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Effect of Harvesting Stage on Biomass Yield and Quality of Wheat (*T. Aestivum*) and Triticale *(×Triticosecale Wittmack)* Fodder under Hydroponic Condition

In Partial Fulfillment of the Requirements for Degree of Master of Science in Animal Production Technology

M.Sc. Thesis

By:

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January, 2025

Addis Ababa, Ethiopia

Effect of Harvesting Stage on Biomass Yield and Quality of Wheat *(T. Aestivum*) and Triticale *(×Triticosecale Wittmack)* Fodder under Hydroponic Condition

A Thesis Submitted to Federal Technical and Vocational Training Institute, Faculty of Agro-Processing Technology

Department of Dairy Processing Technology

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Animal Production Technology

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January, 2025

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ADVISORS' APPROVAL SHEET

This is to certify that the MSc thesis prepared by Fitfit Desalegn entitled **"Effect of Harvesting Stage on Biomass Yield and Quality of Wheat *(T. Aestivum)* and Triticale *(×Triticosecale Wittmack)* Fodder under Hydroponic Conditions"** is in partial fulfillment of the requirement for the degree of Master of Technology in the Department of Dairy Processing Technology with the field of specialization in Animal Production Technology. As thesis research advisor, I hereby certify that I have read and evaluated this thesis prepared under my guidance and supervision. Therefore, I recommend that this student has fulfilled the requirements and hence can hereby submit the thesis research for defense.

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DEDICATION

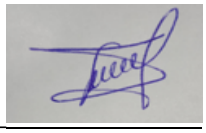
To my beloved husband, Wubetu Enyew: my deepest gratitude for your unwavering understanding and patience. You are the force that propels me forward. Long may you live!

To my little daughter, Meklit: whose boundless energy and joy inspire me every day. You are my constant source of energy and joy. You hold a unique position in my heart.

DECLARATION

I hereby declare that this thesis entitled "**Effect of Harvesting Stage on Biomass Yield and Quality of Wheat *(T. Aestivum)* and Triticale *(×Triticosecale Wittmack)* Fodder under Hydroponic Condition**" was prepared by me, with the guidance of my adviser. I confirm that all sources utilized in this document have been properly cited and referenced. Every diligent attempt has been undertaken to prevent any form of plagiarism during the preparation of this thesis. This thesis is submitted in partial fulfillment of the requirements for MSc degree at FDRE Technical and Vocational Training Institute. I hereby confirm that this thesis has not been submitted to any other institution, anywhere, in pursuit of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Fitfit Desalegn, was born on August 13, 1987, in the Yilmana Densa district, West Gojjam Administrative Zone of the Amhara Region, to her father, Desalegn Adamu, and her mother, Sintayehu Yayeh. She attended her education at Gosheye Elementary School. Secondary and preparatory school education was attended at Adet town. After completing her high school education, she joined the University of Gondar in September 2006 and graduated with a BSc degree in Animal Production and Extension in June 2008. After graduation, she was employed at Addis Zemen Technical and Educational Training (TVET) College in Addis Zemen town in November 2009. The author joined FDRE Technical and Vocational Training Institute in January 2015 to pursue his MSc Degree in Animal Production Technology.After completing the coursework, she carried out her MSc thesis research on "**Effect of Harvesting Stage on Biomass Yield and Quality of Wheat *(T. Aestivum)* and Triticale *(×Triticosecale Wittmack)* Fodder under Hydroponic Condition"** for partial fulfillment of the requirements for the degree of Master of Science in Animal Production Technology.

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LIST OF ABBREVIATION

ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
CF	Crud Fiber
CP	Crude Protein
CRD	Completely Randomized Design
DM	Dry Matter
EE	Ether Extract
FBY	Fresh Biomass Yield
GDP	Growth Domestic Product
HA	Harvesting Age
K	Potassium
LL	Leaf Length
Na	Sodium
NDF	Neutral Detergent Fiber
NDL	Neutral Detergent Lignin
NFE	Nitrogen Free Extract
NLPP	Number of Leave Per Plant
NRPP	Number of Root Per Plant
OM	Organic Matter
PH	Plant Height
PROC GLM	Procedure of General Linear Model
RL	Root Length
SAS	Statistical Analysis System
SL	Steam Length
WHF	Wheat Hydroponic Fodder

ABSTRACT

The experiment was conducted to evaluate biomass yield and chemical composition of wheat and triticale fodder at different harvesting stages under hydroponic conditions. This experiment was done at Adet town, West Gojam zone, Amhara regional state. The experiment was conducted using completely randomized design (CRD) in a factorial arrangement. The two independent variables were fodder grain species (Wheat and Triticale) and harvesting age (10th, 12th and 14th day after planting). Generally, the experiment had 6 treatment combinations with a total of 18 experimental units in the three replications. Fodder crop seeds were sown at the rate of 5 kg/m², and it was sprayed three times per day, in the morning, at midday, and at night. The data collected were growth parameters such as the plant height (PH), leaf length (LL), stem length (SL), root length (RL), number of leaves per plant (NLPP), and number of roots per plant (NRPP); the fresh biomass yield (FBY) was measured and conversion factor (CF) were calculated. The data were subjected to analysis of variance (ANOVA) using the General Linear Model (Proc GLM) procedure of the Statistical Analysis System. In the case of crop species higher value were recorded in wheat at all parameter except RL and NRPP which is 19.2, 9.61, 4.97, 9.07, 1.87, 6.39, 205.07, 1.32, 14.76, 29.7 PH, LL SL, RL, NLPP, NRPP, FBY, CF, DM and DMY respectively. For triticale PH (17.43), LL (7.68), SL (4.4), RL (14.23), NLPP (1.66), NRPP (6.94), FBY (183.61), CF (1.162), DM (13.68), and DMY (24.87) were recorded. In the case of harvesting age, highest values of PH (21.87 cm), LL (10.59 cm), SL (5.48 cm), RL (12.87 cm), NLPP (1.95), NRPP (6.98), FBY (245.9 t/ha), CF (1.714 kg), and DMY (34.71 t/ha) were recorded on the 14th day of the harvesting age. All morphology and chemical composition parameters were significantly ($p < 0.05$) affected by crop species and harvesting stage. However, DM and ADL were significantly ($P < 0.05$) affected by interaction. The highest average crude protein (CP) content was recorded for wheat (18.86%), followed by triticale (17.20%). Other parameters like ash, NDF, ADF, and ADL content were higher in triticale fodder: 5.45, 60.94, 38.10, and 7.64, respectively. Wheat appears to be the better option for hydroponic fodder production compared to triticale.

Key word: fodder crop species, harvesting age, hydroponics, hydroponic fodder

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1. INTRODUCTION

1.1. Background

The livestock industry contributes significantly to physical and economic growth by providing nutritional and food security for a productive and healthy living on a worldwide scale, (Mekuriaw 2021). About 70 million cattle, 42.9 million sheep, 52.5 million goats, 8.1 million camels, 57 million chickens, 2.15 million horses, 10.8 million donkeys, and 0.38 million mules are found in Ethiopia, (CSA 2021). Despite the fact that producing fodder and feeding cattle are the two key components for the sustainability of products and animal husbandry productivity. Lack of feed had been the main obstacle for increasing livestock productivity, (Gupta 2014). The production of enough conventional green fodder and grain to feed a huge number of animals has become a major challenge in many regions of the world. This results from a lack of irrigation facilities, current water scarcity, natural disaster, labor shortages, restricted land allocation, and requirements for fertilizer and manure for cultivation (frequent draught), (Naik *et al*. 2015;Dung *et al*. 2010). Lack of fodder consistently impedes the sustainable development of livestock which makes the animals less productive and less able for reproduction, (Bekuma 2019). Because of this, hydroponic fodder production technology has been promoted as a way to adapt to climate change and overcome the difficulties associated with traditional green fodder production, (Assefa, Mengistu *et al*. 2020). Hydroponics fodder production technology is becoming more and more popular as a solution to this issue, allowing livestock farms to grow some concentrate in addition to enough high-quality fodder, (Bekuma 2019).

Hydroponics is the scientific practice of cultivating plants without the use of soil. The plants are raised in a solution rich in minerals and water. The ideal places for hydroponic fodder production are probably semi-arid, dry, and drought-prone areas of the world that have ongoing water scarcity or lack irrigation infrastructure. Farmers whose soil is stony and unproductive can benefit greatly from hydroponic fodder production. For farmers who lack land, this is a practical and cooperative substitute method for producing fodder, (Bakshi, Wadhwa *et al.* 2017). This technology can be utilized as an alternative to raise animals, particularly in situations When farmers have limited space on their properties and in dry seasons, (Sinsinwar and Krishna 2019). Since the feed is grown in trays that are placed on shelves inside the

hydroponics system, less room is required, and the amount of feed produced can be up to 10 times higher than with conventional fodder production, (Njima 2016). The water consumption in hydroponic fodder production is significantly lower, accounting for only 2-3% of the water utilized in conventional field conditions to yield the same quantity of fodder.Under this technique, fodder can be produced during a short growth period 7 to 10 days, on a tiny piece of land, (Adekeye, Onifade *et al.* 2019). The selection of hydroponic fodder cultivars is dependent upon the specific geographic and agro climatic circumstances, as well as the accessibility of seeds. Wheat is economically viable option for hydroponic fodder production is (Triticum aestivum L.), (Guerrero 2016; Grigas, Dainius *et al*. 2023).

Because the prices of the seed, building the plantation structure, and management are comparatively low when compared to concentrate costs, hydroponic fodder production is straightforward and cheap to implement, making it potentially economically viable in Ethiopia, (Uddin and Dhar 2018). The smallholder farmer has access to the raw resources needed to cultivate fodder as well as the materials needed for construction. The country's climate makes hydroponic fodder production feasible, thus this production system shouldn't be very expensive, (Bakshi, Wadhwa *et al*. 2017). Depending on the producer's capacity for investment, the materials employed in hydroponic technology could also change, (Mekonnen, Yeshambel *et al*. 2019).

