Parasite Control in Pregnant Sheep: Periparturient heaving causes increased numbers of parasite eggs to be shed into the environment, which in turn leads to parasite infections in new lambs with inexperienced immune systems. During the prepartum phase, treatment with effective antiparasitic medications is a beneficial approach; however, because drug-resistant parasites are becoming more prevalent, alternative approaches would need to be taken into consideration. FAMACHA and body condition scores can be used to assess whether anthelmintic medication is required rather than treating your flock as a whole, and it has been shown that increasing protein intake reduces the quantity of fecal parasite eggs (Clune et al. 2021). To lower the risk of parasites, it might also be advantageous in some situations to keep ewes and lambs in dry or enclosed spaces. However, there is a serious risk of parasite infestations in unmanaged pastures with a lot of animal movement. Because of the potential for coccidiosis, a rise in fecal parasite egg counts before parturition should be cautiously watched. Coccidiosis is a single-celled parasite that is naturally present in the sheep's digestive tract and inhabits the intestinal lining cells, despite not being a parasite. During an increase in egg counts, the number of coccidiosis oocysts increases and is shed into the environment via the ewe's faeces. A coccidiosis may be administered to reduce the number of oocysts shed into the lambing pen or environment and to help prevent abortions caused by Toxoplasma gondii, the single-celled parasite responsible for toxoplasmosis. Depending on your choice of coccidiosis, it can help increase rumen capacity and

[3] It enters a period called periparturient rise. The dam's immunity is further weakened by the additional stress that parturition and nursing place on her. The timing causes the number of sensitive animals to rise in tandem with the preparatory egg rise. Season, breed, and animal age and developmental stage all significantly impact an animal's vulnerability to parasites. Young animals grazing continuously on permanent pastures are most susceptible to parasite infections. Animals born in spring are greatly affected by parasite eggs laid on summer pastures when grazing on these pastures. Adult and dry animals are less susceptible to parasitic infections than young ones.

efficiency, as well as help the ewe better meet her energy needs throughout pregnancy.

e. Antibiotic Protocol for Sheep During Pregnancy: Antibiotics used before or during the first trimester of pregnancy may help prevent abortions caused by Chlamydia and Campylobacter species. The FDA authorized the administration of 80 mg of chlortetracycline per animal per day in a research carried out in the USA; nevertheless, a veterinarian should always be consulted. Antibiotic administration protocols should be discussed with a veterinarian to avoid causing widespread antibiotic resistance.

f. Prepare the Lambing Pen for the Birthing Season: The lambing pen should be ready for birth at any time and should be set up well before your first lambs are due. The shelter needs to be cleaned and disinfected, and you must be careful to find and remove any drafts.

When used before or throughout the first trimester of pregnancy, antibiotics may help prevent abortions brought on by Campylobacter and Chlamydia species. In a study conducted in the USA, the FDA approved the daily administration of 80 mg of chlortetracycline per animal; nevertheless, a veterinarian should always be consulted. Clean, dry bedding should be provided for the animals that will give birth, and all heater lamps should be double-checked to ensure they are working properly (Fig 5). If lambing is on pasture, ewes should be placed on clean, well-rested pasture with access to shelter. To prevent infection, it is a good idea in this situation to set up jugs for problematic births and, if at all feasible, to arrange to rotate pastures after a lambing period to keep young lambs apart from older lambs.

Figure 5. Individual lambing pen

APPROACHES TO PREVENT LAMB MORTALITY

Climatic conditions of the birth region

To reduce lamb mortality, the birth time should be changed if necessary. Lambing should be done once the soil temperature has risen above 10 °C, especially in pasture-based sheep management, to minimize lamb mortality from cold weather. To optimize fetal growth and colostrum production, the ewes are offered premium feed in the final stages of pregnancy, as the delivery will occur after the pasture grass has started to grow. However, waiting until the soil temperature is significantly warmer to initiate the birth period is not always the best option (Sharma and Gupta, 2024). This is because a new set of problems may occur due to temperature and humidity, such as increased incidence of fly bites and gastrointestinal parasite infections. Indoor lambing programs are also susceptible to losses due to starvation/exposure, and moving the birth from January to March may similarly reduce losses.

Improve environmental conditions: Maintaining ambient temperatures above 0 °C during indoor lambing programs will greatly lower exposure losses and starving lamb mortality. From an economic standpoint, it is crucial to make sure that these temperature and humidity increases do not result in further health issues for the animals. Large barn rooms require a lot of energy to heat, but additional heat in lamb-rearing units can offer "dry" heat. The practice's cost-benefit ratio is worth taking into account (RSPCA, 2011). Planning a barn with an insulated fall/early rearing section that permits adequate air exchange to avoid dangerous humidity levels while keeping ambient temperatures above 0 °C could be an additional strategy (Figure 6).

Figure 6. Insulated lambing pen.

The cost of insulation materials should be considered about the lambs saved, according to preliminary analyses of the two structures covered above. Put otherwise, it displays a five to seven-year payback period. Improvements have also been made in flock welfare, which is more difficult to quantify economically but should be taken into account as part of an all-encompassing management program. Another benefit, less tangible but important, is improved keeper welfare (Gilbert and Kendrick, 2010). Recently, some private livestock farms have planned a barn specifically for lambing, with a combination of insulated attic and walls, side wall curtains that can be opened almost everywhere on the side wall, and tunnel ventilation using fresh air that can be heated before entering the air distribution tunnels. The heating of the air should be thermostatically controlled in the barn and should be adjusted to keep the barn temperature a few degrees above freezing. This system brings in clean, warm air and maintains the optimum temperature with high air quality for winter lambing.

Ventilation within the barn should be improved. Adequate air exchange is vital to reduce humidity levels, which can lead to increased incidence of pneumonia, diarrhoea and other problems (coccidiosis, etc.). However, this need must be balanced against excessive drafts, which can encourage hypothermia in newborn lambs. Roof vents in the barn and adjustable side wall air inlet controls are other forms of ventilation in passive ventilation systems without producing excessive drafts.

Balanced Nutrition: The primary objective of improving lamb survival during the first week of life is to optimize the food management of pregnant sheep. This issue is very important, and meeting both energy and protein and micronutrient (vitamins and minerals) requirements for pregnancy is of great importance in determining a lamb's live weight and colostrum amount at birth. These are the two main factors affecting live weight in lambs in the first week. Therefore, implementing a correct feeding program that takes into account live weight and physiological periods should be a priority to prevent lamb loss later (Miller et al. 2011). 22% of ewes produce inadequate quality colostrum. High-quality colostrum includes more than 50 mg/ml of IgG despite breed-specific variations in milk content and immunoglobulin concentrations. A value of less than 15 mg/ml IgG is advised as a globally recognized criterion for assessing passive transfer failure in lambs; this parameter was found in 39.5% of lambs with FPT. For the reasons mentioned, lambs need to absorb 3 g of IgG even shortly after birth. Colostrum IgG concentration decreases by 3.3 mg/kg/hour up to 23 hours after birth, reaching its lowest level. Therefore, newborn lambs must receive sufficient colostrum within the first 36 hours following birth. Colostrum volume is essential for lamb growth; lambs typically require 200 ml/kg of colostrum within the first 24 hours of birth, 100 ml/kg during the first 6 hours to avoid hunger, and 50 ml/kg during their first meal.

In parturition time management, or the confusion in the maternity pen and flock management, the length/concentration of the maternity period may increase the potential mortality of the offspring during the maternity period. One of the main reasons for exposure and malnutrition is poor maternity, thus, care should be taken to minimize the amount of time needed for maternity pens and the issues brought on by potential confusion in the pens (animal density, group size, and length of stay). This is a serious problem if cold shock or malnutrition worsens during days two through seven (Greiner and Wahlberg, 2009). Using the ram effect to lengthen the maternity period before mating is one tactic that could help manage the time of parturition. Estrus is synchronized when rams are introduced to ewes that are comparatively isolated from the rams. To do this, ewes are exposed to vasectomized rams for 14 days, after which they are replaced with healthy males. This will intensify estrus, and the majority of ewes will come into estrus in two groups approximately 17-18 and 22-23 days after the first mating. An intensive lambing period has advantages for time management, but labor is not the limiting factor. Intensive calving time greatly increases artificial rearing opportunities, reducing starvation/exposure and rearing costs. Intensive calving periods also reduce the accumulation of potential pathogens in the shelter, as well as the incidence of diarrhoea and possible pneumonia.

Health-Prevention Program. Elimination of chronic diseases (Maedi-visna or progressive pneumonia in sheep will reduce the incidence of starvation/exposure due to inadequate colostrum/milk production. Flocks that have eliminated Maedi-visna report large reductions in the number of lambs reared artificially because older ewes have sufficient colostrum/milk to support their lambs. When abortion is a problem, vaccination programmes can be an important step in reducing losses (Schoenian, 2006). Finally, booster vaccination of ewes against enterotoxaemia types C and D and tetanus in late pregnancy is a potentially cost-effective measure to reduce lamb mortality. When dams are vaccinated and protected to 40–50 days of age, lambs acquire effective protective antibody titers through passive immunity through the consumption of colostrum. However, the vaccination of lambs in the early postnatal period (<2 weeks of age) is not recommended because it is not effective in protecting against the major toxins produced by Clostridium perfringens type D.

Genetics - Hybrid vigour or heterosis is achieved by maximising through crossbreeding. This strategy can reduce mortality by approximately 20%. There are differences between breeds in survival traits, including suckling drive and some aspects of maternal behaviour (Behrendt et al. 2011). In general, breeds selected for some production traits, such as fleece and carcass quality, are inferior to those subjected to natural selection. These traits tend to be antagonistic, as there is difficulty in identifying sheep that are superior in both production and survival. When the heritability of cold stress resistance in newborn lambs was examined, cold resistance had a high heritability (h^2=0.40). It was shown to be mediated mainly by determinants of heat production and reduced hair cover at birth. More recently, certain polymorphisms for regulatory genes involved in the regulation of body temperature in newborn lambs have been associated with neonatal mortality. Research findings suggest the potential of polymorphisms to be used as markers for selection for cold resistance in newborn lambs. It is difficult to measure the effectiveness of treatment interventions in reducing neonatal lamb mortality. Some interventions, such as time-of-birth assistance in dystocia or effective treatment of hypothermic lambs, may only have an important role for the responsible caregiver. However, there are also cases where increasing caregiving time has little effect in reducing mortality and is likely to have a negative effect in terms of return on effort. Therefore, treatment interventions need to be carefully evaluated in terms of their effectiveness.

