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Hydroponic fodder for livestock production and productivity: a Review

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ABSTRACT

Green fodder plants serve as a vital source of nutrition for livestock. However, ensuring an adequate supply of these plants for livestock faces with challenges such as limited agricultural areas, water scarcity, and negative impacts from environmental and climatic factors. To address these challenges, various strategies can be employed. Hydroponic fodder production system is new technology that can be used to produce fodder for livestock feed without using land and soil. Hydroponic fodder production has gained significant attention and is a prominent area of research in the field of agriculture. Many countries are actively working towards developing and implementing this technology to enhance livestock feed production. The purpose of this study is to focuses on the chemical composition and nutritional value of hydroponic fodder in livestock production. Also, the effect of feeding hydroponic fodder on livestock production and productivity has been reviewed. This review helps determine the potential benefits and practical implications of incorporating hydroponic fodder into livestock feeding programs.

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1. Introduction

All over the world, livestock production plays a vital role in the income of villagers. To achieve a stable income, increasing the productivity of livestock and its production is a serious need. To achieve this goal, livestock feed is a must. Feed is the main and, of course, the most expensive element in livestock farming (Dung et al., 2010; Fazaeli et al., 2012). Although other factors also lead to a decrease in livestock production, it can be safely said that the main limiting factor in livestock production in the lives of villagers is livestock feeding (Badran, 2017). This issue is especially prominent in recent years. Severe weather fluctuations, need for labor force, reduction of land for food cultivation, increase in the cost of fertilizers and successive droughts; It has led to the lack of adequate livestock nutrition becoming a serious challenge (Abd Rahim and Omar, 2015; Al-Karaki, 2011; Gupta, 2014). Many villagers around the world are struggling with this challenge and it is necessary to overcome this challenge by taking measures. In the traditional methods of fodder production for livestock, in addition to insufficient access to water and soil resources, other problems such as the long growth period of fodder, the lack of proper use of fertilizers, etc. make livestock production difficult (Mengistu and Assefa, 2012). For this reason, researchers many efforts have been made to increase the size of cultivated land, use plant residues and by-products, and supply new fodder products to compensate for the lack of livestock feed (Seidavi et al., 2021). Among these cases, the last one is the production of new fodder products; A very interesting idea. One of these products is hydroponic fodder.

Hydroponic fodder production system is an alternative technology that can be used to produce fodder for livestock feed without using land and soil. This system uses a mixture of water-soluble minerals for fodder. Hydroponic fodder production systems are one of the most attractive fields of research in agriculture, and many countries are seeking to develop it. A hydroponic fodder production system can produce major grains such as barley, wheat, oat and rye. In addition to not needing water and soil resources directly; Production of fodder in environments free from pollution such as fungicides, insecticides and pesticides is another very important and interesting aspect.

The purpose of this study is to review the existing studies on the contribution of hydroponic feed for livestock production and productivity. The presented review focuses on the chemical composition and nutritional value of hydroponic fodder in livestock production. In the second part of the review the results of the effect of hydroponic fodder on important matters such as milking rate, weight gain, reproductive traits, and ... food-producing animals have been investigated and reported. In the third part of the review; the results of using hydroponic fodder supplements to livestock diets are discussed and presented from the perspective of various researches, and finally, the future research direction is presented in the fourth part of the paper.

2. Concept of Hydroponic Feeds and related definitions

The word hydroponics consists of two separate parts with Greek roots. The first part, hydro, means "water" and the second part, ponic, means "working". Therefore, fodder produced in a solution rich in water or nutrients without using soil is called hydroponic fodder. Hydroponic fodder is also called sprouted grains or sprouted fodder (Dung et al., 2010). These fodders are very tasty and approximately have a height between 15 and 20 cm (Naik et al., 2015). One of the most important points in the production of this type of fodder is that their production environment is a closed and controlled system (Akkenapally and Lekkala, 2021). In terms of growth time, they sprout and grow in a short period of time compared to the traditional method (Akkenapally and Lekkala, 2021). In recent years, various crops of this type of fodder have been produced all over the world. Such fodder crops include mainly those from the Fabaceae family, leguminous species such as alfalfa, clover, or

cowpeas, and those from the Poaceae family, grain species such as barley, oats, wheat, sorghum and corn (Abdula, 2022).