1.2. Statement of Problem

The scarcity of feed has become a significant challenge for livestock farmers. This scarcity is primarily due to the diminishing grazing pastures caused by land conversion and overgrazing, (Mekuriaw 2021). Crop leftovers have little nutritional value and are insufficient to feed cattle all year round. As a result, there is a need to explore alternative feed sources to sustain livestock production, (Mengistu, Gezahegn *et al.* 2017). Hydroponic fodder production has emerged as a potential solution to address the feed scarcity issue, (Naik, Gaikwad *et al.* 2013). Therefore, these studies were educating smallholder farmers on how to effectively use this hydroponic fodder as a source of feed for them. However, there is a lack of knowledge regarding the optimal harvesting stage for maximizing biomass yield and quality of hydroponically grown fodder. Understanding the impact of different harvesting stages on biomass production and

quality is crucial for farmers engaged in hydroponic agriculture to optimize their practices and ensure the availability of nutrient-rich fodder for livestock.

Therefore, the main problem addressed in this research is to determine the effect of harvesting stage on the biomass yield and quality of wheat and triticale fodder cultivated under hydroponic conditions. By investigating this problem, the aim is to provide valuable insights and guidelines for smallholder farmers on the optimal harvesting stage to achieve maximum biomass yield and high-quality fodder, thus enabling sustainable and efficient feed production for livestock.

1.3. Objectives of the Study

General objective:

- To evaluate Effect of harvesting stage on biomass yield and quality of wheat *(T. aestivum)* and Triticale *(×Triticosecale Wittmack)* fodder under hydroponic condition.

Specific objective:

- To evaluate the effect of harvesting age and fodder crop species on growth performance and biomass yield of hydroponic fodder
- To evaluate the chemical composition of wheat and triticale fodder at different harvesting ages under hydroponic condition

1.4. Research Question

- How does the harvesting stage affects wheat and triticale fodder on the biomass yields in hydroponic systems?
- What is the impact of different harvesting stages on the nutritional composition of wheat and triticale fodder grown hydroponically?

1.5. Significance of Study

A soilless cultivation technique known as hydroponics has various benefits, such as regulated nutrient delivery, less water use, and increased crop yields, (Niak, *et al.* 2011). To achieve optimal biomass production and desired quality attributes, hydroponic systems must optimize the harvesting step. By determining the ideal harvesting age, farmers can maximize both the

quantity and nutritional value of the fodder, leading to improved livestock health and productivity. This is particularly important in regions with limited land or water resources, where hydroponics offers a sustainable alternative to traditional fodder production. Farmers interested in hydroponic agriculture might benefit greatly from an understanding of the effects of various harvesting phases on biomass output and quality of wheat and triticale fodder under hydroponic system.

1.6. Scope of the Study

The research was carried out in Addet district and the scope focuses on conducting tests to assess how various harvesting phases affect the biomass production, growth parameter and quality of hydroponically cultivated wheat and triticale fodder. This involves determining the optimal time for harvesting the crops to maximize their yield and assess their chemical composition.

2. LITERATURE REVIEWS

2.1. Livestock Feed Resources in Ethiopia

In Ethiopia, because of insufficient feed supplies and low-quality feeds that are readily available, livestock agriculture gives very low yields despite high populations, contributing just 11.48% of the country GDP, which is significantly less than its potential, (MOFED 2010; Chufa, Yilkal *et al*. 2022). Lack of feed, both in terms of quality and quantity, is one of the main factors limiting livestock productivity. Therefore, better livestock production and sustainable resource management depend on the integration of crops and livestock systems, (Mengistu, Gezahegn *et al*. 2017).

In Ethiopia, the primary sources of feed for livestock are natural pasture, crop residue, marginal pasturelands, and food and vegetable refuse. A small amount of feed comes from agro-industrial byproducts, improved pasture, and forage species, (Derara and Bekuma 2020). However, the amount of these feed resources varies according on the production system, accessibility, agro-ecology, and crop varieties produced. Because of the year-round unfavorable conditions for forage availability and quality, gains acquired during the wet season are either completely or partially lost during the dry season, (Mengistu, Gezahegn *et al*. 2017).

Because cereal crop leftovers and low-quality natural pastures are naturally deficient in some nutrients, they cannot effectively support animal development or even maintenance when given on their own. Additionally, animals' ability to consume such dense feeds is limited. A relatively long dry season that alternates with a brief rainy season is one of the climate factors that lead to low quality and quantity of grasses available for feed. Feeds with higher than 55% cell wall constituent content, lower than 7% crude protein (CP), and low levels of other nutrients may cause nutrient deficiencies that limit the amount of feed that a feed animal may consume, (Derara and Bekuma 2020).

2.2. Hydroponics Fodder Production

The word hydroponics comes from the Greek word "water working," where hydro means "water" and ponic means "working." Hydroponics is a technique that uses water or nutrient-rich solution to grow plants or sprout grains without the need for soil; however, fresh water alone can produce good quality hydroponic fodder, (Tayade and Chavan 2018). In a controlled

setting, like a greenhouse, it just needs a little time to grow and mature. A developing habitat where the environmental conditions are at least partially controlled is referred to as a "greenhouse". It is not necessary to use the fertilizer solution; tap water would work just as well, (Hassen and Ibsa 2022).

In arid regions, very contaminated locations, and metropolitan areas with expensive agricultural land, hydroponic technology is employed. It works well in locations that are semi-arid, arid, or prone to drought; it also works well in areas that have persistent water scarcity or limited resources for fencing, irrigation, and land preparation. When the soil is stony and unfertile, it is also utilized in mining and coastal areas, (Ghorbel, Jamel, *et al*. 2022). Using a sanitary atmosphere, animal feed seeds are germinated to produce a high-quality, highly nutritional, disease-free feed using the hydroponic method of fodder production. Growing fodder with hydroponic culture is an environmentally beneficial practice. Cereals cultivated hydroponically develop up to 50% faster and yield higher quantities of superior quality fodder, (Bekuma 2019).

An efficient substitute method for sustainable cattle production is hydroponic fodder production. For the same amount of forage produced in field circumstances, hydroponic forage production uses only 3-5% of the water required, (Mijena, Aman *et al.* 2022). Hydroponic technology can produce different types of fodder crops, such as barley, oats, wheat, triticale, sorghum, alfalfa, cowpea, and maize, (Bekuma 2019). It takes six to nine days to grow cereal green fodder hydroponically. A few benefits of hydroponic technology include uniform plant production, higher rates of yield, lower labor costs, uniform crop quality, and year-round cultivation, a substantial reduction in the amount of space needed for production, quick economic payback, and high-quality output, (Grigas, Dainius *et al*. 2023).

2.3. The Yield of Hydroponics Fodder

By giving the plants the nutrients directly, they don't need to grow extensive root systems to find food, which can speed up the production of fodder by up to 25%. From one kg of un-sprouted seed were produced 8-10 kg of green fodder on 7-8 days of harvest. When grown fresh, the output of maize fodder produced hydroponically is five to six times higher and more nutritious than when grown traditionally, (Shit 2019).

According to Mekonnen, Yeshambel *et al.*, (2019) green fodder biomass yields after 7 days post-sprouting were 5.21 kg (2.61 kg DM) recorded on barley and 6.32 kg (3.16 kg DM) recorded on oat per 1 kilogram of seed. In the other study the production of hydroponic green fodder of wheat gain 23.57 kg/m^2 fresh yield and 3.10 kg/m^2 of DM from 4.8kg/m^2 of seed and hydroponic green forage of oat 13.23 kg/m^2 yield and 1.39 kg/m^2 of DM were recorded from 6.4kg/m^2 of seed, (Morales, Letica *et al*., 2020).

The crops' fresh yield and D.M. content is essential for successful hydroponics fodder production. The process of seed sprouting results in an increase in fresh weight and a corresponding decrease in D.M. content. This phenomenon is primarily ascribed to the infiltration of water (leaching) and enzymatic activities (oxidation), which exhaust the feed reserves of the seed endosperm without sufficient replacement by photosynthesis during the short growth cycle of the young plant, (Hassen and Ibsa 2022). The fresh yield and D.M. content of hydroponics fodder are primarily affected by the type of crops grown, days of harvesting, drainage of free water before weighing, seed type and quality, seed rate, seed treatment, water quality, pH levels, irrigation frequencies, nutrient solution, light exposure, growing period, temperature, humidity, and cleanliness of the greenhouse, (Upreti, Ghimire *et al.,* 2023). Utilizing nutrient solutions increases the ash content and ultimate weight of the hydroponic feed by reducing D.M. loss, which may be caused by the absorption of minerals, (Abdula 2022).

2.4. Crops of Hydroponic Systems

Farmers whose soil is stony and unproductive can benefit greatly from hydroponic fodder production. For farmers without land, it provides a practical and farmer-friendly substitute technique for producing fodder. Hydroponics can be used to grow a variety of fodders, such as alfalfa, triticale, rye, sorghum, maize, barley, wheat and oats. The seeds sprout within 24 h and grow up to 20-30 cm in 7-8 days, when they are ready for harvest and feeding, (Bakshi, Wadhwa *et al.,* 2017). But, the selection of the hydroponics fodder depends on the agro-climatic and environmental circumstances and accessibility of seeds. The variety of grain selected for growing of hydroponics green fodder because of its lower cost, quick growing habit, availability and good biomass production, (Haidree, Raza *et al.,* 2020).

Triticale

Triticale *(×Triticosecale Wittmack),* the first hybrid cereal grain, was developed by crossing wheat *(T. aestivum)* as female and rye as a pollen source. Triticale combines the grain quality and yield potential of wheat with the capacity to withstand disease and environmental stress, such as poor soil tolerance, resistance to cold, drought, and disease, and low input requirements of rye, (Upreti, Ghimre *et al.*, 2022).