SUGGESTIONS

Developing programs to reduce lamb mortality begins with evaluating the causes of death on an individual farm basis. Determining whether lambs die in or out of utero and whether they consume milk is critical to identifying some of the dam's problems and possible solutions. Lamb mortality prevention programs should be prioritized to target the areas with the greatest potential impact.

Examples of high-impact areas include optimizing dam nutrition programs, improving climatic conditions (temperature and humidity) in the maternity pen, regular fertility records and developing breeding programs accordingly, and implementing vaccination. Many factors play a role in lamb survival between ultrasound and the control of pregnancy and litter size and the determination of single-twin pregnancies. While some factors such as dystocia, stillbirths, starvation and failure to find the dam play a role in the major causes of prenatal lamb mortality, the role of lactation order is not fully understood. Immune deficiency in the offspring is considered a risk factor for infectious reproductive diseases. Therefore, female yearlings may be more susceptible to infectious diseases because they have less time to be exposed to infection and develop immunity before pregnancy. Consequently, the small effects of infectious diseases on lamb survival may also explain the lack of correlation between lamb survival for female lambs and multiparous ewes on the same farm. The effects of infectious diseases on lamb survival for ewes should be investigated further.

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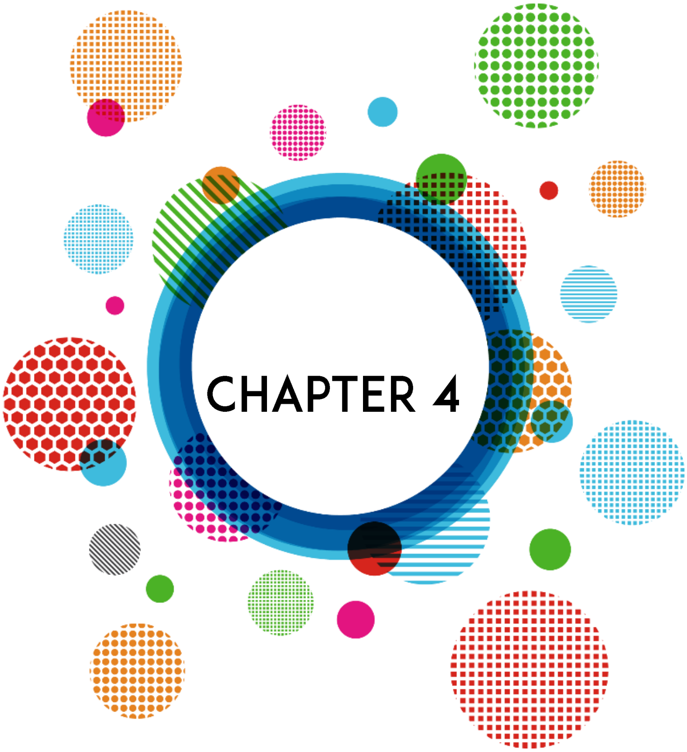

Strategies to Improve Water Efficiency in Agriculture

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1. Introduction

Water efficiency in agriculture has become an urgent global concern due to factors such as climate change, population growth, the depletion of freshwater resources, and the widespread occurrence of environmental degradation (Teweldebrihan, 2025). Moreover, only 1% of the world's water is usable. High-quality, non-saline water is among the most critical global resources for meeting the increasing demand for fiber, feed, staple foods, and fuel (Evans & Sadler, 2008).

Water is used in many sectors; however, agricultural irrigation is the largest consumer. Irrigation has shaped the economies of arid and semi-arid regions in various parts of the world. In particular, it has increased the income of rural communities, ensured economic stability, and created new opportunities for development (Qadir et al., 2007).

The effects of climate change on arid and semi-arid regions are highly significant, leading to numerous environmental, economic, and socio-economic consequences. These effects include increased temperature and evaporation, changes in precipitation patterns, soil degradation and desertification, reduction in available water resources, loss of biodiversity, and a decline in agricultural production (IPCC, 2023).

Moreover, the water scarcity experienced due to climate change, which is expected to intensify in the coming years, increases the demand for water resources, particularly with the rise in the global population, posing a significant threat to agricultural sustainability (Teweldebrihan, 2025). If plants do not receive sufficient water in agricultural production, desired yields may not be achieved, even with the use of high-quality seeds and fertilizers (Yadav et al., 2024). Considering the likelihood of this issue spreading globally, humanity faces the inevitable reality of hunger.

This study examines strategies that could contribute to the sustainable management of water resources in order to address the need for approaches that water efficiency and balance production needs and water allocations in arid and semi-arid regions.

2. Strategies to Improve Water Efficiency

To enhance water efficiency, several approaches can be implemented, including replacing high crop water consumption (ET_c) crops with those requiring lower ET_c, promoting virtual water trade, improving irrigation systems, and planning water resources using modern techniques. Additionally, to increase the economic efficiency of water use, water can be allocated from low-value crops to high-value crops. However, an important consideration is that high-value crops should have a shorter growing period and should not require replanting within the same year. Furthermore, it should not be overlooked that each watershed requires different solutions depending on its specific soil, socio-economic conditions, climate, and water supply characteristics (Demirel, 2023; Evans & Sadler, 2008; Koc, 2018).

Water efficiency increases when evaporation, crop water consumption, and water use by other sectors are reduced. The available water resources within a watershed can be effectively preserved for use in other sectors by minimizing non-recoverable water losses and improving efficiency (Fraisse et al., 1993).

Water is a critical production resource in many sectors. Reducing total ET_c can have positive watershed-wide effects on regional conservation efforts. Local economic benefits can be enhanced through the modernization of water distribution systems, as well as on-farm and off-farm irrigation systems that modify water allocation planning. If this increase is achieved, more water can be allocated to time-sensitive sectors such as municipal services, hydroelectric power generation, industrial applications, tourism, and recreation. Additionally, reducing early-season water releases from reservoirs can ensure timely and adequate water availability in the later stages of the irrigation season, thereby improving irrigation planning efficiency to achieve optimal yields (Evans & Sadler, 2008).

In landscaping and agricultural areas, selecting drought-resistant plants appropriately and utilizing rainwater efficiently through water harvesting methods can significantly enhance water efficiency. Additionally, optimizing the timing and location of spatially diverse landscape elements, such as recreational areas in urban environments, can contribute to water conservation. When integrated with other water management strategies, this approach ensures more efficient use of water resources (Mengu & Akkuzu, 2008; U. N., 2006).

Conservation tillage, reducing planting density, using drought-resistant improved varieties, and implementing cultural practices such as pest control can positively impact water use and crop productivity. Additionally, strategies such as intercropping, double cropping, relay cropping, row cropping, and crop-specific rotations are also effective practices that can enhance water efficiency (Li et al., 2011).

2.1 Virtual Water and Trade

The concept of virtual water was first introduced by J. A. Allan in 1993, highlighting that humans utilize water not only for drinking and domestic use but also in various other activities. Allan defined virtual water as the presence of water in a product's production process as an input, existing beyond its original form. In regions experiencing water scarcity, virtual water transfer through food imports can help alleviate water stress (Haddadin, 2003).

A certain amount of water is consumed in the production processes of all types of products, which is defined as virtual water. For instance, the production of a hamburger requires 2,450 liters, a cup of coffee requires 140 liters, and a portion of rice requires 150 liters of water. These examples can be further expanded (Demirel, 2023).

The sector with the highest virtual water consumption is directly agriculture. The amount of virtual water used in agricultural products varies depending on geographical location, climate conditions, production technology, and inputs used. The virtual water consumption in animal product production is significantly higher than that of plant-based products. The primary reason for this is the large amount of water required not only for the animals' direct consumption but also for feed production. This, in turn, increases the virtual water footprint of animal products (Greenpeace, 2016).

Virtual water enables the import and export of water between countries, which would otherwise be difficult to physically transfer between basins. Through virtual water trade, while the physical transfer of water occurs in small quantities, large amounts of virtual water are exchanged (Chapagain and Hoekstra, 2003).

Virtual water trade plays a crucial role in improving water use efficiency and organizing consumption-oriented water management. Particularly, regions or countries experiencing water scarcity have the opportunity to import high-water-consuming products instead of producing them, thereby enabling virtual water transfer. For example, Jordan, one of the most water-stressed countries, possesses only 1 billion m^3 of limited water resources but achieves a virtual water transfer of 5 billion m^3 by importing crops such as rice and wheat. Similarly, countries like Lebanon, Kuwait, Israel, and Malta utilize virtual water trade to mitigate water stress (Anac et al., 2011)

The virtual water flow through agricultural trade is 1263 km^3 per year, while the virtual water flow in the industrial sector amounts to 362 km^3 per year. Additionally, 15% of agricultural production and 34% of industrial production are included in virtual water flows through exports. Of the total virtual water trade, 78% is agriculture-based, while the remaining 22% is industry-focused (Demirag, 2013). Nearly 80% of the global virtual water flow occurs through agricultural trade (Demirel, 2023).

In global virtual water trade, the largest share belongs to beef at 13%, followed by soybeans at 11% and cocoa and wheat at 9% each. Although rice consumption accounts for the highest water use in agricultural production, wheat holds a larger share in global trade, leading to a higher proportion of virtual water trade (Chapagain and Hoekstra, 2004).

Especially, the export of virtual water in agriculture can be effective only in countries with vast agricultural land, low population, and technical superiority. In this context, virtual water should be considered as an indicator of production and efficiency at the country level and as a reflection of globalization (Seekell et al., 2011).

2.2 Integrated Basin Water Management

In every management process, there are stages such as problem identification, decision-making, and resource allocation. The management of the expectations, goals, and perspectives of all stakeholders involved in this process constitutes the concept of "integrated management." For the integrated management of a river basin to be achieved, the stages outlined in Figure 1 must be implemented. First, the problems related to water resources in the basin must be identified, and the objectives that the management should establish based on these issues must be determined. Additionally, the management's preferences for various scenarios should be explicitly defined. This process requires a comprehensive policy analysis, considering the needs of all segments of society, the multiple objectives associated with different water uses, and interdisciplinary evaluations. Furthermore, it is essential to define the boundary conditions and impacts that will shape management policies. The identification of the basin system and the preparation of the information system according to the necessary criteria are crucial. In the basin modeling process, the integration of data management and Geographic Information Systems (GIS) is among the critical aspects. Another key phase is the development of alternative management plans. Enhancing the decision-making process through the development of expert systems represents the final stage of integrated basin management. When all these stages are systematically executed, increasing water efficiency also becomes feasible(Gureli & Tokgozlu, 2022; Harmancıoglu, 2002; Tas, 2021).