3. Chemical composition and nutritional value of hydroponic fodder

One of the important topics in hydroponic fodder review is to pay attention to its chemical composition and nutritional value. In general, the chemical composition of hydroponic fodder is completely different depending on the type of grain used and also the specific growth conditions. But in general and with any type of grain; Hydroponic fodder is rich in protein, fiber, vitamins and minerals. This makes this fodder a nutritional supplement for livestock feed. In Livestock, these cases are examined in more detail.

3.1. Dry matter

Researches on hydroponic fodder dry matter have generally calculated the amount of DM in different grains. Suma et al (2020) showed that during sprouting; the amount of seed dry matter decreases by 7-47%, which is related to physiological and metabolic function. It was concluded in the study of Chavan et al (1989) that there are changes in the nutrient content of grain and hydroponics, which decreases DM content. This is due to the decrease in starch content. In fact, when the amount of starch decreases; both organic matter and dry matter content will decrease. Molla and Sharaiha (2010) reviewed all the factors that affect the fresh yield and the amount of dry matter of fodder cultivated by hydroponic method has been done. Several factors such as diversity, quality and seed strength in plant species, environmental factors such as water quality and quantity, water pH, the amount of light and humidity of the type of environment (greenhouse or natural environment) were evaluated, were among these factors. Shtaya (2004) showed that the loss of dry matter in hydroponic wheat after 12 days of planting is 25% of the total dry matter and after 5 to 7 days it is 17%. This result shows that as the number of days under cultivation increases, the amount of wasted dry matter decreases. The results of another research showed that the amount of dry matter in hydroponic barley is 18.3% (Abd Rahim and Omar, 2015).

The study of Fazaeli et al (2012) showed that on the eighth day of cultivation, the percentage of dry matter decreased from 91.4% in barley seeds to 13.3% in hydroponic barley. It was also reported that the dry matter of hydroponic corn is 18.48% and the dry matter of hydroponic barley is 14.2% (Kide et al., 2015).

3.2. Energy

The energy in hydroponic grains such as barley, wheat or oats comes from carbohydrates stored in the grain. Carbohydrates are broken down during germination and growth to provide plant energy for root, stem, and leaf growth. In the next step, this energy will be used for plant metabolic processes such as photosynthesis, respiration, and absorption of nutrients.

In the hydroponic process, nutrients and water are delivered directly to the roots of the plants, allowing them to effectively absorb and use the energy from the seeds to grow and flourish. On dry matter bases, the energy value of sprouts is less than grains with gross energy loss (Arif et al., 2023).

3.3. Palatability

According to the report provided by FAO in 2001; Hydroponic green fodder sprouts are very appetizing, very palatable and absolutely loved by animals. In addition, this type of fodder is very digestible (Shipard, 2005). "palatability" indicates the animal's reaction and appetite, which is based on the quality of the food (Baumont, 1996). It was shown that due to the palatability of hydroponic fodder, DM consumption Higher than the basic diets

(containing 20% low-digestible wheat straw) was recorded in a group of goats (Arif et al., 2023).

It was shown that growing Konkan Kanyal goats fed with corn and barley hydroponic fodder (20%:20%); had the highest consumption of DM compared to other groups. This difference is due to the palatability and appetite of hydroponic fodder. Of course, one of the points of this research is the use of hydroponic fodder mixed with corn and barley (20%:20%), which feature of the mixture of corn and barley has been considered in less researches (Kide et al., 2015). In the study of Ibrahim et al (2001) better palatability was attributed to higher consumption of carbon dioxide in groups fed with hydroponic barley fodder. In general, the research results show; Hydroponic green fodder sprouts are very appetizing, very palatable and absolutely loved by animals.