Triticale seeds can also serve as a potential basis for green fodder. By inheriting favorable genes from both wheat and rye, triticale exhibits the ability to adapt to less favorable conditions for wheat, while simultaneously achieving a higher biomass yield and improved forage quality. In a comparative study involving wheat, rye, and triticale, triticale consistently outperformed the other two crops in terms of fodder yields.Triticale has an excellent protein content and is composed of important amino acids (lysine) in addition to having high productivity (biomass and grain), (Uyutova, Semenova *et al.*, 2023).

Wheat

Wheat *(Triticum aestivum)* is widely cultivated in various climates around the globe and is considered one of the most commonly grown cereal crops, (Robin, Ghosh *et al*. 2021). Globally, wheat *(Triticum aestivum)* ranks among the most crucial cereal crops due to its extensive cultivation area and substantial production levels, (Lulu, Bekele *et al.* 2020). Wheat *(Triticum aestivum)* can also be an economically effective choice for the production of hydroponic fodder (Grigas, Dainius *et al.*, 2023). hydroponic wheat fodder increased the DM, CP, EE, CF, K, and Na contents by 5.0%, 44.0%, 132.5%, 176.9%, 150%, and 320%, respectively, compared with conventional wheat fodder, (Ahamed, Shamim *et al.*, 2023).

Wheat hydroponics is more nutritious than conventional type fodder; as it contains more crude protein (13.30-13.6 vs.10.70-11.14 %), ether extract (3.27-3.50 vs. 2.20-2.30 %), nitrogen free extract (66.70-75.32 vs.51.80- 53.54%) but less crude fiber (6.37-14.10 vs. 22.25-25.90 %), total ash (1.75-3.80 vs. 9.40- 9.84%) and acid insoluble ash (0.30-0.57 vs. 1.03-1.40 %), (Tayade and Chavan 2018). About 6.3 kg hydroponic wheat fodder was recorded at day 8 from 1 kg of wheat seed. Similarly, the germination of wheat for 5 to 7 days resulted in 17% loss of total DM while a 25% loss in DM of wheat after 12 days of sprouting. Organic matter (OM) content of wheat seed (98 g/100g DM) at day 0 reduced to 97g/100g DM at 8th day of sprouting, (Bari, Islam *et al.*, 2022).

According to Ali *et al.,* (2019 the protein content of hydroponic wheat fodder on the 8th day was 15.75%, it surpass the protein content of conventional green wheat fodder, which was 11.02%. On the 8th day, the hydroponics fodder wheat exhibited the highest ether extract content 2.80% and its crude fiber content started at 2.40% and rose to 5.20% by the 8th day of growth. Notably, the hydroponics system had significantly lower crude fiber content compared to the conventional fodder.The total ash content of the hydroponics wheat fodder was 3.00% on 8th day, which was lower than conventional fodder (8.28%). The nitrogen free extract content of the wheat fodder decreased to (73.25%) on 8th day of growth as compared to seed (83.40%).

Wheat grain is the ideal choice for cultivating hydroponics fodder. The hydroponics green fodder appears as a dense mat, measuring around 20-30 cm in height, comprising of roots, seeds, and plants. In order to produce one kilogram of fresh hydroponics Wheat fodder, approximately 1.50-3.0 liters of water is necessary. It is common for hydroponics Wheat fodder to yield 5-6 times its original weight on a fresh basis, with a dry matter (DM) content ranging from 11-14%. However, it has also been observed that the DM content can reach up to 18%. It is recommended to supplement each cow's diet with approximately 5-10 kilograms of fresh hydroponics Wheat fodder per day, (Tayade and Chavan 2018).

2.5. Seed Rate

The yield of the fodder is also influenced by the seed rate, which is the amount of seeds loaded per unit surface area and varies depending on the type of seeds. For hydroponic barley, wheat, or sorghum fodder production, the suggested seed rate is 4-6 kg/m2, and for maize fodder, it is 6.4-7.6 kg/m2, respectively, (Bakshi *et al.,* 2017).

2.6. Nutrient Solution and Water

The use of nutrient solution for production of hydroponics forage is not mandatory as it can be produced by tap water, (Naik, Swain *et al.,* 2015). The nutrients required for hydroponics are dissolved in water and primarily exist in inorganic and ionic states. Plant uptake of nutrients can only proceed when they are present in an available form for absorption, and in most situations, nutrients are absorbed in an ionic form, (Ali and Meselmani 2022).

An aqueous solution with a high concentration of inorganic ions which are essential to the plant's ability to complete its life cycle serves as the nutrient solution for hydroponic systems. As of right now, most plants are thought to require 17 elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, copper, potassium, calcium, magnesium, sulfur, zinc, manganese, molybdenum, boron, chlorine, iron, and nickel, (Ghorbel, Jamel, *et al.* 2022) . Additionally, elements such as sodium, silicon, vanadium, selenium, cobalt, aluminum, and iodine are recognized for their advantageous properties, as they can enhance plant growth, mitigate the harmful impacts of certain elements, or serve as substitutes for essential nutrients.The nutrient composition determines essential pH, electrical conductivity and osmotic potential of the solution, (Shit 2019).

Water is very important for seed germination and seedling growth as it is essential for enzyme activation, reserve storage breakdown and translocation, (Adekeye, Onifade *et al.,* 2019). Water consumption for hydroponic feed production is decreased because of water recycling practices. Therefore, 1kg of maize hydroponic feed is produced in 7 days with 1.5 liters (if water is reused) or 3 liters (if water is not reused), (Naik, Swain *et al.,* 2015).

2.7. Effect of Harvesting Stage on Yield and Chemical Composition on Hydroponic Fodder

2.7.1. Effect of Harvesting Stage on Yield of Hydroponic Wheat Fodder

Biomass yield of hydroponic fodder was increased gradually from day 0 to 8. About 6.3 kg hydroponic wheat fodder was recorded at day 8 from 1 kg of wheat grain sowing at day 0. The higher amount of biomass yield at 8th day of sprouting may be due to greater height in plant, root length and root number, (Bari, Islam *et al.,* 2022).

Table 1 Effect of harvesting stage on yield of hydroponic wheat fodder

Day of harvest	Plant height(cm)	Seed rate/tray	Fodder yield(kg)	Reference
1	0.99	1kg	1.85/m^2	(Bari, Islam *et al.* 2022)
2	2.32	1kg	2.14/ m^2	
3	4.20	1kg	2.70/ m^2	
4	6.8	1kg	3.29/ m^2	
5	8.47	1kg	4.19/ m^2	
6	10.34	1kg	5.26/ m^2	
7	11.98	1kg	5.98/ m^2	
8	14.10	1kg	6.27/ m^2	
7	25.03	1kg	6.76kg/ m^2	(Upreti, Ghimre *et al.*, 2023)
7	8.42	1kg	6.14kg/ m^2	(Mahale,Dhage *et al.*, 2020)
14	17.26	1kg	8.05kg/ m^2	
15	15.9±0.1	250gm	766±4gm/216cm^2	(Moin,Salam *et al.*, 2023)

2.7.2. Effect of harvesting stage on chemical composition

The yield, morphology, and nutrient composition of hydroponic wheat fodder exhibited significant variations throughout the sprouting cycle as the growing days increased. Effect of growing days on nutrient changes in hydroponic wheat sprouts is shown in Table 2. The dry matter (DM) content of hydroponic wheat fodder was decreased remarkably with the advancement of growing days and it was more than 90% in initial wheat grain and less than 1/8th in day 8. The sharp reduction of DM content probably due to large uptake of water during germination of seed that causes remarkable increase in moisture content in hydroponic fodder, (Bari, Islam *et al.*, 2022).

Table 2 Effect of harvesting stage on chemical composition of wheat hydroponic fodder

Day of harvest	DM	CP	CF	EE	Ash	NFE	ADF	ADL	Ca	P	
6	17.18	18.92	4.11	2.51	2.83	71.62			0.15	0.73	(Bari, Islam *et al.*, 2022)
7	14.88	19.74	4.57	2.66	2.93	70.14			0.16	0.77	
8	14.19	19.83	4.68	2.70	2.96	69.82			0.17	0.77	
8	88.82	28.72	20.02	4.74	4.91						(Islam,Jalal *et al.*, 2016)
9	94.38	31.74	24.19	6.34	4.93						
10	90.55	21.86	22.08	4.33	4.57						
7	15.04	13.64	5.43	2.97	2.8	75.16				1.15	(Mahale, Dhage *et al*., 2020)
14	14.64	18.94	8.1	3.13	3.38	66.46				2.64	
7	9.49	26.44		1.22	3.13		23.05	8.43	0.36	0.29	(Shah, Manoj *et al.*2023)

Where, DM=dry matter, CP= crude protein, EE= ether extract, CF= crude fiber, NFE= nitrogen free extract, ADF= acid detergent fiber, ADL=acid detergent lignin, Ca= calcium and P= phosphorous

2.8. Nutritive Value of Hydroponic Fodders

Triticale fresh forage was very high quality, with 24.7% crude protein in the dry matter and metabolizable energy values of 10.6 MJ/kg dry matters, (Haque, Sufian *et al.,* 2014). Among

the various small grains, wheat consistently exhibited the lowest yields of dry matter. Triticale, when harvested just before the boot stage, is known to produce superior silage, similar to other small grains. However, as maturity advances, dry matter yields tend to rise, (Tabassum, Uddin *et al.*, 2014).