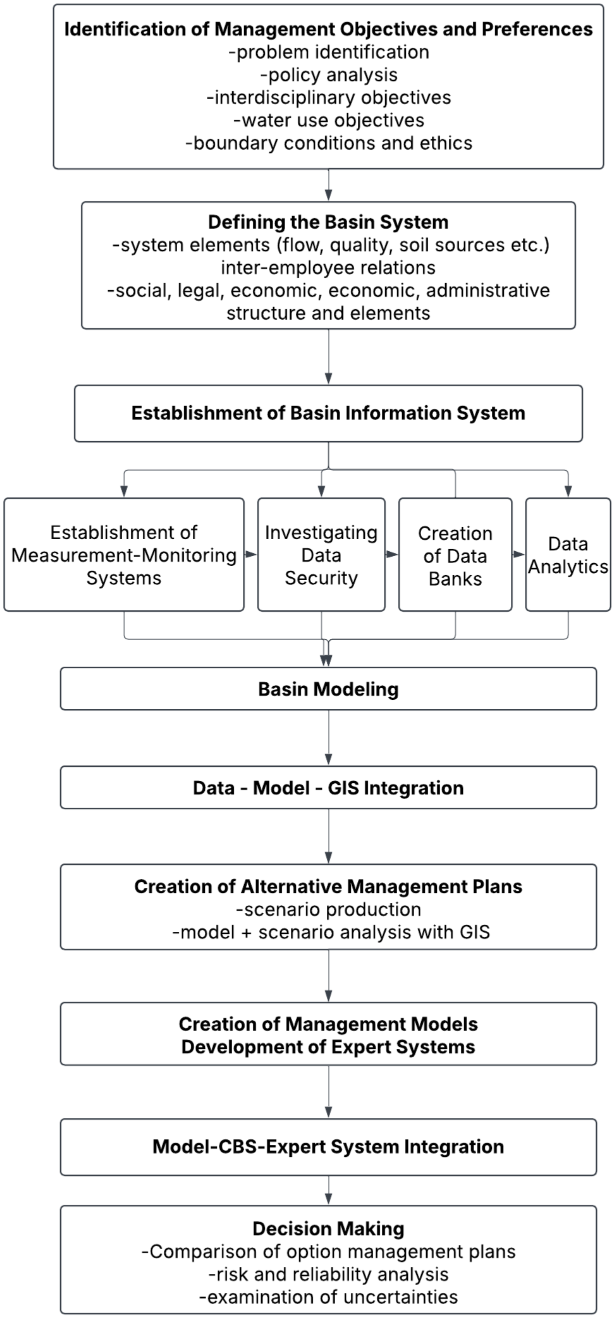

Figure 1. Stages of integrated watershed-water management (Harmancıoglu, 2002; Güreli and Tokgözlü; 2022; Tas, 2021).

2.3 Water Harvesting and Rainwater Harvesting

Technologies that harvest water vapor from the air, powered by widely accessible and reusable solar energy, are considered a significant potential source of freshwater. Water in the atmosphere is regarded as a vast renewable water resource. Additionally, it serves as a powerful source capable of meeting global water demands and providing access to water in regions where available water resources are scarce. In this context, it holds strategic importance in mitigating the increasing severity of water stress (Hanikel et al., 2020).

The atmosphere is estimated to contain approximately 12.9 teratons of water, which is more than six times the total volume of the world's rivers. Atmospheric water primarily consists of clouds, fog, and small water droplets (Beysens & Milimouk, 2000). The water content in the Earth's atmosphere, in the form of vapor and droplets, holds a significant amount of water, accounting for approximately 10% of all freshwater sources (Kim et al., 2017). Therefore, the efficient utilization of atmospheric water could help mitigate water scarcity and improve water efficiency (Sarginci & Bildiren, 2022).

Rainwater harvesting is a method of collecting and storing rainwater in soil, underground water reserves, or surface storage facilities for future use. This approach, along with complementary practices such as increasing the organic matter content in soil, contributes to groundwater recharge, soil improvement, and increased agricultural production and productivity in water-scarce regions. All these factors positively influence water efficiency (Yeniceri, 2018).

Rainwater harvesting methods are generally classified into three main categories: on-farm systems, valley floor systems, and off-valley systems (Ekinci, 2015).

Various examples of rainwater harvesting applications can be found worldwide and in Turkey. Notable examples include water harvesting systems in the Rajasthani Desert of India, rain gardens in Melbourne, and rainwater collection systems in Izmir. It is possible to state that such projects and applications contribute to increased water efficiency (Anonymous, 2025a; Anonymous, 2025b; Anonymous, 2025c).

A guideline document on rainwater harvesting has also been prepared by the **G**eneral Directorate of Water Management under the Ministry of Agriculture and Forestry. This guideline provides detailed information on calculations of collectable rainwater volume, required water demand, storage capacity, treatment requirements, and cost-benefit analysis (GDWM, 2020).

2.4 Agricultural Production

Water use efficiency (WUE) is defined as a measure of productivity, particularly in plant production (Evans & Sadler, 2008). Maximizing WUE requires maximizing crop growth while minimizing water losses. To achieve this: (1) Reducing water losses through leakage, surface runoff, weed transpiration, and evaporation to the lowest possible level. (2) Selecting high-yielding crop varieties well adapted to local soil and climatic conditions. (3) Optimizing growth conditions through proper timing of planting and harvesting, fertilization, tillage, and pest control are essential. All these measures enhance crop growth and, consequently, contribute positively to water use efficiency (Pascale et al., 2011). Agricultural production strategies aimed at improving water use efficiency are examined in detail under the following subheadings.

2.4.1 Correct Irrigation Programming

Especially at the micro level, when preparing an irrigation program, specific factors such as region, soil, and plant characteristics should be considered, and three fundamental questions should be answered: *Which method?*, *When?*, and *How much?*. The selection of the method should take into account various criteria, including plant type, water requirements, soil structure, slope, climatic conditions, water source availability, as well as economic and technical factors (Gungor et al., 2012). Depending on these criteria, if one of the pressurized irrigation systems is chosen, water savings of **30% to 50%** can be achieved compared to surface irrigation systems. Consequently, this contributes to improving water use efficiency (Cevik, 2019).

There are four common methods for answering the questions "When?" and "How much?" in irrigation programming. These are soil moisture conditions, plant water status, model usage, and evaporation and water balance methods. When examining the direct responses of some of these methods to soil moisture or plant soil moisture, identifying the targeted soil moisture levels is crucial for both irrigation programming and ensuring that soil moisture returns to the desired levels, alongside the predictions of the current soil moisture status (measured or calculated). In this context, the current factors in the atmosphere-plant-soil system affecting soil moisture should be considered during the programming process. Since all four irrigation programming methods take into account soil water content, which serves as a bridge between the water needed for plant growth and irrigation methods, future programming methods should focus on managing soil moisture content, based on a better understanding of the effects on plant development through the integration of existing irrigation programs or by developing new models using smart algorithms. By applying these methods, more accurate, practical, and easily adaptable irrigation programs should be developed for real-time agricultural operations. Furthermore, to achieve better results in these irrigation applications, online data access and weather station networks should be improved. When all of these steps are implemented, an increase in irrigation efficiency will be inevitable (Gu et al., 2020).

Various methods for conserving water in agricultural production have been investigated. One of these studies concerns the amount of water applied. Methods such as deficit irrigation, partial irrigation, and drip irrigation have shown that water use efficiency can be increased (Jalota et al., 2006; Zhang and Yang, 2004). In general, these techniques are expected to result in higher water use efficiency, but lower yields. This raises the question of whether it is possible to increase water use efficiency without a significant decrease in yield. Many studies have shown that there is a negative parabolic relationship between irrigation and grain yield, which constitutes the majority of total biomass. This suggests that when water availability is sufficient, excessive vegetative growth can lead to unhealthy canopy structures, lower root activity, and reduced harvest rates or harvest indices. This means that biomass production supported by high water availability will not lead to high water use efficiency when defined as grain production per unit of irrigation water. Therefore, the goal is to limit water supply by increasing harvest rates or harvest indices and increase grain yield. Recent studies have shown that in some irrigation practices, grain yield can increase while the amount of water applied to the crop decreases (Suzan et al., 2021; Yang et al., 2002).

Drought stress or water deficit that may occur during the development of the cereal grain shortens the grain filling period. If the grain filling rate is not adjusted to high levels, the final grain weight will decrease. The increased growth rate under water stress depends on the presence of assimilates. An alternative source of assimilates, depending on the species, can be stem reserves in the form of sugars, fructose, or starch, which are stored before anthesis. These reserves can be easily utilized during grain filling, and their presence can become a critical factor in sustaining grain yield and grain filling under water stress. Thus, water use efficiency can be improved by reducing or even eliminating water application during the grain filling phase (Ali & Talukder, 2008).

2.4.2 Mulching

The benefits of mulching are well known, especially in the production of vegetable crops. Mulches are used to raise soil temperature, control weeds, and ultimately increase crop yield. Mulches reduce nutrient leaching and balance soil moisture. The increase in soil nutrients and the reduction in weeds have a positive impact on water use efficiency (Pascale et al., 2011).

2.4.3 Protective Agriculture Practices

Conservation agriculture is a farming system that prevents losses in arable land while also being able to rehabilitate degraded lands. Conservation agriculture has three fundamental principles: minimizing soil tillage, maintaining organic cover on the soil surface at all times, and ensuring crop diversity. These principles have many benefits, including those related to water use efficiency. Additionally, the amount of organic matter in the soil is of great importance. This is because organic matter promotes the aggregation of soil particles, which increases the soil's aeration capacity and, consequently, effective root depth. This allows plants to benefit from a wider soil structure. With deeper roots, plants can also tolerate drought more effectively. Organic matter not only increases the soil's infiltration capacity but also enhances its water retention capacity. The longer the amount of moisture held in the field capacity, the more available plant nutrients are increased. In soils with low organic matter content, plant roots tend to concentrate in the upper layers of the soil due to inadequate aeration, requiring more fertilizers and water. As a result, this reduces water use efficiency. Furthermore, it makes soil cultivation more difficult and leads to the continuous formation of clods (Corsi, 2018).

In conservation tillage practices, when direct seeding is applied, infiltration rate increases, evaporation decreases, surface runoff is reduced, and more water can be retained in the soil. When direct seeding is performed, crop residue helps retain moisture and increases the amount of organic matter. All of these factors are practices that enhance water use efficiency(Arisoy, 2022) .