3.4. Protein

According to the definition, crude protein is the total nitrogen compounds present in the tested grain or product, which is obtained by multiplying the total nitrogen content of the tested substance by the corresponding special coefficient. Checking the amount of CP in hydroponic fodder and comparing it with other grains and feeds is also an important issue. Research has shown that hydroponic feed is significantly superior to conventional (non-legume) feed in terms of organic matter; it has ether extract, nitrogen free extracts and crude protein. Specifically, hydroponic sprouted barley is characterized by increased crude protein, crude fiber, ash, minerals and vitamins (Abdullah, 2001; Morgan et al., 1993; Peer and Leeson, 1985).

In the study of Brown et al (2018) It has been described that longer sprouting time is responsible for more significant losses in DM and increased protein content (Brown et al., 2018). They stated that the increase in CP content is due to losses in DM. Similar to the results presented by Brown et al (2018), Naik et al (2014) reported that in sprouts, CP was concentrated to a greater extent in dry matter bases than in barley seeds.

Another group of research investigated the amount of CP in hydroponic grain. It was reported that the amount of CP in hydroponic corn fodder is equal to 16.5%, which was consistent with previous research. The same research declared the amount of CP in hydroponic barley fodder to be 14.44% (Kide et al., 2015).

In the study of Sneath and McIntosh (2003) an important result of the superiority of hydroponic fodder CP compared to CP in the barley was reported. They reported that the amount of CP in hydroponic barley is equal to 24.9%, while the amount of CP in grain was equal to 14%. This amount is about 1.8 times. The same conditions apply to Oat. According to the results of this research, Oat fodder increased from 12.3% in seeds to 20.7% in sprouts.

3.5. Vitamins

Hydroponic fodder contains a variety of vitamins that are essential for the growth and development of plants. These fodders are a rich source of vitamin A, vitamin E, vitamin C, thiamin, riboflavin, biotin, niacin, free folic acid, antioxidants such as beta-carotene and minerals (Chung et al., 1989; Cuddeford, 1989).

However, according to the research results; Among the types of vitamins, hydroponic fodder has a higher percentage of vitamins C and E. Vitamin C acts as an antioxidant and helps protect the plant from damage caused by free radicals and environmental stressors. Vitamin E also helps plants maintain their cellular integrity. Also, the results show that sprouting improves the vitamin content of seeds (Sneath and McIntosh, 2003).

Table 1. Summary of results of chemical composition and nutritional value of hydroponic fodder

Dry matter	The percentage of dry matter in hydroponic grains is acceptable and in a suitable numerical range.
Energy	The energy in hydroponic grains such as barley, wheat or oats comes from carbohydrates stored in the grain.
Dry matter	The percentage of dry matter in hydroponic grains is acceptable and in a suitable numerical range
Protein	Hydroponic feed has a significant advantage over conventional (non-legume) feed in terms of protein.
Vitamin	Hydroponic fodder is a rich source of vitamin A, vitamin E, vitamin C, thiamin, riboflavin, biotin, niacin, free folic acid, antioxidants such as beta-carotene and minerals.

4. Hydroponic fodder supplements to livestock diets

In this part of the research, the results of the research on the use of hydroponic fodder as a supplement for livestock diets have been investigated. The focus is on dairy cattle, calves, goats, ewes and beef cattle. The most important results are presented in the form of a table.

4.1. Dairy cow

In a general conclusion, research has proven that green fodder is tastier and has better digestibility than dry fodder, and on the other hand, green fodder has led to improved nutrient digestibility, health and performance of animals (Helal, 2018). It is reported that sprouted grains are efficiently digested compared to grain seeds because of the high activation of hydrolytic enzymes as a result of germination (Almuhayawi et al., 2021).