Table 3 Nutritional quality of triticale and other cereal grains

	% Dry matter					
	Dry matter (DM)	Ash	Crude protein	Acid detergent fiber	Digestible organic matter in DM	Metabolizable Energy (MJ/kg dry matter)
Triticale	90.3	2.6	15.9	4.8	74.5	11.2
Wheat	89.1	15.8	11.8	3.9	74.7	11.2
Maize	89.5	13.1	11.1	4.6	74.5	11.2
Barley	87.5	4.5	12.1	-	75.7	11.4

Source : Tabassum, Uddin *et al.*, 2014

Hydroponic wheat fodder had shown better CP content than hydroponic oat fodder and hydroponic maize fodder, but wheat fodder contained lower fractions of Calcium (Ca) and was high in Acid Detergent Lignin (ADL). Modest CP and ADL content and better Ca contents were found in hydroponic oat fodder. Better fiber fractions with lower NDF, ADF and ADL contents were found in hydroponic maize fodder, (Upreti, Ghimre *et al.*, 2023).

Table 4 Nutrient composition of hydroponic fodder from different cereal grains

Nutrient composition (%)	Maize		Oat		Wheat	
	Mean	SEM	Mean	SEM	Mean	SEM
Dry matter	12.55	2.05	14.13	0.71	14.49	1.18
Crude protein	12.51	0.83	13.96	2.08	16.16	1.59
Neutral detergent fiber	37.49	3.68	60.22	2.86	62.72	6.68
Acid detergent fiber	12.58	1.83	32.63	2.03	29.63	2.37
Acid detergent lignin	3.78	0.96	7.72	0.62	8.17	0.82
Calcium	2.41	0.22	2.88	0.74	2.19	0.40
Phosphorus	0.3	0.05	0.18	0.08	0.35	0.05

SEM: standard error of mean

Source : (Upreti, Ghimre *et al.*, 2023)

2.8.1. Energy

Hydroponically grown sprouts and processed grains are both nourishing and easily digestible sources of nutrition. The sprouting process of grains transforms the starch content into sugar, enhancing their nutritional value. On dry matter bases, the energy value of sprouts is less than grains with gross energy loss, (Abdula 2022).

2.8.2. Protein

Animal performance is strongly influenced by the crucial component, protein. Consequently, it is necessary to examine the feed's feed value, (Abdula 2022) Sprouts have higher concentrations of ash, crude protein, and other minerals than grains do, with the exception of potassium. The decrease in dry matter content, particularly in carbohydrates, is the primary cause of the increase in dry crude protein content, (Ghorbel, Jamel, *et al*. 2022). In addition, the absorption of nutrients aids in the metabolism of nitrogenous compounds, causing an enhancement in the crude protein content. Nutrient solutions improve the crude protein level of the hydroponic fodder than using tap water, (Grma and Gebremaryam 2019).

2.8.3. Vitamins

The vitamin C and E content of hydroponic fodder is particularly high. Grain vitamin content is increased through sprouting, (Hassen and Ibsa 2022). However, the increase in individual vitamins is so little that it has minimal effect on feed value when used practically to meet the nutritional needs of cereal-based diets, (Abdula 2022).

2.8.4. Minerals

Root development aids in the uptake of minerals in hydroponic feed, which quickly alters the ash and protein concentrations starting on day four, (Hassen and Ibsa 2022). Additionally, absorption speeds up the nitrogenous component metabolism, raising the level of crude protein, (Abdula 2022). The mineral concentration varies depending on the type of irrigated water used for the hydroponic feed. On the other hand, chelating sprouting increases the availability of minerals, (Grma and Gebremaryam 2019). it is also found that the seed rate has no effect on the proximate constituents of different portions i.e. roots with germinated seeds, leaves and plants of hydroponic maize fodder, (Suma, Vivek *et al.*, 2020).

2.8.5. Anti-nutritional factor versus hydroponic feed

Plant seeds contain phytic acid in both the seed coat and the germ. The primary way that phytic acid affects the body is by establishing insoluble bonds with minerals like calcium and iron, which prevents the blood from properly absorbing those minerals, (Suma, Vivek *et al.*, 2020). Mineral deficiency symptoms were observed in experimental animals fed a diet high in phytic acid and low in minerals. Phytic acid levels are lowered by sprouting. There is less phytic acid when sprouting occurs, (Grma and Gebremaryam 2019). During germination, enzymes additionally eliminate additional potentially hazardous substances. Probiotics' digestive enzymes function as biological catalysts in the breakdown of protein, fat, and carbohydrate, (Suma, Vivek *et al.*, 2020). Sprouts have 100 times more enzymes than fruits, and as a result, the physiological action of vitamins, minerals, and trace elements is determined by enzyme activity, (Hassen and Ibsa 2022). Between germination and seven days is considered to be the time when the sprouts have the most enzyme activity. Cereal grains that have not germinated still contain active enzymes due to the inhibitors. With the application of these inhibitors, seed deterioration is stopped for years, (Abdula 2022).

2.9. Effect of Sprouted Grains on Feed Intake and digestibility

2.9.1. Effect on Intake

Determining the dry matter intake is crucial for feed evaluation since it can help with optimal nutrient utilization in addition to preventing nutrient excess or shortage. Green fodder's high moisture content resulted in decreased dry matter intake for dairy and feedlot cattle. In comparison to the control treatment, dairy cows supplemented with 7% maize hydroponic fodder consumed more dry matter and as fed overall. This might result from the hydroponically grown maize feed's high palatability, which would encourage consumers to consume more different kinds of feed. Reduced DM consumption linked to feeding hydroponically produced green fodder could be attributed to the product's high-water content, which may have made it bulky and reduced animal DM intake, (Salo 2019).

2.9.2. Effect on Digestibility

In comparison to grains, shoots, and root sprouts, the digestibility of sprouts is higher, yet shoots can also be highly digestible. The early-life tenderness of the fodder may be the cause of the rise in the digestibility of dry matter, organic matter, crude protein, and crude fiber in maize, (Ghorbel and Nedim 2022). Sprouting barley fodder has an advantage in terms of digestion even when its dry matter content decreases. The sprouts in the rumen have a higher digestion than the broken grain, (Grma and Gebremaryam 2019). Shoots degrade rapidly in the rumen when compared to root sprouts, indicating a difference in digestibility between the two. Therefore, ruminant animals prefer leafy than steamy. As a result, ruminant animals like green food over steaming, (Hassen and Ibsa 2022).

Hydroponics feed is tasty, and the germinated seeds implanted in the root system are absorbed alongside the plant's shoots, resulting in no nutrient waste, (Abdula 2022). Increased digestibility when broilers and other large animals are fed grain that has sprouted. Changes in the rate and amount of digestion and absorption may have contributed to this. Enzymes are created during germination, which lowers the digest's viscosity and enhances nutrient absorption and digestion. The grass juice component, which could be a beneficial source of nutrients for rumen microorganisms, is also responsible for this. The tenderness of the hydroponic fodder may have contributed to the general increase in the ration's nutritional digestibility when fed, (Salo 2019).

2.10. Effect of Hydroponic Feed on Livestock Productivity

Sprouted grains are an excellent source of pigments that include xanthophylls, chlorophylls, grass juice, and protein sparing factors, all of which enhance cattle reproduction and productivity. Along with this, aiding in the removal of the fodder's toxicants and other anti-nutritional elements like phytic acid and oxalic acid, (Shit 2019).

Since sprouts are an enzyme-rich diet, animals prefer the highly digestible, tasty fodder produced hydroponically. Comparable to highly digestible legumes like clover, the digestibility of the green fodder grown hydroponically, (Ningoji, Thimmegoda *et al*. 2021). Hydroponic fodder possesses a remarkable level of moisture, allowing animals to consume 1-1.5 percent of their body weight or 15-25, 0.25-2.0, 1.5-2.0, and 0.1-0.2 kilograms per animal per day in the case of large ruminants, adult pigs, small ruminants, and rabbits, respectively, (Haidree, Raza *et al.* 2020).

2.10.1. Milk production

Research has shown that supplying hydroponic feed to cows can increase milk output more than feeding them hay, silage, or cereal grains, (Abdula 2022). The economic viability of hydroponic fodder production technology is evident through these factors. Milk yield was improved by 10.07%, (Shit, 2019; Girma & Gebremariam, 2019) and 13.7%, (Mijena, Aman *et al.*, 2022) after feeding dairy cattle on hydroponics fodder and this is due to the higher nutrient digestibility of the fodder. Thus, improvements in hydroponic feed technology can boost milk yield and dairy productivity, particularly in areas where seasonal droughts persist, (Abdula 2022).

Dairy cows that get 7% of their diet consisting of hydroponically grown maize fodder from their corn silage base see a rise in their intake of dry matter, energy consumption, nitrogen conception, nutrient digestibility, and persistence of milk supply throughout their late lactation, (Teref and Mengstu 2022)

2.10.2. Meat production

Lambs' body weight gain is enhanced with hydroponic feed. High levels of bioactive enzymes and components that enhance animal performance are the reason for this, (Suma, et al. 2020). Additionally, the increased body weight indicates improved nutritional digestion and microbial

activity in the rumen, (Abdula 2022). In beef cattle average increase of 200g is achieved through feeding the hydroponic fodder than maize. Similarly, 8% improvement is reported in birds and other animals, (Grma and Gebremaryam 2019). Hydroponically grown feed increased goat body weight from 34.74 to 61.93 g per day. Cross-bred calves, goats, and Awassi lambs fed hydroponically grown maize and barley feed showed superior body weight gain, (Ningoji,Thimmegoda *et al.*, 2021).

2.10.3. Poultry production

A result of the application of the Hydroponic Green Fodder technology in poultry farms, in 2019, the total number of eggs obtained from each chicken increased by 11.6%, the weight gain (200 g) in each chicken (in broiler) intended for slaughter - increased by 13.3%, the number of chicks leaving the incubator increased by 12.2% Thus, from 1 kg of wheat within 5-6 days, 4-5 kg of green mass is obtained, (Rusramova and Hasanov 2021).