2.4.4 Plant Selection and Preference for Crops with Low Plant Water Consumption

Plant selection can cause significant differences in water use efficiency. Choosing an appropriate crop rotation can improve water use efficiency by helping to manage pests, diseases, nutrient supply, and weed control. Adding a legume crop to a cereal rotation can increase soil fertility by adding atmospheric nitrogen and organic matter, which is reflected in increased yield in subsequent cereal crops (Ali & Talukder, 2008).

The water requirements of plants vary. Crops with lower water demand also have lower plant water consumption, which increases water use efficiency. This way, water savings are achieved, and the saved water can be used to irrigate additional land. This practice can also enhance productivity. For example, compared to legumes, wheat, and oilseed crops, rice is considered a crop with a higher water requirement. If land type and environmental conditions permit, crops with lower water requirements should be planted as much as possible (Ali and Talukder, 2008). In a study conducted in the Manisa region of Turkey, due to drought stress, crops like olives and wheat, which have lower water consumption compared to the widely grown grapevine, were recommended. It is also known that olives and wheat are more drought-tolerant than grapevines (Suzan, 2024).

2.4.5 Use of Wastewater in Agriculture

Urban wastewater is generally used for agricultural irrigation purposes. However, due to the substances in most industrial wastewater, its use can be hazardous. On the other hand, industrial wastewater from food and beverage industries (such as beer, sugar, fruit processing, yeast, etc.), which is relatively cleaner, can be used for agricultural irrigation either directly or in a diluted and controlled manner (Banerjee, 2016).

In many regions worldwide, wastewater is used for agricultural irrigation either untreated, treated, partially treated, or diluted. For example, in Spain, about 71% of treated water, more than 80% in Israel, and 65% in California are used for agricultural purposes. However, due to the scarcity of available fresh water sources and the high costs of wastewater treatment and collection, in developing and underdeveloped countries, wastewater can be used for agricultural irrigation either without treatment or diluted with a resource like rainwater (Leas et al., 2013). Approximately 20 million hectares of land worldwide are irrigated with partially treated or untreated wastewater (Biswas et al., 2017). For instance, about 25% of the crops grown in Pakistan and most of the 260,000 ha of agricultural land in Mexico are irrigated with untreated wastewater (Gatta et al., 2016; Pedrero et al., 2010).

The use of treated wastewater in agricultural irrigation offers benefits such as increasing water efficiency, providing a new water source for plant growth, and reducing the consumption of clean water resources (Ak & Top, 2018). However, it should be noted that the degree of treatment required for wastewater to be used in agricultural irrigation can vary depending on factors such as the quality of the wastewater, the type of crops to be cultivated, regional conditions, and the standards set by the country’s regulations (Hussain et al., 2002).

2.4.6 Training of Farmers

Farmers, who hold the largest share among water users, generally consist of individuals who have not received formal training in irrigation, although this varies by region. Studies have shown that the majority of farmers do not seek training on irrigation from either irrigation associations or other public institutions and instead follow traditional methods passed down through the years. Furthermore, it has been found that, in situations where irrigation water is insufficient, most farmers rely on their own experience to practice water rationing. Another finding from the research is that farmers do not use a specific method when deciding on the timing of irrigation. All these non-scientific approaches negatively impact water efficiency. If farmers are provided with the necessary training and relevant practices, long-term environmental sustainability can be achieved, especially in regions experiencing water stress, and water efficiency can be improved. To achieve this, it is essential for relevant institutions to offer maximum incentives and support programs to farmers (Yasar et al., 2007; Aslan and Candogan, 2022; Suzan et al., 2023).

3. Conclusion

Water is a limited natural resource without substitutes. Recently, factors such as the effects of climate change (e.g., rising temperatures and irregular rainfall) and increasing population have intensified the pressure on available water resources. This situation has become even more pronounced, especially in arid and semi-arid regions. As the largest user of water, the agricultural sector is inevitably affected by this issue. Topics such as food security and hunger are of such importance that they can directly affect a nation's national security. In this context, numerous studies have been conducted worldwide, and strategies to increase water efficiency in agriculture have been developed.

In this study, research related to the topic has been reviewed, and the strategies examined scientifically have been presented under a single heading. These strategies include virtual water trading, the creation and implementation of integrated watershed management plans, water harvesting, and rainwater harvesting. Additionally, strategies that should be applied in agricultural production have been specifically discussed. This section addresses topics such as the implementation of proper irrigation schedules, mulching, conservation agriculture practices, plant selection and the preference for crops with low water consumption, the use of wastewater, and the education of farmers.

When these strategies are applied, the negative impacts of drought in environmental, economic, and socio-economic areas can be reduced or completely eliminated. It is anticipated that this study will guide decision-makers and farmers engaged in agricultural production. In this way, the development of sustainable agricultural production systems and the more efficient use of water resources will become feasible.

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CHAPTER 5

Sustainable Processing of Wood Wastes into Valuable Products: Methanol from Wood Waste

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1. INTRODUCTION

Due to sustainable material and ease of workability, wood has been utilized in numerous ways, including structural, construction, architectural, energy, or ornamental purposes, since human beings (Bowyer et al., 2003; Sahin and Onay 2020; Ross, 2021; Sahin et al., 2021). As a result of technological developments, the utilization techniques have also been changed from direct benefits (i.e., burning, lumber or structural elements) to advanced chemical modifications (i.e., chemical conversions, pulp and paper, cellulose derivatives, etc. (Fengel and Wegener, 2011; Sahin et al., 2011; Sahin et al., 2020). Although wood has delicate chemical constituents that could be converted to valuable chemicals, it has been used in the chemical industry for not more than a century (Tillman, 2012; Ross, 2021). Currently, like other industries, the forest products industry is energy intensive and highly dependent on fossil fuels. After primary processing of wood to end-use products, various types and kinds of waste disposal could be created, depending on the type of process (Şahin, 2005; Şahin et al., 2006; Şahin, 2021). Besides solid wastes, there have also been more complex and modified wastes that could be obtained from pulp and paper mills. However, solid wood-based wastes could be advantageous for direct use in other primary and/or secondary processes, such as chips or flakes for the composite industry or direct burning of bark or other non-processable fines/chips to generate biomass energy (Şahin et al., 2006; Bayram et al., 2024). This type of utilization or recycling of wood waste could be considered as cost-effective and requires a little technology to recover.

These days, researchers have an emerging topic about reducing energy consumption by obtaining valuable chemical products and fuels from wood-based secondary materials. Besides wood itself, wood-based wastes and residues have been the subject of extensive research as an alternative energy source to petroleum and coal and also as a feedstock for various chemicals such as alcohols, acids, resins, or other related products (Aina, 2006; Şahin et al., 2006; Suteu et al., 2016; Cesprini et al., 2020; Özkan et al., 2025; Hajkova et al., 2025). However, cellulose and lignin are very important natural polymers found in wood that can be directly produced by hydrolysis or could be found in pulping mills that may be treated and further transformed into some chemicals. On the other hand, the conversion of wood wastes into products requires very advanced treatment technologies (Young, 1996; Şahin et al., 2025).

However, recycling of wood waste that is generated from the woodworking industry is a challenge because of the complexity of recycling and restricted regulations regarding solid waste landfilling or burning (Coudert et al., 2013). Numerous disposal treatment practices have been developed in recent years, including wood waste recycling via chemically, biologically or combination of those methods. The chemical conversion of wood waste, such as to methanol options, is limited because of the cost of the process and the required complex processing systems (Coudert et al., 2013).

The chemical structure of wood, either solid or waste, has similar chemical constituents that consist of 95-99% lignin, cellulose and hemicellulose (Helm, 2001; Şahin et al., 2006; Fengel and Wegener 2011). Therefore, the basic organic structures of wood waste can be considered the same as wood. Regarding this issue, the reactions and products that occur during chemical treatments under various conditions are similar in almost all woods. In this study, the methanol production from wood-based sources has been summarized below in view of an environmentally friendly, sustainable energy source.

2. WOOD WASTE IN EUROPE AND THE USA

Wood is a well-known natural material with specific physiohemical properties that may be used for a wide range of applications. For effective utilization and high benefits, proper information about wood waste kinds and types is an important issue which is necessary for optimum utilization.

In 2015, the total consumption of industrial roundwood in the United Nations Economic Commission for Europe (UNECE) region was reported to be 1.28 billion m^3, of which approximately 16% was used for fuel (O'Driscoll, 2016). However, one of the simplest and cost-effective ways for an end-of-life option for wood waste has been incineration, due to its relatively high calorific value. Beside this simple utilization, wood waste may well be suited for a range of more complex recycling options, potentially cascading from direct reuse to subsequent recycling in applications with other high-value products (e.g. chemical conversions). According to recent research from the European Union, approximately 337.000 m^3 of wood products became wood waste in 2010, 46% of which was recycled and 51% burned (Mantau, 2010). These make researchers increase their focus on recycling and circular economy in Europe (Iaquaniello et al., 2018; Magda and Toth 2019). Although the general properties of all woods are similar in detail, there are considerable differences, especially anatomical and physical properties. Regarding this issue, the utilization of wood waste rather than burning, is a challenge to convert valuable secondary products.

EPA reports a brief summary of wood waste material data of wood in municipal solid waste (MSW), including furniture, some durable goods, wood packaging (pallets) and some other miscellaneous products (EPA, 2025). They collected data on the generation, recycling, composting, combustion with energy recovery and landfilling of wood materials in MSW, in the USA. EPA estimated various types of wood wastes for specific recycling rates. For wood pallet recycling of valuable goods (excluding wood combusted as fuel), approximately 3.1 million tons were recycled in 2018 with a recycling rate of 17.1%. However, the total amount of wood in MSW that was combusted in 2018 was 2.8 million tons, which indicates 8.2% of MSW combusted with energy recovery that year. Moreover, it was estimated that landfills received 12.2 million tons of wood, which was 8.3% of all MSW landfilled in 2018. Table 1 shows a general comparison relating to the total number of tons of wood generated, recycled, composted, combusted with energy recovery and landfilled in the period from 1990 to 2018 (EPA, 2025).

Table 1. The data on wood in MSW in USA by weight (x1000 tons)

Management	**1990**	**2000**	**2010**	**2018**
Generation	12210	13.570	15.710	18.090
Recycled	130	1.370	2.280	3.100
Energy recovery (combustion)	2.080	2.290	2.310	2.840
Landfilled	10.000	9.910	11.120	12.150

3. CHEMICAL PROPERTIES AND THERMAL CONVERSION OF WOOD

The softwoods and hardwoods have similar chemical constituents, although their physochemical properties are different. Typically, woods contain 40-50% cellulose, 20-30% lignin, 25-35% hemicellulose and 1-5% other secondary substances (extractives and volatile substances) (Şahin et al., 2006; Fengel and Wegener 2011). Table 2 summarizes the chemical contents of softwoods and hardwoods.