Fazaeli et al (2021) showed that by using hydroponic fodder replacement for dairy cows, no noticeable change in the weight and production of cow's milk was felt. The diets used in this research were hydroponic barley fodder (20-60%) with corn silage. On the other hand, Agius et al (2019) reported that milk quality improves with barely fodder inclusion (7.58%). Suma et al (2020) also reported the effect of hydroponics maize fodder supplementation (12%) on the health performance of cows. In research of Upreti et al (2020) it was shown that the replacement of concentrate with hydroponic maize (6.1 kg/h/d) leads to an increase in milk production.

In the research Nugroho and Permana (2015) the increase in dry matter consumption, energy consumption, nitrogen uptake, nutrient digestibility and maintaining the continuity of milk production are among the advantages of using hydroponics maize fodder (7% on a dry matter basis). Similar results are presented in Naik et al (2015) study. This research showed that cows that were fed with sprouted barley fodder (1.4 kg); they have less milk protein production, but milk urea N has been more. It has been shown that the use of hydroponic barley in ruminant diets increases milk production by about 3.9% (Naik et al., 2014). It was also shown that hydroponic corn increases milk production by about 13.7% (Heins, 2017). In the study of Salo (2019) the positive effect of adding hydroponic grain to cow diets has been presented, based on which diets have increased milk production and improved butter quality. the positive effect of adding hydroponic grain to cattle diets has been reported in another studies (Kaouche-Adjlanea et al., 2016; Mooney, 2005).

It has been shown that milk production (8.7-10%), milk fat content (14%), meat yield, carcass quality, daily live weight gain and growth rate are due to increased digestibility

(Farghaly et al., 2019; Sharif et al., 2013). In other researches it was also shown that hydroponic fodder has led to an increase in milk production by 8 to 14 percent (Farghaly et al., 2019; Heins, 2017; Kaouche-Adjlanea et al., 2016; Mooney, 2005; Rachel et al., 2020; Reddy et al., 1988; Salo, 2019; Sharif et al., 2013). In the Another study it was shown that feeding with hydroponic fodder leads to an increase in the digestibility of nutrients (Reddy et al., 1988).

4.2. Calves

Various researches have been conducted to investigate the effect of hydroponic fodder on calves. The results of Fazaeli et al (2011) study showed that the inclusion of green fodder (22.8% based on DM) in the livestock of calves has no advantage over barley and the cost of feed increases. But the results of the Verma et al (2015) showed that feeding hydroponic barley fodder at the rate of 2.5 to 5 kg per day for calves leads to an increase in dry matter consumption, digestibility of nutrients and improvement in the growth rate of Hariana male calves. It has been reported that it is better to use hydroponic corn fodder for feeding heifers when traditional feed is not available or it is not possible to cultivate due to climate and weather reasons (Naik et al., 2016). In Jediya et al (2021) study a complete research has been done on a group of Gir calves. The results of this research show that the use of hydroponic corn fodder has a beneficial effect on the growth performance and digestible nutrients in Gir calves, so that it can replace up to 75% of the raw protein of the concentrate mixture.

The most important issue in the management and growth of cattle herds in livestock farms among livestock breeders is the optimal growth of calves, which also requires the best food for calves, i.e. calf starter, which causes better growth of calves and feed costs. Some researches such addressed this issue and showed that if calf starter is replaced with hydroponic corn fodder (50 to 75% based on DM), it will not have any adverse effect on the growth and digestibility of calf brain material (Rani et al., 2019). A similar research showed that feeding hydroponic corn fodder as a partial substitute for calf starter (7% based on protein) improves calf weight gain, improves dry matter consumption, and reduces production costs (Rajkumar et al., 2018).

4.3. Goath

Goats, as another group of animals, have been evaluated in some research for the use of hydroponic fodder. It has been shown that increasing dry matter consumption, increasing body weight and increasing economic efficiency are the three main advantages of using corn and hydroponic barley fodder (20-40%) for goats (Gebremedhin, 2015).