2.11. Advantage of Hydroponic Fodder Production

2.11.1. Efficient utilization of water

Since water is given directly to the roots and is frequently recycled and utilized multiple times, hydroponic systems save water waste, (Bakshi,Wadhwa *et al.*, 2017). Just 3-5% water is needed in the hydroponic green fodder production technique to produce the same amount of crop as in soil culture, (Mijena, Aman *et al.*, 2022). According to Shit, (2019) reported that 1.5 - 2 liters of water is sufficient for producing 1 kg of hydroponic fodder, whereas 1 kg of green fodder of barley, alfalfa, and Rhodes grass under conventional field conditions requires 73, 85, and 160 liters of water respectively.

2.11.2. Economically feasible

Only seed and water are needed for hydroponic fodder production, along with a small amount of effort. Because there are no expenses associated with weeding, herbicides, insecticides, or fungicides, production costs are minimized. Because hydroponics requires no fuel for harvesting or post-harvest processing, it reduces post-harvest losses, (Mijena, Aman *et al.*, 2022).

2.11.3. Reduced labor cost and need

In conventional fodder production requires continuous presence of labor from cultivation to harvesting of the grass, but in hydroponics labor required is 2- 3 hours / day only. Hence the cost of production of hydroponic fodder is less, (Chikhalikar and Khillare 2021). whereas for same fodder production through tradition system requires more labor to undertake land preparation, sowing, irrigation, cutting, transporting fodder from field to cattle shed, cutting the chaff and finally feeding the cattle, (Ramteke, Raina *et al.,* 2019).

2.11.4. Save space and time

Because hydroponic fodder can be produced in a small footprint, it has clear advantages in areas where the amount of land available for agriculture is extremely low or nonexistent. Continuous production of fodder eliminates the requirement for long-term feed storage and the potential loss of nutrients that comes with it, (Mishra 2019). They also stated that in an area of 50 m^2 under hydroponics fodder production, approximately 600 kg of fodder can be produced daily while about one hectare of land is required to produce the same amount of fodder in another fodder production option, (Mijena, Aman *et al.,* 2022).

2.11.5. Dry and drought-prone regions

Areas of the nation that are semi-arid, arid, or prone to drought are most likely the ideal places for hydroponic fodder production. Crop failures would not be a risk if fodder was grown indoors. All year-round production of high-quality fodder is possible. Food supply coverage would be provided. Water resources could be used more effectively if they were scarce, (Mishra 2019).

2.11.6. Constant supply of quality fodder

Soilless fodder is rich in proteins, high quality and full of vitamins and minerals. These superior characteristics soilless system, make it a very useful agricultural system for fresh fodder, (Haidree, Raza *et al.,* 2020). It is a rich source of vitamin A, vitamin E, vitamin C, thiamin, riboflavin, niacin, biotin, free folic acid, anti-oxidants like β-carotene and minerals, (Bakshi, Wadhwa *et al.,* 2017). However, growing green fodder in a hydroponic system is entirely regarded as a natural supply. The hydroponic method can be used to cultivate green feed for a variety of fodder crops that could contaminate animals and animal products in a clean

environment free of chemicals including pesticides, herbicides, fungicides, and artificial growth promoters, (Mijena, Aman *et al.*, 2022).

2.11.7. Reduces growth time

Hydroponic technology takes only 8days to develop from seed to fodder where it took at least 45 days for a conventional fodder to grow, (Shit 2019). According to Haidree, Raza *et al.*, (2020) 7–10 days required for the growth of hydroponic fodder and not require high space, but less space is required for the production of hydroponic fodder.

2.11.8. Availability of green fodder round the year

This technology can provide green fodder all year round in accordance with the needs of livestock that consume it. It is possible to arrange a steady supply of green succulent feed regardless of the weather rain, storm, or sunshine, (Chikhalikar and Khillare 2021).

2.11.9. Minimizing wastage of green fodder

As there won't be any waste of the green fodder during feeding as there would be with chopped traditional grasses during animal eating, green fodder generated hydroponically will be totally utilized, (Chikhalikar and Khillare 2021).

2.12. Methodology of Hydroponic Fodder Production

2.12.1. Seed storage, preparation and washing

In the hydroponic fodder production system, the seed cost contributes 85-90% of the total cost of production (Niak,Dhuri *et al.*, 2014). It entails obtaining high-quality, viable, sound, intact and untreated seeds and grains. Before seed washing, seeds are directly dried in the sun for one day, (Shit 2019).

2.12.2. Seed cleaning

The seeds must be washed firstly for 5 minutes thoroughly with tap water till all dirt and poor-quality seeds are removed. Next, seeds should be soaked in 0.1-1.5% bleach solution (sodium hypochlorite) or 1-2% hydrogen peroxide solution for 30-60 minutes, (Bakshi, Wadhwa *et al.*, 2017). Then, the cleaning solution is drained off and seeds are then washed in tap water, (Ghorbel and Nedim 2022)

2.12.3. Seed soaking

An essential stage in producing hydroponic fodder is soaking the seeds, which allows for a quick uptake of water to aid in the metabolism and usage of the seeds' reserve materials for plant growth and development, (Niak, Swain *et al.*, 2015). The seeds are soaked in fresh aerated water for different periods: 4 h (Niak, Dhuri *et al.* 2014), 8 h, 12-16 h or overnight, 24 h depending on the hardness of the seed coat. The germination rate can be influenced by the temperature of the water or solution used for soaking. It is important to note that the ideal temperature for soaking is 23ºC, (Shit 2019).

2.12.4. Germination of seed

Following the soaking process, the seeds are evenly distributed at a depth of up to 1 cm in trays made of plastic or lightweight metal. These trays are equipped with holes to allow for the drainage of excess water/nutrient solution, which can then be gathered in a tank for recycling purposes, (Shit 2019). Germination of the seeds is also influenced by the seed rate. An elevated seed density increases the likelihood of microbial contamination in the plant root mat, hence limiting the growth of hydroponic fodder, (Niak, swain *et al.*, 2015). The optimal seeding rate for cultivating hydroponic barley, wheat, or sorghum fodder is 4-6 kg/m2, while for maize, it is advised to use a seeding rate of 6.4-7.6 kg/m^2, (Ghorbel and Nedim 2022).

2.12.5. Loading Seeds in Trays and Racking

A custom-designed structure designed to accommodate plastic trays capable of holding 1-1.25 kg of seed, resulting in the production of approximately 5.5-7.5 kg of green fodder, (Ghorbel and Nedim 2022). The seed trays should be sanitized and devoid of any dust or dirt. After germination of seeds, trays are transferred and put in the sprouting section (height between two rows must be around 5 inches). Finally, trays should be distributed evenly on both sides of the alley for even sun light, (Shit 2019).

2.12.6. Shifting trays and harvesting

Either nutrient-enriched solution or fresh tap water is used to irrigate the germinating seeds. It is not recommended to expose the trays to intense sunshine, wind, or rain. Drip or spray irrigation is used to keep the seeds moist but not saturated during the growing season, (Shit 2019). Trays must be shifted to the next level daily so that it moves one step ahead in the growth cycle. If left side tray shows more growth, the trays must be rotated to the right and

vice-versa. On 9th day, the fodder mat is harvested from the tray and can be fed to the livestock. The trays are washed with cleaning solution before reusing it for the next cycle, (Ghorbel and Nedim 2022).

2.13. Disadvantage of Hydroponic Fodder Production

Although hydroponic farming is an advantageous technique which is appreciated by most farmers it has some significant limitations.

Technical Knowledge: means this type of hydroponic technology may not require major labor input, but few needed manpower must be efficient and skilled. Especially when it concerns monitoring and handling the controlled environment parameters inside the green house, (Ghorbel, Jamel, *et al*. 2022).

Availability and Price of Seed: Seed availability is one of the main challenges facing farmers. The cost of hydroponic fodder can be significantly impacted by the scarcity of seeds in the market, as the initial cost of seeds can account for up to 90% of the total cost, (Ghorbel, Jamel *et al.*, 2022).

Dry Matter Loss: Hydroponic fodder is susceptible to be highly perishable in hot climate and a lack of oxygen if it is not properly stored, (Ghorbel, Jamel *et al.*, 2022). When seeds are soaked, enzymes found in the endosperm are activated, converting stored starch to simple sugar. This sugar releases carbon dioxide and water, creates energy, and causes DM to be lost. The starch in the seed is replaced by fiber and pectin in the roots and green shoots, (Bakshi, Wadhwa *et al.*, 2017).

Higher Risk of Fungus and Microbial Infections: The biggest threat to fodder production technology is hydroponic fodder, which is extremely susceptible to ambient temperature and humidity. If humidity and temperature are not controlled, bacteria, fungus, and mold may proliferate. Feeding livestock contaminated with moldy straw can lead to digestive issues, which in severe situations might result in death, (Ghorbel, Jamel *et al.*, 2022).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted from March 23 to April 22, 2024 in *Addet* district, *Addet* is a town in northwestern Ethiopia. This town is 2, 216 meters above sea level and is located in the *Mirab Gojjam* Zone of the Amhara Region, south of Bahir Dar. Its latitude and longitude are 11°16′N 37°29′E / 11.267°N 37.483°E. Within *Yilmana Densa* woreda, it is the biggest settlement. *Addet* is geographically encircled by the *Shenna* and *Shegize* rivers. *Zerabruke* (*Anbesit Mewucha*) and *Felseta Mariam deber* are the names of the southern regions of *Addet*. *Kurrastiyon* or *Ersha Mermer* is the name of the northern region. *Ereberbe Gabriel* is the name of the southeast region (*Yegetoch Bahir zafe*). (CSA 2005) reported in that there are 21,117 people living in this town, 10,508 of them are men and 10,609 of whom are women. (CSA 2023) reported that there are 144,743 cattle, 82,305 sheep, 19,889 goats, and 214,390 chickens found in *Yilmana Densa*.