Table 2. The chemical constituents of woods (%).

Chemical constituents	**Softwoods**	**Hardwoods**
Cellulose	40-50	40-50
Hemicellulose	25-30	30-35
Lignin	20-25	20-30
Extractives and other volatiles	1-2	1-5

Due to these variations, the chemical conversion of different types of wood occurs at different degrees (Zobel et al., 1989; Young, 1996; Helm, 2001; Fengel and Wegener 2011). During the chemical conversion of wood, very complex reactions are formed. Therefore, in order to better understand the chemical reactions that occur during treatments, it is necessary to know the effects of some of the following main wood properties:

- Anatomical establishments (trachea and tracheids, fibers, rays, lumen),
- Moisture content,
- Specific gravity,
- Chemical constituents (relative ratio of cellulose, hemicellulose and extractives).

In strong treatment conditions such as acidic or alkali hydrolysis at high temperatures, breakdown of glycosidic bonds in the structure of carbohydrates is provided depolymerize to form numerous chemical derivatives, including carbonyl, carboxyl, sugars, acids and other phenolic substances (Helm 2001; Young, 2008; Fengel and Wegener 2011). However, the presence of water, acids and oxygen in those environments accelerates the reactions. Besides the initial breakdown of chemical bonds, increased temperature causes further depolymerization in the polymeric structure of substances from which some gases and tar are formed (Şahin, 2005). Moreover, the extent and type of products related to carbohydrates are different in softwoods and hardwoods due to types and kinds of constituents. For example, the xylan content is high but the glucomannan content is low in hardwoods compared to softwoods, and vice versa (Helm 2001; Young, 2008; Fengel and Wegener 2011).

In general, the high oxygen content of a compound is inversely related to its heating value (Young, 1996). Regarding this issue, the heating value of lignin, which is $C_{10}H_{11}O_2$ according to elemental analysis, is higher than that of cellulose, which is $C_6H_{10}O_5$ (Fengel and Wegener 2011). Similarly, fossil fuels contain almost no oxygen and have high heating values. For example, coal has a heating value of 5.000-10.000 Btu/lb, while natural gas and oil have a heating value of 15.000-20.000 Btu/lb (Young 1996; Şahin et al., 2006).

The degradation reactions of lignin occur at >140 ºC by the breakdown of aromatic alkyl-ether bonds while the dehydration reactions occur around 200-300 ºC, the side aliphatic chains are separated from the aromatic ring. Finally, the carbon-carbon bonds between structural units are broken between 370-400°C

(Helm, 2001; Fengel and Wegener 2011). However, thermal decomposition at high temperatures generally occurs between 500-1300 °C, resulting in various types of thermal breakdown products while volatile substances evaporate. It has been proposed that more than 50 different substances are formed by the thermal decomposition of biomass and about 35 of these have been identified, such as CO, CO_2, H_2O, alcohols, acids, furfural, aldehydes and ketones, etc. (Young 1996; Helm 2001; Fengel and Wegener 2011). Those gases can be collected as condensate by cooling and could be utilized as energy sources (Young 1996; Şahin et al., 2006).

4. METHANOL FROM WOOD

The use of fossil fuels, namely petroleum, coal and natural gas, for energy causes the world to warm globally. It has been determined that the carbon dioxide and other toxic gas rates in the atmosphere have increased every year since 1950, when measurements began, due to the increasing use of fossil fuels (Fenger, 2009). However, this is one of the reasons for the temperature on earth and the formation of acid rain.

Forests, unlike fossils or other energy sources, have the ability to renew themselves. Although it is possible to obtain energy from wood using different methods, burning is the most widely used method for energy production due to its ease and low cost. It has already been well-established that any carbonaceous material such as coal, lignocellulosics (e.g. wood, agricultural waste/residue) and garbage can be utilized for methanol production (Hokanson and Rowell, 1977). However, wood-based wastes could be considered as a complex carbohydrate-lignin structure, requiring multi-stage and severe reactions to conversion of some chemical groups (i.e., methanol). Due to special properties, some additional processing steps may be required when wood processes counterpart products from other fossil fuels (Ragauskas et al., 2006). Moreover, methanol is produced from wood and is often called *wood alcohol*, which is the simplest alcohol and widely utilized in different industrial applications (Fengel and Wegener 2011). In general, methanol produced from lignocellulsoic sources, called biomethanol, can also be produced by the hydrogenation of captured carbon dioxide and hydrogen (Hokanson and Rowell, 1977).

There is huge demand for methanol in the chemical industry besides fuel source. Methanol from wood or other biomass is typically produced under high temperature (250–300 °C) and pressure conditions (5–15 MPa). With the help of an appropriate catalyst, the formed syngas can be converted to methanol (IRENA and METHANOL Institute, 2021). It has been proposed that biomethanol has a high octane number (87–110) with low flammability and low emissions that be considered as an energy source (Deka et al., 2022). Although fewer amounts may be obtained, various by-products and fuel can be obtained from wood by using gasification methods. Numerous researchers have already pointed out that methanol may provide promising renewable energy alternatives (Petersen et al., 2015; Yadav et al., 2020; Deka et al., 2022), which, if used sustainably, could reduce the environmental impact of fossil fuels. However, methanol production using life cycle assessment (LCA) has been the topic of many research tasks in recent years that assess the potential environmental impact of the process (Oguzcan et al., 2019). Yadav et al. (2020) have studied life cycle assessment in order to analyze the potential environmental impact and environmental cost of a novel methanol production process from wood compared to conventional processes. It has been proposed that a lower global warming impact could be possible because of the environmental impact of methanol production from pine stem wood (Kajaste et al., 2018). Due to raw material variations and applied technological processes, the methanol production rates of different wood species are different (Petersen et al., 2015). In general, the conversion efficiencies from biomass to methanol are found to be between 50 to 70% depending on the selected technology (Furusjo et al., 2018).

4.1. General Process for Methanol Production from Wood wastes

The methanol production process from biomass could be summarized under four main stages (Hokanson and Rowell, 1977; Yadav et al., 2020):

- Wood handling and pre-treatment,
- Gasification and preliminary gas cleanup,
- Syngas cleaning,
- Methanol synthesis and purification.

The general flowsheet for the methanol production process are given in Figure 1.

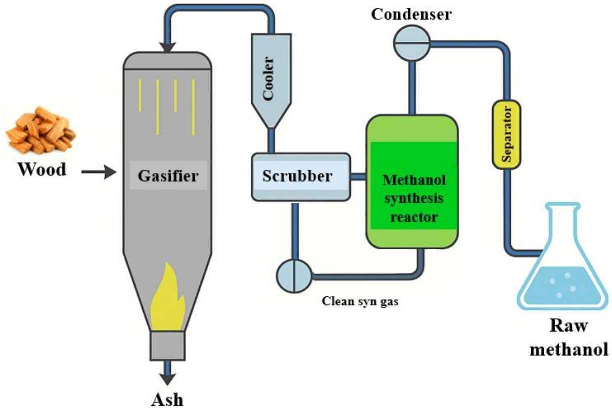

Figure 1. A genaral flow chart for methanol producing from wood

Wood handling and pre-treatment: Wood waste is usually brought to the plant by truck and deposited in a pit. However, the size of wood waste can be reduced in size through chipping, grinding and milling and drying before being fed to the gasifier. A drag conveyor feeds the wood waste to a pneumatic conveying system is useful to deliver the feed to a storage pile. In this case, wood waste is discharged from the bottom of the bin at a steady, uniform rate for transfer to the feed hopper over the gasifier, through a set of conveyors. The steam and air are introduced at the base of the reactor. It is important to note that wood piles combine with water and oxygen to generate heat as the material decomposes that is a high potential to create fire.

Gasification and preliminary gas cleanup: Several types of gasifiers have been developed for the partial oxidation of wood and other lignocellosics that are designed to operate at atmospheric pressure (Hokanson and Rowell, 1977; Furusjo et al., 2018; Deka et al., 2022). In general, the gasification reactions occur at a high temperature (> 1000 ^{0}C). However, the gasifiers produce a crude gas consisting primarily of hydrogen, carbon monoxide, and carbon dioxide, with minor amounts of heavier hydrocarbons and oil-tar fractions
(Ragauskas et al., 2006; Petersen et al., 2015). These are potentially useful for methanol synthesis after an extensive purification to bring it up to Syngas. Because the resulting crude gas still contains varying amounts of carbon dioxide, methane, and other hydrocarbons, it must be removed/purified prior to its use in methanol synthesis. Hence, crude gas from the gasifier passes upward through a single cooler-absorber-scrubber, cooling the gas from about 190° to 30 °C in three stages of contacting (Hokanson and Rowell, 1977; Helm, 2001; Carvalho et al., 2018; Furusjo et al.,2018;).

The crude gases are contacted by recirculated liquor streams, which are cooled in plate exchangers while recovered water is used to complete the removal of organic compounds (e.g., acetic acid). The cooled and scrubbed gas then flows to the carbon dioxide removal system.

Crude gas from partial oxidation units is processed to remove water vapor, tars, organics, hydrocarbons, and CO_2. In the shift recator, following cryogenic separation of the inerts, the gas is compressed for shift conversion.

$$\mathbf{CO+H_2O} \longrightarrow \mathbf{H_2+CO_2} \text{ (exotermic)}$$

Because the shift reaction produces two carbones, it is necessary to utilize the hot potassium carbonate absorption system. This removes about 95% of the CO_2 during the shift reaction. The synthesis gas is compressed to a pressure ranging from 1500 to 4000 psi and fed into a methanol synthesis reactor. In the reactor, approximately 95% of the gas is converted to methanol. The clean gas containing primarily H_2 and CO is then processed in a shift reactor to react part of CO to form additional H_2, so the final gas contains H_2 and CO in a 2:1 ratio (Young, 1996; Helm, 2001; Tillman, 2012; Petersen et al., 2015; Carvalho et al., 2018).

$$\mathbf{2H_2 +CO} \longrightarrow \mathbf{CH_3OH} \text{ (exotermic)}$$

The crude methanol product from the synthesis reactor passes to a distillation train for separation of the light ends and higher alcohols from the methanol product. The mixture of light ends and higher alcohols is used as a fuel in the boiler.

Syngas cleanup: The partially purified gas from the gasifier is compressed to about 100 psi pressure. Although various single or multi-stage processes can be used for gas purification, the cost of the process is usually dictated by the selected process. In general, two-stage purification systems have been preferred to remove CO_2 due to a cost-effective approach. The CO_2-free gas passes to a cryogenic system, where methane and higher hydrocarbons are removed. The hydrocarbons are used for energy (burning in the boiler). The products from these systems are a gas that contains a mixture of CO and H_2, but which is not a useful grade for methanol synthesis (Hokanson and Rowell, 1977; Carvalho et al., 2018; Deka et al., 2022).