It has also been shown that the digestibility of nutrients, productive performance and profitability of Tellycherry buck kids are significantly improved by supplementing hydroponic corn fodder (25-50%) (Ebenezer et al., 2021; Gebremedhin, 2015). Of course, the percentage of hydroponic corn fodder in this case is somewhat higher than other research.

4.4. Ewes

Like other animals, ewes and sheep have changes in diet and production under the influence of hydroponic fodder. It was shown that by adding hydroponic barley fodder (15-25%) in the diets of Awassi female lambs, the pregnancy rate and percentage of twins in ewes fed with fodder improved (Eshtayeh, 2004). Also, this research indicated that the use of this fodder had no problem with the health of the ewes. Other results showed that hydroponic barley sprout as a supplementary diets; For sheep, has a positive effect on animal performance (Farghaly et al., 2019). It was shown that sprouted barley at different levels (10-30%) can improve the reproductive traits of Avasi male lambs (Al-Saadi and Al-Zubiadi, 2016). It was

reported that the increase in dry matter consumption, nutrient digestibility and nitrogen retention are among the effects of using hydroponic barley fodder (Raeisi et al., 2018).

In the study of Guerrero-Cervantes et al, it was shown that green wheat cultivated by hydroponic method during pregnancy and lactation has no negative effect and is completely acceptable (Guerrero-Cervantes et al., 2016). However, in the study of Chethan et al (2022) a negative impression was made on the use of conventional green fodder mixed nutrition with hydroponic corn. Based on the Mekonnen et al (2019) study by replacing oat fodder (948g/lamb/day) with commercial concentrate, researchers were able to record the daily weight gain of ewes. The research results of Ata (2016) showed that hydroponic barley fodder significantly improves feed consumption, ADG and FCR in a three-month-old lamb. It was also stated that 50% of sorghum and barley placed in the hydroponic system will increase feed efficiency, growth performance and sheep carcass quality (Devendar et al., 2020). The results presented by Shit (2019) also shows that hydroponic fodder leads to better weight gain of lambs.

4.5. Beef cattle

Among other studied animals, beef cattle are more important in terms of weighing. It has been shown that feeding beef cattle with hydroponic fodder leads to the production of more lean meat with omega-3 fatty acids and vitamins (Shit, 2019). Also, in the study of Tudor et al (2003) showed an average increase in weight in beef cattle by feeding hydroponic feed compared to corn. Therefore, providing a comprehensive plan based on hydroponic fodder for feeding beef cattle, which considers the nutritional needs, cost and availability of their feed, as well as other aspects of feeding beef cattle, can benefit by improving the quality of the final product. Improve livestock farming. The table 3 summarizes the most important studies investigating the effect of hydroponic fodder supplementation on livestock performance and livestock production. As it is known, most studies show the positive effect of using this fodder on livestock performance and livestock production, which is a practical result.

Table 2. Summary of the most important studies investigating the effect of hydroponic fodder supplementation on livestock performance and livestock production

complementary diets	Animal	References	summary of results
hydroponic barley fodder(20-60%) with corn silage	Dairy cow	(Fazaeli *et al.*, 2021)	No noticeable change in cow's weight and milk production
Hydroponic maize fodder supplementation	Dairy cow	(Agius *et al.*, 2019; Rachel *et al.*; Reddy *et al.*, 1988)	Improving milk quality
hydroponics maize fodder supplementation (12%)	Dairy cow	(Suma *et al.*, 2020; Upreti *et al.*, 2020)	health performance of cows.
hydroponic maize (6.1 kg/h/d)	Dairy cow	(Tudor *et al.*, 2003)	Increase milk production
hydroponics maize fodder (7% on a dry matter basis)	Dairy cow	(Nugroho and Permana, 2015)	increased dry matter intake, energy consumption, nitrogen conception, nutrient digestibility, and maintain persistence of milk production
Hydroponic maize fodder supplementation (15 kg HMF/cow/day)	Dairy cow	(Naik *et al.*, 2014)	increase the digestibility of nutrients, milk production, and net profit