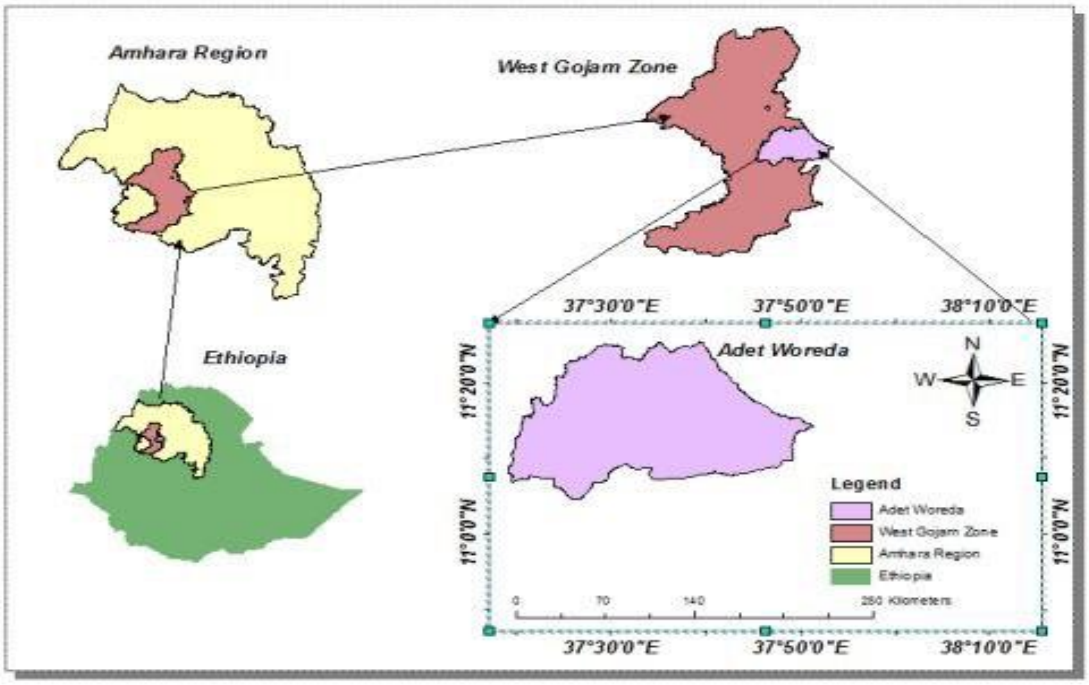


Figure 1 Map of the study area

3.2. Description of Experimental Materials

Materials used during the experiment were seeds, plastic trays, a plastic bucket, a hydroponic unit, scissors, a measuring cylinder, a water sprayer, a weighing balance, a meter, wood, a nail, a gunny bag, and white plastic.

In the present research, the two types of forage crops that were assessed are wheat *(Triticum aestivum)* and triticale *(Triticoscale Wittmack).* The seeds for wheat and triticale, along with items such as white plastic sheets, a gunny bag, and nails, were acquired from the local market in Addet town, while the plastic trays were from Bahir Dar city.

3.3. Preparation of Shed, Shelf and Tray

Green fodders were produced at a hydroponic fodder production unit having a 3m x 2m x 2m length, width and height, respectively. The racks were prepared using wood stands with two shelves organized in parallel with a capacity of 18 plastic hydroponic trays with a length, width and depth of 35 cm, 25 cm and 7 cm, respectively for growing seeds to produce green fodder. The spacing between each tray was 10 cm. There was enough ventilation system for proper air exchange through the opening of the door. The roof and sides of the shed of the hydroponic unit were covered by white plastic.

3.4. Hydroponic fodder Production procedure

The daily operation of the fodder shed involves the following tasks: (Sawant 2023)

1. Initially, the seeds were being weighed after their purchase from the market.

2. Water and seeds of wheat and triticale was added to a plastic bucket, and seeds that had floated on the water would have been removed. The seeds were rinsed with clean water twice.

3. Those seeds were treated with 1% bleaching solution (*berekina*) for 2 hr to prevent mold growth, (Jeton 2016) .

4. After soaking with *berekina* again, seeds were washed with fresh water 2 times.

5. The seeds of triticale and wheat were allowed to soak in water for around 12 hours, (Gebremedhin, Diase *et al*., 2015).

6. Then passing away, breathing time is about one hour.

7. After breathing time, the seeds were placed into a gunny bag (24 hours for wheat seed and triticale).

8. Before using the tray, wash it properly and check all holes to see if they are blocked or not.

9. After germination properly occurred, and then seeds were placing in the trays through spreading.

10. Water was given three times a day (morning12 PM, midday 6AM, and at night 12AM).

11. The samples were collected on the 10^{th}, 12^{th}, and 14^{th} days and measured the biomass yield and growth parameters.

12. 500 gm. fresh sample was taken from each tray at each harvesting date and dried by oven for dry matter determination and chemical composition analysis.

3.5. Experimental Design and Layout

The experiment was conducted by using a 2 X 3 (two fodder crop species and three harvesting ages) factorial arrangement in a Completely Randomized Design (CRD) with three replications. The two fodder crop species were wheat and triticale and the three harvesting ages were 10^{th} day, the 12^{th} day and 14^{th} day. There are six treatments which are wheat harvested at 10, 12, 14 days and triticale harvested at 10, 12 and 14days. Treatments were assigned randomly for each tray. The size of each tray was $875cm^2$ (35cm × 25cm). Total 18 trays were organized in shelf.

Table 5 Treatment combination

		Harvesting age		
		Day 10	Day12	Day14
Variety	Wheat	W10 (T1)	W12 (T2)	W14 (T3)
	Triticale	T10 (T4)	T12 (T5)	T14 (T6)

Where, T1-T6 = Treatment one up to treatment six, T1= wheat harvested at the 10^{th} day; T2= wheat harvested at the12^{th} day; T3= wheat harvested at the 14^{th} day, T4= triticale harvested at 10^{th} day, T5= triticale harvested at 12^{th} day and T6= triticale harvested at 14^{th} day

3.6. Sowing, Watering and Harvesting

Plastic trays were perforated with 1.5 mm diameter holes at the bottom with a 20 mm gap to allow excess water to drain. Plastic trays were placed on the shelves, and treatments were randomly assigned. Each treatment seed was sown at a rate of 437.5 g/tray, taking an average of 5 kg/m² from the recommended seeding rate of 4-6 kg/m² for hydroponic cultivation of fodder barley, wheat, or sorghum, (Al-Karaki and Al-Momani 2011).

Trays were irrigated 3 times a day (in the morning, midday, and in the afternoon) using a water sprayer for 20 seconds. During the experiment, 300 ml of pure water was used in a single prepared tray per day. Based on this, about 5400 ml of water was used for 18 trays per day and 59400 ml of water to accomplish the experiment. The amount of water used during the experiment was calibrated based on the recommendation of 3 L of water (without recycling) to produce 1 kg of green fodder, (Naik, et al. 2013). At the end of the experiment, the sprouts were harvested on the 10^{th}, 12^{th}, and 14^{th} days after planting.

3.7. Data Collection and Measurement

Biomass yield was assessed by harvesting the plants at different stages and measuring parameters such as biomass yield and growth. Harvesting was done by hand. Fresh biomass yield (FBY) and growth parameters such as plant height (PH), leaf length (LL), stem length (SL), root length (RL), number of leaves per plant (NLPP), number of roots per plant (NRPP), and conversion factor were recorded during each harvesting age. The value of each data measure was recorded on prepared sheets of the record book and Microsoft Excel.

Fresh fodder biomass yield: At harvesting, the total weight of green fodder obtained was calculated by adding the weight of the forage and the tray and subtracting the weight of the tray. The weight of fresh fodder yield and seed was weighed by using a sensitive balance, (Alemnew and Mekuriaw 2023).

Total fodder weight = (fodder weight + tray weight) – tray weight

Plant height (cm): The plant height was calculated in centimeters from tray level to the tip of the longest leaf by using a ruler. In each tray, 10 plants were selected randomly at each harvesting stage, and their mean height was recorded.

Root length (cm): Root length was calculated in centimeters from the length of roots from selected plants at each harvesting stage from the grain level to the tip of the longest root by using ruler.

Number of leaves per plant (NLPP): The data concerning number of leaves were recorded by counting leaves from each tray at each harvesting stage, and their means were calculated.

Leaf length (LL) was measured as the length of leaves from the branch to the tip of the longest leaf at each harvesting stage by using ruler.

Stem length (SL) was measured as the length of the stem from grain level to the first branch of leaf by using ruler. Number of roots per plant (NRPP) was counted as the number of roots on selected plants at each harvesting stage, and their means were calculated.

The value of conversion factors was subtracting the weight of the initial planted seed from the produced green fodder weight.

Dry Matter: Fresh fodder samples from each tray were collected, weighed, and the samples were dried by oven for the determination of dry matter (DM), (Grigas, et al. 2023).

$$DM=100-\frac{(W1-W2)}{W1}\times 100$$

Where; DM is the dry matter content;

W1 is the mass of the sample before drying, g; and

W2 is the mass of the sample after drying, g

3.8. Chemical Composition Analysis

About 500 grams of forage samples were collected from each tray during every harvesting phase for the purpose of dry matter assessment and further chemical analysis. The samples were dried in an oven at a temperature of 65°C for a period of 24 hours. After drying, the samples were ground to a particle size that would allow them to pass through a 1 mm mesh screen sieve and were stored in airtight plastic bags until the chemical analysis could be conducted. The determination of ash and crude protein was carried out in accordance with the methods established by AOAC (1990). Neutral detergent fiber (NDF), acid detergent fiber

(ADF), and acid detergent lignin (ADL) were analyzed using the techniques described by Van Soest and Robertson (1985). All the grounded feed samples were analyzed three times and values were recorded.