After the cryogenic separation of the inerts, the gas is compressed to 400 psi pressure for shift conversion/reactions. In this stage, a portion of the CO reacts with water vapor to form additional H_2, to the extent that the final gas contains the required two parts of H_2 to one part of CO. However, the shift reaction also produces CO_2 which must be removed from the gas prior to the methanol reaction that is done in a second hot potassium carbonate absorption system which removes very high amount of CO_2 (> 95%).

Methanol Synthesis and Purification: The synthesis gas, containing a mixture of H_2/CO (2:1 vol/vol), is compressed to 2.500 psi and fed into the methanol synthesis reactor. Inside the reactor, about 95% of the gas is converted to methanol. However, the mixture then passes to distillation columns for separation of the light ends and higher alcohols. As a result of this complex multistage process, besides commercially worthwhile methanol products, some light ends and higher alcohols are also produced and is used as a fuel in the boilers (Young, 1996; Hokanson and Rowell, 1977; Tillman, 2012; Petersen et al., 2015).

4.2. Process Technology

In general, solid carbonaceous materials can be partially burned or oxidize the material to produce a crude gas called *Syngas*, which consist primarily of H_2, CO and CO_2 with minor amounts of heavier hydrocarbons. For these conversions, various types of gasifier reactors have been developed for the partial oxidation of biomass at atmospheric pressure. Some of the important gasifiers reactors are: Batelle, Thermex, Copeland, Lurgi, Winkler, koppers-Totzek. However, the Moore-Canada and Purox gasification systems were reported to be better processes than others that briefly explained in below (Hokanson and Rowell, 1977; Carvalho et al., 2017; Carvalho et al., 2018).

Purox gasifier reactors: It was developed in the 1970s by Union Carbide, a process for the partial oxidation of garbage using oxygen that is passed countercurrent to downflowing residue. It has been designed as a moving bed reactor system (Hokanson and Rowell, 1977).

Moore-Canada gasifier reactors: Moore-Canada of Richmond has developed a moving reactor for producing methanol from wood waste. The working conditions of Moore reactor is similar to Purox in that the feed material enters at the top and the ash is discharged from the bottom. But the distinct difference is the use of oxygen rather than air. In contrast to Purox, the Moore reactor relies on the use of air as the oxidizing medium. The raw gas has a lower heating value than Purox sytem (180 Btu vs 350 Btu). Table 3 shows some basic properties of raw gas produced by two different gasifiers**.**

Table 3. The properties of raw gas produced from Moore-Canada and Purox gasifier reactors (Hokanson and Rowell, 1977).

Raw gas	**Moore-Canada (%)**	**Purox (%)**
Hydrogen	18.3	26.0
Carbon monoxside	22.8	40.0
Carbon dioxside	9.2	23.0
Methane	2.5	5.0
Hydrocarbon	0.9	5.0
Oxygen	0.5	0.5
Nitrogen	45.8	0.5
	100	**100**

5. PROPERTIES OF METHANOL FROM DIFFERENT SOURCES

Although biomass could be used to produce methanol and other valuable chemicals, the conversion of fossil fuels such as coal is reported to be considerably more efficient than that of waste wood. It has been proposed that coal conversion to Syngas is more efficient because it has a higher carbon content and less oxygen than wood, but it involves more processing facilities because of the greater amount of ash and sulfur (wood has no sulfur) (Hokanson and Rowell, 1977; Yadav et al., 2020; Deka et al., 2022). Due to simplicity and higher efficiency process, natural gas conversion to methanol is also a considerably more cost-efficient method than a wood waste facility. But those conversions rather than biomass did not assess the environmental impact of the processes (Carvalho et al., 2018).

However, the circular economy is an important step towards creating a sustainable future with better use of resources and energy. In this sense, biomass wastes (in particular, wood waste represent an untapped source of carbon and hydrogen) produce a large range of chemicals, from methane to alcohol (Iaquaniello et al., 2018). Considering sustainability, the pre-treated wood-waste feedstock can also enhance methanol conversion efficiently (Carvalho et al., 2018). Table 4 summarizes methanol types and manufacturing process steps according to feedstock.

Table 4. Methanol types according to manufacturing process and feedstock (IRENA and METHANOL Institute, 2021; Peregoa and Riccib, 2023).

Methanol Type	Primary Feedstock	Production Method	Carbon Intensity	Sustainability
Bio-methanol	Biomass	Gasification/Reforming → Syngas → Methanol	Low	Sustainable
Grey methanol	Natural gas (no CCS)	Reforming → Syngas → Methanol	High	Non-Sustainable
Brown methanol	Coal (no CCS)	Gasification → Syngas → Methanol	Very High	Non-Sustainable

Besides, methanol also serves as a raw material for chemical products, such as formaldehyde, acetic acid, and a wide variety of other chemical products, including polymers, paints, synthetic chemicals and others. In the USA, to find environmentally friendly energy sources and to reduce petroleum consumption, one proposal is to use methanol alone and/or blend 10 to 15% of methyl alcohol (methanol) in gasoline for automotive use (Magda and Toth, 2019). Figure 2 summarizes methanol-based some chemicals. Which is commonly utilized in chemical industry. Table 5 shows the properties of methanol produced from different sources, comparatively.

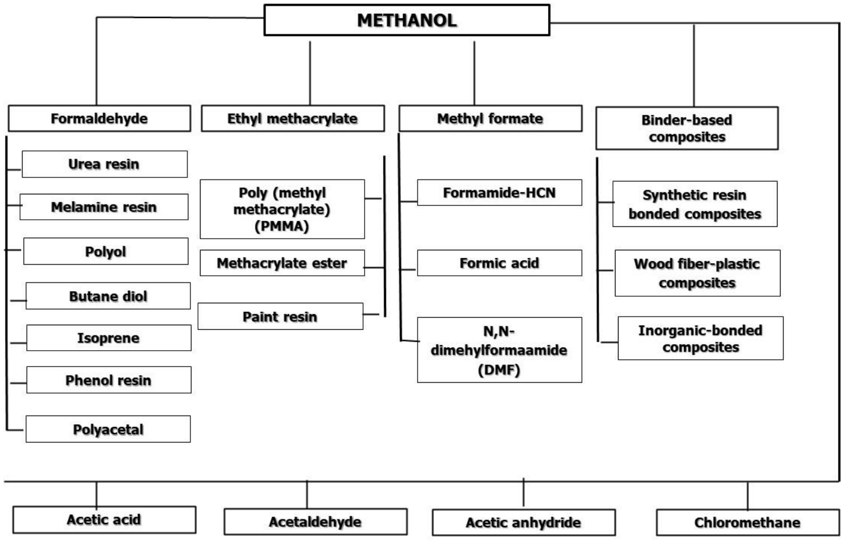

Figure 2. Utilization of Methanol for chemical industry (Carvalho et al., 2018; IRENA and METHANOL Institute, 2021; Deka et al., 2022).

Table 5. The comparative properties of Methanol from different production route (Hokanson and Rowell, 1977; Carvalho et al., 2017; Carvalho et al., 2018; Yadav et al., 2020; IRENA and METHANOL Institute, 2021; Peregoa and Riccib, 2023).

Property	Fossil-Based Methanol	Bio-Methanol
Lower heating value [MJ/kg]	19.7	18.5
Carbon Footprint [kg CO_2e/kg methanol]	1.30 – 1.50	0.20 – 0.50
Purity Range [%]	>98	90 – 98
Production Cost [€/ton]	100 – 300	300 – 500

6. CONCLUSIONS

The forest products industry generates a huge amount of waste, including chips, shavings, sawdust and bark. However, these have similar physicochemical properties as wood that could be recovered or recycled into valuable products. Methanol production from biomass or fossil fuels has been a well-known process, although it was first produced from wood, called wood alcohol. There has been intensive research conducted a technical and economic feasibility study for producing methanol from various types of sources.

Although the general properties of methanol from biomass and fossil fuels are quite similar, synthetic methanol has a manufacturing cost advantage over biomethanol. When sustainability and circular economy are taken into account during wood waste recycling, biomethanol might provide an important advantage when considering environmentally friendly fuel from renewable sources. Regarding these issues, research on the conversion of wood waste to valuable products has been an increasing trend worldwide.

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CHAPTER 6

Feeding the Future: Navigating Challenges and Harnessing Opportunities in 21st Century Cereal and Pseudocereal Production and Consumption

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Introduction

Cereals (Poaceae) and pseudocereals (dicotyledonous plants) are vital global food sources, supplying carbohydrates, proteins, and micronutrients. Major cereals include wheat, maize, rice, barley, sorghum, millet, oats, and rye, while key pseudocereals are quinoa, buckwheat, and amaranth (Mir et al., 2019). Pseudocereals are rich in antioxidants like polyphenols, offering anti-inflammatory, anticancer, and antidiabetic benefits, ideal for functional foods (Zhu, 2019).

Valued for climate resilience, crops like millets, quinoa, and amaranth thrive in marginal lands, supporting food security as arable land declines (Singh & Sood, 2021). Genomic advances enhance nutrient bioavailability, addressing hidden hunger and sustainability (Pirzadah & Malik, 2020). With a projected population of 9.2 billion by 2050, food production must rise 70%, adding 1 billion tonnes of cereals annually (Ghasemzadeh, 2012). Climate change threatens yields, with maize and wheat losses up to 34% (Hellin et al., 2012). Innovations like climate-resilient crops, CRISPR-based biofortification, and seed nutri-priming mitigate these risks (Bhattacharya et al., 2024).

This review analyzes cereals and pseudocereals' roles in energy, nutrition, and food security, covering taxonomy, production, climate adaptation, nutritional enhancements, socio-economic factors, and technology. It identifies research gaps and offers recommendations for sustainable food systems.

Defining Cereals and Pseudocereals: Taxonomy and Nutritional Profiles

Cereals, from the Poaceae family, are vital global food sources, supplying ~50% of human energy and protein. Major cereals—wheat, rice, maize, barley, sorghum, millet, oats, and rye—occupy 60% of cultivated land, with 65–75% carbohydrates, 6–12% proteins, and 1–5% fats (Mir et al., 2019). Since the agricultural revolution 10,000 years ago, they have been dietary staples (Cordain, 1999).