barley fodder (1 .4kg)	Dairy cow	(Soder *et al.*, 2018)	Less milk protein production More urea N milk
Hydroponic maize fodder supplementation	Dairy cow	(Farghaly *et al.*, 2019; Sharif *et al.*, 2013)	improve carcass quality, daily live weight gain
barley (2.5 to 5kg day)	Calves	(Verma *et al.*, 2015)	increased dry matter intake nutrient digestibility improved growth rate
Hydroponics maize fodder	Calves	(Jediya *et al.*, 2021)	beneficial effect on growth performance and digestible nutrients in Gir calves
hydroponic maize fodder (50-75% on a DM basis)	Calves	(Rani *et al.*, 2019)	Positive effect of using hydroponic corn fodder for calf starter
hydroponics maize fodder (starter)	Calves	(Rajkumar *et al.*, 2018)	The positive effects of using hydroponic corn fodder instead of calf starter in improving calf weight gain, improving dry matter consumption and reducing production cost.
maize and barley (20-40%)	Goath	(Rani *et al.*, 2019)	Increasing consumption of dry matter, increasing body weight and increasing economic efficiency
hydroponic maize fodder (25-50%)	Goath	(Ebenezer *et al.*, 2021; Gebremedhin, 2015)	improve nutrient digestibility improve productive performance
hydroponic barley fodder (15-25%)	Ewe	(Jemimah *et al.*, 2022)	improve conception rate and twin percentages
Hydroponic barley fodder	Ewe	(Al-Baadani *et al.*, 2022; Al-Saadi and Al-Zubiadi, 2016; Raeisi *et al.*, 2018)	Improving reproductive traits Increase in dry matter consumption Improve the digestibility of nutrients
Feeding a mixture of conventional green forage with hydroponic corn	Ewe	(Chethan *et al., 2022)*	Negative effect on the growth of lambs
oat fodder (948g/lamb/day)	Ewe	(Mekonnen *et al.*, 2019)	Daily weight gain
50% of sorghum and barley hydroponic	Ewe	(Devendar *et al.*, 2020)	Improving growth performance and sheep carcass quality
Hydroponic barley fodder	Beef cattle	(Tudor *et al.*, 2003)	increase weight

5. Future research

In the future, several branches of research in the field of hydroponic fodder can be followed. The first area is about the design of hydroponic fodder irrigation systems. Despite the good progress made in this field, it is still far from an optimal irrigation system. The second field of research is on investigating the effects of hydroponic fodder diets on different breeds of animals in different climates. It seems that there is no comprehensive research on this matter. The third area that can be a general plan for future research is to find mixed diets with the highest efficiency on animals. Mixed diets with different percentages should be investigated to achieve this goal.

A fourth area that can be researched is the detailed investigation of the commercial potential of incorporating a hydroponic diet into livestock farming. It may still be economical to use traditional methods and non-hydroponic fodder. It is hoped that in the future, by designing an optimal cycle of hydroponic fodder production and consumption from beginning

to end, it will be possible to achieve higher quality products with less water consumption in the absence of suitable soil and increase food security around the world.

6. Conclusion

The positive aspects and results of the latest research on hydroponic fodder as an attractive and practical solution to solve environmental problems, climate change and drought were introduced in this research.. The results of the studies showed that the digestibility and better taste of hydroponic fodder has made it very attractive for livestock. On the other hand, hydroponic fodder supplement for livestock feeding can increase milk production and composition, dry matter consumption, nutrient digestibility and improve the health status and increase the daily weight of calves, sheep and goats. Various studies reported a positive relationship between the use of hydroponic fodder and its beneficial effect on the quality of life of farm animals, which was reviewed in the paper. The results of this study emphasize that hydroponic fodder has high nutritional value due to the conversion of complex compounds into simpler and more essential forms and the activation of enzymes during sprouting and can lead to improvements in digestibility and nutrient intake and lead to an increase in Livestock milk and milk fat production and ultimately increase food security in the future.

Conflict of interest

The authors have no conflicts of interest

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