3.9. Statistical Analysis

The data on fresh biomass yield, growth components, and chemical compositions were analyzed through analysis of variance (ANOVA) employing the General Linear Model (PROC GLM) procedure of the Statistical Analysis System (SAS, 2008) version 9.4. Additional comparisons of means were carried out using the LSD test at a 5% probability level. The model used for the data analysis was

$$Yijk = \mu + vi + hj + (vh)ij + eijk$$

Y_{ijk} = response variable

μ = overall mean

v_i = effect of i^{th} level of grain variety

h_j = effect of j^{th} level of harvesting stage

$(vh)_{ij}$ =effect of interaction of harvesting age with grain variety

e_{ijk} = random error

4. RESULTS AND DISCUSSION

4.1. Growth Parameters of Fodder Crop Species Harvested at Different Age under Hydroponic Condition

4.1.1. Plant Height

In Table 6, the effects of species, harvesting age, and their interaction on plant height are outlined. The findings indicate that plant height was significantly affected by species and harvesting age. Among the two crop species, wheat had a significantly ($P < 0.001$) higher (19.2 cm) plant height value as compared to triticale fodder (17.43). The current result (17.43) was below the findings of Cayan and Sahin (2022) who reported the plant height of triticale on 12th day was 25.91cm. The differences in growth performance observed among these fodder crops may be attributed to variations in their genetic composition and the species' ability to adapt to specific environmental conditions.

In the case of harvesting ages, the highest value of plant height (21.87 cm) was recorded at 14th days compared to 10th (14.75 cm) and 12th (18.33 cm) days of harvest which indicated plant height increases as the age of plants increased. This might be due to longer harvesting time that enhanced the plant's use of nutrients in the seed and continued to increase in height. The current result was in line with the finding of Niak, Dhuri *et al*., (2011) The hydroponic fodder looks like a range of 11-30 cm height consisting of root, seed and plant and. On the other hand, the plant height value (21.87 cm) harvested at 14 days in the current study was above the result of Mahale, Dhage *et al*. (2020) and Moin, Salam *et al*. (2023), who reported 17.26 cm and 15.9 cm plant height for wheat species harvested at 14 and 15 days, respectively. The current study was below the result of Upreti, Ghimre *et al.* (2023), who reported plant height of wheat harvested on the 11th day is 25 cm. The reasons might be due to differences in environment, harvesting age, seed type and quality, seed rate, water quality, nutrient solution, type of greenhouse, irrigation frequency, temperature, and management factors that affected the growth of the fodder.

Table 6 Effect of harvesting age and crop species on morphology of hydroponic fodder

	Morphology parameter									
Fodder crop species	PH (cm)	LL (cm)	SL (cm)	RL (cm)	NLPP (cm)	NRPP (cm)	FBY(t/ha)	CF (kg)	DM %	DMY (t/ha)
Wheat	19.2[a]	9.61[a]	4.97[a]	9.07[b]	1.87[a]	6.39[b]	205.07[a]	1.320[a]	14.76[a]	29.70[a]
Triticale	17.43[b]	7.68[b]	4.40[b]	14.23[a]	1.66[b]	6.94[a]	183.61[b]	1.162[b]	13.68[a]	24.87[b]
Significant level	**	**	**	**	**	**	**	*	**	**
Harvesting age (days)										
10	14.75[c]	6.66[c]	3.86[c]	10.18[c]	1.60[c]	6.38[b]	147.43[c]	0.8525[c]	14.34[a]	21.19[c]
12	18.33[b]	8.69[b]	4.72[b]	11.91[b]	1.77[b]	6.63[b]	189.72[b]	1.158[b]	14.24[b]	25.96[b]
14	21.87[a]	10.59[a]	5.48[a]	12.87[a]	1.95[a]	6.98[a]	245.90[a]	1.714[a]	14.07[c]	34.71[a]
Significant level	**	**	**	**	**	**	**	**	**	**
CV%	4.23	10.66	8.1	5.52	3.26	3.20	6.68	9.58	0.102	7.16

PH=plant height, LL= leaf length, SL= stem length, RL= root length, NLPP= number of leave per plant, NRPP= number of roots per plant, FBY= fresh biomass yield, CF= conversion factor, DMY= dry matter yield, **= significant at 0.01%, *= significant at 0.05% and CV= coefficient of variation

4.1.2. Leaf Length

The effects of harvesting age, crop species and their interaction on leaf length are presented in Table 6. Leaf length was significantly affected by harvesting age and crop species Significantly

($P < 0.0001$) the higher leaf lengths (10.59) were recorded on the 14th day of harvesting than harvesting on the 12th and 10th days. The reason might be due to continued growth of leaves for a certain period in its life. The current result was comparable with the finding of Girma *et al*. (2019), who reported increased leaf production for oat species when harvested on the 10th to 14th day. The current result was contrary to Lamidi, Ingweye *et al*. (2022), who reported 14.29 cm length of leaf for maize at harvesting of 10 days. The reasons might be due to differences in environment, harvesting time, and grain type.

Significantly ($P < 0.01$), the highest leaf length value of 9.61 cm was recorded for wheat species as compared to triticale (7.68 cm). The variation in leaf length among the two fodder crop species might be due to the differences in genetic makeup and adaptability of the crops to a particular environment. LL was increased along with the advancement in harvesting age, as supported by Alemnew and Mekuriaw (2023), who reported 7.76 cm leaf length for barley species harvested at 10 days.

4.1.3. Stem Length

Table 6 illustrates the effect of harvesting age, crop species, and their interaction on stem length. Stem length was affected by harvesting age and crop species ($P< 0.05$). Significantly ($P < 0.0001$) higher average stem length was recorded on the 14th day of harvesting (5.48) than harvesting on the 12th (4.72) and 10th (3.86) day. Similar to the current study, Carmi, Aharoni *et al*. (2006) reported increased stem proportion with delaying in harvesting time. The current result was similar to Jemimah, Gnanaraj *et al.,* (2018) stated that the harvesting age is prolonged the stem length also increased.

In the case of crop species, significantly ($P < 0.01$), longer stem length (4.97 cm) was recorded for wheat than triticale (4.4 cm). The longer stem length recorded for wheat might be due to species variation and best adaptability to this technology.

4.1.4. Root Length

Table 6 illustrates the impact of harvesting age, crop species, and their interaction on root length. In the current study, root length was significantly ($P < 0.0001$) affected by harvesting age and crop species. Longer root length (12.87 cm) was recorded at the 14th harvesting age than harvesting at the 12th (11.91cm) and 10th (10.18 cm) day. This indicated that the roots

were still growing up until the last harvesting age, which helped the plant to absorb nutrient solutions for its growth and development.

On the other hand, the mean root length of hydroponic triticale fodder, recorded as 14.23 cm, was higher than that of hydroponic wheat fodder (HWF, 9.07 cm). The root lengths recorded for triticale species in this study were higher to the value Mine, Guzel *et al.* (2021) reported, which was 6.261 cm recorded for triticale at the 8th day of harvesting. The longest root length for the triticale crop indicated its potential to grow fast and quest more nutrient solutions better than wheat crop species under investigation. The current result was higher than the finding of G/Mariam (2020), who reported that root length of wheat at the 12th day of harvest is 9.65 cm. Bari, Islam *et al.* (2022) and Rajesh, Sivakumar *et al.* (2018) reported that root length of wheat at the 8th day of harvest is 15.7 cm. The reason could be attributed to environmental conditions, harvesting time, seed type and quality, seed rate, water quality, nutrient solution, type of greenhouse, irrigation frequency, temperature, and management factors.

4.1.5. Number of Leaves per Plant

The number of leaves per plant was significantly ($P < 0.001$) affected by harvesting age and crop species presented in Table 6. Significantly, the highest number of leaves per plant was recorded for 1.95 at the 14th day of harvest than the 12th (1.77) and 10th (1.60) day of harvest. As the harvesting period extends, photosynthesis continues until the nutrients within the seed are fully consumed. This continuous photosynthetic process facilitates the growth of the plant and the expansion of its leaves. Thus, an extended harvesting period may result in increased leaf production for the plant, (Girma, Diriba *et al.* 2018). The number of leaves is crucial for increasing biomass production and improving the nutritional value of the green fodder, (Shawal, Ilahi *et al.,* 2021).

In the case of crop species, a significantly ($P < .0001$) higher number of leaves (1.87) was recorded for wheat than triticale (1.66) fodder. The current finding was comparable with the result of Alemnew and Mekuriaw (2023), who reported 1.85 numbers of leaves were recorded on barley fodder at 12th day of harvest. Contrary to the current study, Jemimah, Tensingh *et al.* (2015) reported four numbers of leaves per plant on the eight days of harvesting age for maize species. The variation in the number of leaves among the fodder crops and three harvesting

ages could be due to the differences in the genetic make-up and adaptability of the species for hydroponic technology.

4.1.6. Number of Root per Plant

The number of roots per plant was significantly ($P < 0.05$) affected by species and harvesting age presented in Table 6. The highest (6.98) number of roots per plant was recorded at 14^{th} day of harvest than harvesting at 12^{th} (6.38) and 10^{th} (6.63) days. Among crop species, the number of roots per plant was higher in order of triticale 6.94 greater than wheat 6.39 ($P < 0.001$). The variation among crop species could be due to the differences in the genetic make-up and adaptability of these species for the hydroponic conditions. Contrary to the current study, Bari, Islam *et al.* (2022) reported 7.98 numbers of roots per plant at eight days of harvesting age for wheat species.

4.1.7. Fresh Biomass Yield

Fresh biomass yield was significantly affected by crop species and harvesting age presented in Table 6. Significantly ($P < 0.0001$) higher fresh biomass yield (245.9 t/ha) was recorded at the 14^{th} day of harvesting than harvesting at the 12^{th} and 10^{th} day of harvest. The higher fresh biomass yield at 14^{th} day might be due to higher growth parameters (plant height, stem length, leaf number, leaf length, number of leaves per plant, number of roots per plant) recorded at this stage of growth, which has led to high fresh biomass yield.