Pseudocereals, including amaranth, buckwheat, and quinoa, are broadleaf plants rich in high-quality proteins, fiber, vitamins, minerals, and phytochemicals. Gluten-free and adaptable to poor soils, they suit gluten-sensitive diets and diverse food applications like bread and pasta, enhancing their nutritional value (Martínez-Villaluenga et al., 2020).

Major Cereals

- **Wheat (*Triticum spp.*)**: A key cereal providing 58% starch, 13% fiber, 11% protein, and minerals like potassium and magnesium (Peña et al., 2002). Whole grain wheat reduces risks of cardiovascular disease, diabetes, and cancers (Shewry & Hey, 2015). Common wheat (*Triticum* aestivum) and durum wheat (*Triticum durum*) are used for bread and pasta.

- **Rice (*Oryza sativa*)**: A staple for over half the global population, rich in carbohydrates, with moderate protein and micronutrients like B vitamins (Fukagawa & Ziska, 2019). Brown rice offers more fiber than white, valued for its gluten-free properties (Tagliapietra et al., 2024).

- **Maize (*Zea mays*)**: Domesticated 7,000 years ago, a global staple with 72% starch, 7–12% protein, and antioxidants (Ranum et al., 2014). Quality protein maize enhances lysine and tryptophan, addressing malnutrition (Reddy et al., 2012).

Minor Cereals

- **Sorghum (*Sorghum bicolor*)**: Drought-tolerant, rich in carbohydrates, protein, and iron, aiding diabetes management (Ganapathy et al., 2015). Its climate resilience drives renewed interest (Hariprasanna & Rakshit, 2016).

- **Millet (*Various species*)**: Nutrient-dense, climate-resilient grains with protein, fiber, and minerals, supporting sustainability (Kumar et al., 2022). Breeding and policy efforts aim to overcome market challenges (Raut et al., 2023).

- **Oats (*Avena sativa*)**: High in β-glucan fiber, reducing cholesterol by 5–10% with 3 g daily intake, supporting gut health (Othman et al., 2011). Used in cereals and dairy alternatives.

- **Barley (*Hordeum vulgare*)**: Used for feed (70%) and malting (21%), with growing food interest due to high protein in hull-less varieties (Badea & Wijekoon, 2021).

- **Rye (*Secale cereale*)**: Adapted to harsh climates, rich in fiber and minerals, reducing diabetes and cardiovascular risks (Wrigley, 2019). Used in breads and biofuels.

Key Pseudocereals

- **Quinoa (*Chenopodium quinoa*) & Amaranth (*Amaranthus spp*.)**: Nutrient-dense, gluten-free pseudocereals with all nine essential amino acids, ideal for vegetarians (Tang & Tsao, 2017). Rich in fiber, minerals, and antioxidants, they reduce risks of cardiovascular disease, diabetes, and cancer (Martínez-Villaluenga et al., 2020). Amaranth's high lysine, iron, and phytochemicals like squalene address malnutrition, while both crops' climate resilience supports food security (Soriano-Garcia et al., 2019).
- **Buckwheat (*Fagopyrum esculentum*)**: Gluten-free, rich in carbohydrates, fiber, proteins, and minerals like magnesium. Its flavonoids and phenolic acids offer antioxidant, cholesterol-lowering, and blood sugar-regulating benefits (Giménez-Bastida & Zieliński, 2015). Used in noodles and cereals, it supports celiac diets and health (Sofi et al., 2023).

Historical Significance and Global Production Trends

Cereal domestication (wheat, rice, maize) drove agricultural societies, while pseudocereals like quinoa and amaranth sustained ancient American civilizations (Doebley et al., 2006). Cereals lead global production, but pseudocereals gain traction for their nutrition and gluten-free properties, promoting diversification (Taylor & Emmambux, 2008).

Food Systems Resilience and Sustainability

Food systems, spanning production to consumption, face disruptions from climate change and economic instability (Gregory et al., 2005). Resilience relies on anticipation, adaptation, and transformation, guided by the ABCD framework (Agency, Buffering, Connectivity, Diversity) (Piters et al., 2021). Governance gaps exacerbate unequal access, necessitating inclusive policies and balanced trade-offs for sustainable, resilient food systems (Hertel et al., 2021).

Frameworks for Analyzing Agricultural Challenges

- **Food Security Framework**: Focuses on availability, access, utilization, and stability, recently expanded to include agency and sustainability to address ecological and systemic inequalities (Clapp et al., 2022). It supports nutrition-sensitive postharvest technologies to enhance food security (Opara, 2013).

- **Sustainable Livelihoods Framework (SLF)**: Analyzes household resilience through human, financial, physical, natural, and social capital (Yuniarti & Purwaningsih, 2017). Institutional barriers often hinder asset use, requiring systemic changes for poverty reduction (Mensah, 2011).
- **Value Chain Framework**: Examines supply chains to improve efficiency, reduce costs, and expand markets, particularly in developing nations facing infrastructure challenges (Trienekens, 2011). It enhances millet production and profitability (Venkatesa Palanichamy et al., 2024).
- **Climate-Smart Agriculture (CSA) Framework**: Combines traditional practices like intercropping with advanced techniques such as improved varieties to boost productivity and lower emissions (Rosenstock et al., 2015). Effective CSA needs coordinated governance (Zheng et al., 2024).

These frameworks guide policymaking for resilient, sustainable agriculture.

Climate Change Impacts and Adaptation

Abiotic Stresses: Climate change intensifies drought, heat, salinity, and flooding, reducing crop yields by up to 70% and affecting growth and nutrition (Rane et al., 2021). Combined stresses are complex, requiring study of plants' phenological and biochemical adaptations (Rivero et al., 2022). Advances in stress-responsive genetics aid breeding resilient crops, but multi-stress impacts on yield and nutrition need further research (Kumar, 2020).

Drought, Heat, and Salinity Impacts on Yield and Quality

- **Drought & Heat Stress**: These reduce cereal and pseudocereal yields by impairing growth, grain development, and nutrition. Drought causes stomatal closure and osmolyte accumulation, while heat disrupts pollination and photosynthesis, leading to poor seed quality, e.g., pollen sterility in rice (Rivero et al., 2022). Solutions include breeding drought- and heat-tolerant varieties with stable membranes and agronomic practices like seed priming.
- **Salinity Stress**: Affecting 7% of global land, salinity causes osmotic stress and ion toxicity, limiting water uptake and seed metabolism (Begum et al., 2013). Strategies include enhancing root-microbe

interactions, seed priming, and using growth regulators to improve resilience (Ibrahim, 2016).

Climate-smart breeding and precision agriculture are vital for mitigating these impacts and ensuring food security.

Breeding for Abiotic Stress Tolerance

Developing stress-tolerant cereals and pseudocereals is key to climate adaptation. Conventional breeding, like hybridization, integrates with molecular tools such as marker-assisted selection and CRISPR/Cas9 for precise gene editing (Doggalli et al., 2024). Genomic advances and QTL mapping (e.g., DRO1, Saltol) enhance drought and salinity tolerance (Raj & Nadarajah, 2022). Combining these approaches improves adaptability, but multi-stress tolerance needs further research (Prabhu et al., 2023).

Agronomic Strategies for Abiotic Stress Management

- **Water Conservation**: Regulated deficit irrigation and drip irrigation optimize water use, reducing losses while maintaining yields (Evans & Sadler, 2008). Mulching and cover crops further conserve water (Alharbi et al., 2024).
- **Soil Management**: Biochar, manure, and conservation agriculture improve soil structure and salinity resilience (Blanchy et al., 2023). Optimized irrigation and phytoremediation enhance soil health (Mukhopadhyay et al., 2021).
- **Crop Diversification**: Crop rotation and intercropping stabilize yields, suppress pests, and boost agroecosystem resilience (Renard et al., 2023).
- **Planting Date Adjustments**: Early or mid-season planting avoids peak stress, improving yields in crops like soybean and Miscanthus (Ashman et al., 2023).

These strategies, combined with breeding, enhance crop resilience to climate change.

Biotic Stresses

Climate change alters pest and disease dynamics by shifting temperature and humidity, affecting pest distribution and virulence (Legrève & Duveiller, 2010). Globalization introduces new threats. Enhanced monitoring, biocontrol, resistance breeding, and technologies like gene editing are critical for resilient crop protection (Chattopadhyay et al., 2019).

Climate Change Effects on Pathogen and Pest Dynamics

Climate change impacts pathogen and pest dynamics, threatening food security:

- **Range Expansion**: Rising temperatures allow pests and pathogens to invade new regions, increasing overwintering and generations while disrupting crop-pest synchrony (Skendžić et al., 2021). Elevated CO_2 and altered precipitation affect plant susceptibility, reducing pest management efficacy (Grace et al., 2019). Adaptive strategies like integrated pest management and predictive modeling are needed (Reddy, 2013).
- **Increased Reproduction**: Warmer temperatures accelerate pest and pathogen life cycles, e.g., faster cricket egg development (Adamo & Lovett, 2011) and invasive species growth (Keller & Shea, 2021). Extended pathogen seasons devastate crops (Kumari et al., 2024).
- **Altered Host-Pathogen Interactions**: Temperature and CO_2 shifts modify plant physiology and pathogen distribution, increasing crop susceptibility and outbreaks (Lahlali et al., 2024). Adaptive practices and research are essential (Gregory et al., 2009).
- **Vector Distribution Changes**: Climate shifts alter insect vector behavior, affecting virus transmission (Canto et al., 2009). CO_2 impacts plant quality, with some pests increasing feeding (Trębicki et al., 2017). Vector range shifts occur, though tropical heat may reduce some pests (Caminade et al., 2019).

Further research and innovative management are critical to mitigate these impacts.

Integrated Pest and Disease Management Strategies

Integrated pest and disease management (IPM) reduces biotic stresses on cereal and pseudocereal crops by combining eco-friendly methods to minimize losses and environmental harm:

- **Resistant Varieties**: Breeding resistant crops using marker-assisted selection and gene editing lowers pesticide use and enhances sustainability (Padmavathi & Padmaja, 2022).

- **Crop Rotation**: Alternating crops disrupts pest and pathogen lifecycles, boosts soil biodiversity, and improves disease control (Shimada et al., 2021).
- **Biological Control**: Natural enemies like predators and parasitoids suppress pests via conservation, introduction, or augmentation, offering long-term, species-specific control (Sanda & Sunusi, 2014).
- **Cultural Practices**: Crop rotation, sanitation, and soil solarization create unfavorable conditions for pests, reducing chemical reliance (Thapa & Juyal, 2022).
- **Monitoring and Scouting**: Precision tools like remote sensing and IoT sensors enable early pest detection, optimizing interventions (Chattopadhyay et al., 2024).
- **Judicious Pesticide Use**: Targeted applications within IPM minimize environmental and health risks, balancing yield protection with ecosystem safety (Ruba et al., 2023).

Water Resource Management for Cereal and Pseudocereal Production

Effective water management is vital for sustainable cereal and pseudocereal production amid climate change, focusing on optimized irrigation, conservation, and watershed strategies:

- **Efficient Irrigation**: Drip irrigation and laser leveling reduce water use by 21–31% in South Asia, though expanded irrigation areas may offset savings (Mitra et al., 2017). Conservation incentives are needed for net gains (Koech & Langat, 2018).
- **Water Harvesting**: Rainwater harvesting reduces reliance on potable water, aiding stormwater management and boosting cereal yields in Africa and Asia (Wisser et al., 2009). Rain gardens enhance infiltration.
- **Deficit Irrigation**: Strategic water reduction, e.g., 75% less during tomato end-growth, achieves high water use efficiency (9.2 kg/m^3) with minimal yield loss (Gebreigziabher, 2024). In maize, 50% deficits late in growth optimize yields (Kahsay & Reda, 2019).
- **Water-Smart Cropping**: No-tillage and strip tillage conserve water, with strip tillage gaining up to 60 mm annually (Bosch et al., 2005).

Combining with drought-resistant varieties and precision farming boosts efficiency (Soujanya & Gurjar, 2024).

- **Watershed Management**: Protecting wetlands and riparian forests controls pollution, improves water quality, and mitigates floods, supporting food security (Edwards et al., 2015).

Soil Health Degradation and Sustainable Land Management Practices

Soil health is critical for sustainable cereal and pseudocereal production, as degradation from erosion, nutrient depletion, and compaction lowers yields and increases climate vulnerability. Sustainable land management practices are essential to enhance soil quality:

- **Conservation Tillage**: No-till and reduced tillage reduce erosion, improve water infiltration, and increase organic carbon, enhancing soil structure and productivity while mitigating emissions (Bezboruah et al., 2024).
- **Cover Cropping**: Cover crops reduce erosion by 96%, improve infiltration, and boost organic matter, supporting microbial activity and nutrient cycling while fixing nitrogen (Haruna et al., 2020).
- **Crop Rotation**: Diverse rotations enhance soil structure, microbial diversity, and nutrient cycling, reducing pests and external inputs via legume nitrogen fixation (Farooq et al., 2019).
- **Integrated Nutrient Management**: Combining organic and inorganic fertilizers with residues optimizes nutrient availability, boosts yields, and enhances soil fertility (Kamboj et al., 2024).
- **Agroforestry**: Integrates trees with crops to improve soil structure, reduce erosion, and enhance nutrient cycling, supporting long-term sustainability (Haruna et al., 2020).

Enhancing Nutritional Value, Processing, and Utilization

Genetic Improvement and Biofortification

Genetic biofortification increases iron, zinc, and provitamin A in cereals and pseudocereals to address micronutrient deficiencies in developing nations (Kiran et al., 2022). Breeding and genetic engineering, including CRISPR/Cas and high-throughput phenotyping, enhance nutrient density in millets and pseudocereals like quinoa and amaranth, reducing saponins and improving yield and stress tolerance (Anuradha et al., 2023).

Targeting Micronutrients

Micronutrient deficiencies ("hidden hunger") cause anemia, immunity issues, and developmental delays. Biofortification delivers essential nutrients to vulnerable populations (Rollán et al., 2019):

- **Iron-Biofortified Rice**: Enhances iron storage and transport genes to combat anemia in rice-dependent regions, using transgenic or conventional breeding methods (Matres et al., 2021).
- **Zinc-Biofortified Wheat**: Genomic selection boosts zinc by 20–30% and yield, addressing deficiency despite genetic complexity (Roy et al., 2022).
- **Vitamin A-Biofortified Maize**: Increases β-carotene to reduce vitamin A deficiency, using breeding or genetic engineering, with consumer acceptance in regions like Zambia (Aman, 2021).

Improving Protein Quality and Quantity

Cereals and pseudocereals are vital protein sources, but their protein content and quality vary. Genetic improvement enhances protein levels and essential amino acid balance through:

- **High-Protein Varieties**: Breeding programs increase protein in sorghum, wheat, and soybean without yield loss, using genomic selection and cross-breeding to combine high-protein and high-yield traits (Michel et al., 2019).
- **Amino Acid Profiles**: Genetic engineering boosts lysine, methionine, and tryptophan in maize by modifying storage protein genes and biosynthetic pathways, addressing nutritional deficiencies (Singh & Yadav, 2010).
- **Protein Digestibility**: Processing techniques like fermentation and cooking reduce antinutrients, improve amino acid profiles, and enhance mineral availability. Bacterial proteases further increase digestibility in grains and legumes, supporting nutrition and food security (Mak et al., 2024).

Reducing Anti-Nutritional Factors

Cereals and pseudocereals contain antinutrients like phytic acid and tannins, which reduce nutrient bioavailability. Genetic and processing strategies mitigate these:

- **Low-Phytate Varieties**: Breeding low-phytate mutants reduces phytate by 50–95%, enhancing iron and zinc absorption in cereals and legumes (Raboy, 2002). Alternative approaches, like increasing mineral content or using phytases, address phytate's physiological roles (Frossard et al., 2000).
- **Processing Techniques**: Soaking, germination, and fermentation lower phytic acid, tannins, and trypsin inhibitors, improving protein digestibility and mineral absorption (calcium, iron, zinc) (Gupta et al., 2015). Decortication and heat treatments further enhance nutritional quality, addressing deficiencies sustainably.

Post-Harvest Technologies and Value Addition

Nutritional Benefits and Processing

Pseudocereals like quinoa, amaranth, and buckwheat offer superior proteins, fibers, and bioactive compounds compared to cereals (Nandan et al., 2024). Germination and fermentation enhance nutrients, while dehulling may reduce fiber (Gowda et al., 2022). Fermentation improves safety and creates bioactive peptides (Petrova & Petrov, 2020). Modern products like gluten-free pasta and probiotic sourdough address dietary needs and malnutrition (Poshadri et al., 2024).

Minimizing Post-Harvest Losses

- **Improved Harvesting**: Combine harvesters reduce wheat losses to 2.92% versus 4.28% manually, with optimal timing enhancing quality (Lund et al., 2020).
- **Proper Drying**: Microwave and vacuum drying control moisture and pests efficiently, improving storage (Jimoh et al., 2023).
- **Hermetic Storage**: Airtight systems prevent pest damage and aflatoxin in maize, preserving quality (Odjo et al., 2022).
- **Improved Transportation**: Optimized routes cut transit losses by 16–24%, boosting market access (Ljungberg, 2006).

Innovations in Food Processing

Pseudocereals' balanced amino acids and bioactive compounds support gluten-free and functional foods, with processing like fermentation enhancing bioavailability (Martínez-Villaluenga et al., 2020; Poshadri et al., 2024).

Functional Properties

Sorghum, millet, and pseudocereals offer excellent water absorption and protein solubility, ideal for gluten-free flours and sustainable foods (Vidaurre-Ruiz et al., 2023).

Gluten-Free Product Development

Quinoa, amaranth, and buckwheat enable gluten-free bread and pasta, benefiting celiac patients with enhanced nutrition via enzymatic processes (Martínez-Villaluenga et al., 2020).

Dietary Diversity and Malnutrition

Pseudocereals naturally provide micronutrients, supporting biofortification and dietary diversification to combat hidden hunger (Pirzadah & Malik, 2020).

Combating Hidden Hunger

Biofortification and agricultural strategies enhance nutrient content, requiring policy support to overcome socio-economic barriers (Meena et al., 2018).

Culinary Traditions

Pseudocereals' nutritional and gluten-free properties make them versatile for global diets, though underutilized; expanded production could boost sustainability (Nandan et al., 2024).

Socio-Economic, Policy, and Market Dimensions

Global Market Dynamics

Trade policies enhance food security but challenge small farmers, requiring support for market access (Smith & Glauber, 2019).

Trade Agreements

Agreements improve market stability and water productivity by 93%, but low-income importers face costs, needing balanced policies (Falsetti et al., 2022).

Smallholder Integration

- **Credit and Inputs**: Credit boosts yields by 0.17–0.25 t/ha in Ghana, but access remains limited (Nordjo & Adjasi, 2020).
- **Farmer Organizations**: Increase incomes by 20–25%, though governance issues persist (Bizikova et al., 2020).
- **Infrastructure**: Cold storage and roads reduce losses, but benefits may favor wealthier farmers (Chegere, 2018).
- **Fair Trade**: Certification ensures equitable pay, benefiting 1,880 organizations by 2020, though broader impacts vary (Mutea et al., 2024).

Consumer Preferences

Health awareness drives demand for pseudocereals' gluten-free, nutrient-rich profiles, supporting sustainable diets (Nandan et al., 2024).

Labeling Requirements

Accurate gluten-free labeling is critical for celiac safety, though inconsistencies persist, requiring stricter enforcement (Rajnincová et al., 2019).

Conclusion and Recommendations

Conclusion

This review underscores challenges and opportunities in 21st-century cereal and pseudocereal production, vital for global food security. Population growth, climate change, and socio-economic disparities reduce yields and limit nutritious food access. Innovations like genetic improvement, biofortification, climate-smart practices, and post-harvest technologies enhance resilience and sustainability. Pseudocereals such as quinoa and amaranth offer gluten-free, nutrient-rich options, aligning with consumer trends. Integrating smallholder farmers into value chains via supportive policies ensures equity and viability. Gaps in regional strategies and scalability require interdisciplinary efforts for resilient food systems.

Recommendations

1. **Regional Research**: Develop localized adaptation strategies, e.g., drought-resistant crops, and promote cross-regional data sharing.
2. **Biofortification**: Enhance micronutrients via CRISPR and breeding, with public-private partnerships for smallholder adoption.

3. **Climate-Smart Agriculture**: Promote deficit irrigation and crop diversification, investing in IoT and drones for efficiency.
4. **Post-Harvest Technologies**: Support affordable storage and processing to cut losses, improving transport networks.
5. **Inclusive Policies**: Integrate smallholders via fair trade, credit, and cooperatives, reducing trade barriers.
6. **Socio-Economic Support**: Provide subsidized seeds and nutrition education, strengthening farmer organizations.
7. **Interdisciplinary Research**: Fund studies on stress resilience and technology scalability.
8. **Digital Tools**: Develop mobile apps for real-time market and climate insights.

These steps aim to bolster sustainable, equitable food systems addressing global challenges.

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