The current finding was similar to the work of Girma, Diriba *et al*. (2019) and Chrisdiana (2018), who reported higher fresh biomass yield when the harvesting age of hydroponic forages was increased. Contrary to the current result as well as the previous studies, Lamnganbi and Surve (2017) reported fresh biomass yield reduction after the 8th day of harvesting due to mold growth, rotting, and drying up of roots with increasing harvesting age.

In the case of crop species, significantly ($P < 0.01$) higher fresh fodder yield (205.07 t/ha) was recorded for wheat than triticale (183.61). The current result is in line with the result of Al-Karaki and Al-Hashimi (2012), which reported 131 t/ha wheat fodder was harvested on days of the 8^{th}.

4.1.8. Conversion Factor

In Table 6, the effects of species and harvesting age on the conversion factor (CF) are presented. The CF was significantly ($P < 0.05$) affected by harvesting age and species. Significantly ($P < 0.0001$) higher CF was obtained at day 14^{th} (3.9 times the original seed) than 12^{th} and 10^{th} days. The highest CF value in the current study at the 14^{th} day harvesting age indicated the increment of the fresh biomass yield to grain seed ratio with the increasing of the harvesting day.

The current result is comparable to Girma, Diriba *et al.* (2019), who reported that the fresh weight of the oats variety green fodder was increased about 3.4 times the original seed weight after sprouting for 14 days. Similar results have also been reported by other authors Dung, Godwin *et al*. (2010) also estimated that fresh sprouts weighed about 3.7 times their original seed weight after 7 days.

The higher CF was obtained for wheat fodder 3.01 times the original seed as compared to triticale fodder 2.656 times higher. It showed the difference in the ratio of green hydroponic fodder to grain seed among experimental species. The current result is comparable to the report of Al-Ajmi, Kadhim *et al*. (2009), who reported 2.76 to 3 times more green fodder per kg of barley seed. This ratio depended on several factors such as management, type and quality of grain, amount and frequency of irrigation, nutritious solution, temperature, humidity, density and position of lights, seed rate on each tray, and growth stage (Mooney 2005; Bari, Islam *et al*. 2022).

4.1.9. Dry Matter Percentage

The effect of harvesting age, crop species, and their interactions are presented in Table 7. The DM percentage was significantly affected by species ($P < 0.001$), harvesting age ($P < 0.001$), and their interactions ($P < 0.05$). Significantly ($P < 0.01$) higher DM% was observed on 10 days (14.34) than on 12 days (14.26) and 14 days (14.12) of harvest. The current result is comparable with Rahul and Sonali (2018), who reported that 11-14% DM for hydroponic wheat fodder. During sprouting of seed, there is an increase in the fresh weight and a decrease in DM content, which is mainly attributed to the imbibition of water (leaching) and enzymatic activities that deplete the food reserves of the seed endosperm (oxidation) without any adequate

replenishment from photosynthesis by the young plant during a short growing cycle, (Niak, Swain *et al.*, 2015a; Sneath and Mclntosh 2003).

Among the crop species wheat (14.76) had higher DM percentage than triticale (13.68). The DM percentage recorded on the 10^{th} (14.92), 12^{th} (14.79), and 14^{th} (14.56) days of harvesting was comparable with the finding by Mahale, Dhage *et al*. (2020), who reported that the DM of wheat on the 14^{th} day of harvest is 14.64.

Table 7 Interaction effects on DM% and ADL% of the hydroponic wheat and triticale fodder

Harvesting age (days)	Variety	DM%	ADL%
10	Wheat	14.92^{a}	6.91^{c}
	Triticale	13.77^{d}	6.71^{cd}
12	Wheat	14.79^{b}	6.29^{d}
	Triticale	13.68^{e}	7.55^{b}
14	Wheat	14.56^{c}	7.66^{b}
	Triticale	13.58^{f}	8.64^{a}
Significant level		**	**
CV%		0.102	4.19

Where DM= dry matter, ADL= acid detergent lignin, CV= coefficient of variation and **= significant at 0.01%

4.1.10. Dry Matter Yield

The effects of harvesting age, crop species, and their interaction effects on dry matter yield are indicated in Table 6. Dry matter yield (DMY) was significantly ($P < 0.01$) affected by crop species and by harvesting age with not significant interaction effects ($P > 0.05$). Significantly higher DMY was obtained for wheat than triticale. The higher dry matter yield value of wheat might be associated with the value of fresh biomass yield. The DMY value 34.71 t/ha harvested at 14 days in the current study was lower than the result of G/Mariam (2020), who reported a 37.33 t/ha dry matter yield for wheat species harvested at the 12th day. The current result is comparable with Adekeye, Onifade *et al*. (2019), who reported that DMY of wheat at the age of 12 days is 28.85, 33.25, and 37.64 by using nutrient solution, borehole water, and fish hatchery wastewater, respectively. The current DMY result of wheat and triticale in

hydroponic technique is higher than the result of Kidane (1993) and Taylor (1981), who reported 4 to 6 tons/ha for natural pasture of forage production.

4.2. Chemical composition of hydroponic fodder

4.2.1. Crude Ash

The ash content was significantly ($p < 0.001$) affected by the grain variety and harvesting stage, (Table 8). The maximum ash content was recorded in triticale (5.45%) than in wheat (4.41%). The ash content of hydroponic fodder on 10^{th}, 12^{th}, and 14^{th} days of harvest were 4.09%, 4.97% and 5.73% respectively. The current result agrees with Bari, Islam *et al*. (2022), who reported that the growing date increases the result of minerals also rising. The value of ash on wheat in the current study is in agreement with the report of Moin, Salam *et al.* (2023) who reported 4.15% of hydroponically grown wheat variety at the 15th day of harvest. The present study is also in agreement with the results reported by Alemnew and Mekuriaw (2023), who reported that the ash content of hydroponic barley fodder on the 12^{th} and 10^{th} days of harvest was 5.06% and 4.60%, respectively, and the result is similar to triticale fodder. The current result was contrary to the results reported by Ali, Miah *et al*., (2019) who observed the ash content of hydroponics wheat fodder was 4.09 on 8^{th} day of harvest and Mahale, Dhage *et al.*, (2020) reported that ash content of wheat on 14^{th} day harvest is 3.38. The result of triticale fodder also agrees with the result of Islam, Jalal *et al.* (2016), who reported that the ash content of maize fodder was 6.16%, recorded on the 10^{th} day of harvest.

4.2.2. Crude Protein (%)

The influence of harvesting age, crop species, and their interaction on crude protein (CP) is presented in Table 8. It was found that the crude protein percentage was affected by the species ($P \leq 0.05$) and the harvesting age ($P \leq 0.001$). In the case of crop species wheat have the higher yield of CP 18.86% than triticale has 17.2%.

The crude protein content of hydroponic fodder was 15.67%, 18.25% and 20.18% recorded on 10^{th}, 12^{th} and 14^{th} day of harvest. The present study is in agreement with the results reported by Upreti *et al*. (2023), who reported that 16.16% of CP was obtained at 11 days of harvesting wheat fodder, and Alemnew and Mekuriaw (2023) reported that 21.39 CP was obtained from the Debark-1 barely variety on the 12^{th} day of harvest. On the other hand, the current result

20.18% is higher than the result of Mahale, Dhage *et al.* (2020), who reported that CP content of wheat on day 14 is 18.94, and Moin, Salam *et al*. (2023) reported that CP content of wheat on day 15 is 17.71, and also my result is lower than the result of Bari, Islam *et al*. (2022), who reported that CP content of wheat is 19.83 on the 8th day of harvest. It is also lower than the result of Shah, Manoj *et al*. (2023) reported that 26.44% of CP was recorded on the 7th day of wheat fodder. The variation might be due to the environmental condition of the hydroponic unit, seed rate, water quality, and nutrient solution.

In the harvesting age, the lowest CP content was recorded on the 10th day (15.67%) and increased to the maximum mean value on the 14th day (20.17%). The results indicated that extending the growth period led to a higher proportion of leaf in the fodder, resulting in a greater increase in CP composition compared to the grain component. The result is in agreement with the report of Hande, Onur *et al*. (2014), who reported higher CP content with increasing harvesting days. The present result is also in agreement with the findings of Fazeli, Golmohammadi *et al*. (2012), who reported that there was an increase in the CP content of the seeds as they sprouted. The decrease in DM content during sprouting could be the reason for this, as supported by Lorenz's (1980) research showing a higher concentration of nutrients during germination as DM decreases.

4.2.3. Neutral Detergent Fiber

The NDF content was significantly influenced (P <0 .0001) by variety and harvesting age as presented on table 8. The highest NDF values were recorded on triticale 60.94% than wheat 56.08%. The highest NDF content of hydroponically grown fodder 61.46 was recorded on the 14th day of harvesting and 55.96 and 58.12 were recorded on 10th and 12th day respectively. This implies that the NDF content was increased with prolonged harvesting time, which is in line with the reports of Fazaeli, Golmohammadi *et al*. (2012), Naik, Dhuri *et a*l. (2012), and Bulcha, Diriba *et al.* (2022), who indicated that with the progress of the harvesting period, the plant cell wall components were increased. The current study is lower than the results reported by Upreti, Ghimire *et al*. (2023), who reported that 62.72 was recorded on wheat at 11 days of harvest. The difference in NDF contents of different varieties and harvesting ages in the current study may be due to growth stage, genetic makeup, temperatures, and variations in management during the experiment.

According to Singh and Oosting (1992), feeds with an NDF value of less than 45% are classified as high quality, while those rated from 45% to 65% are identified as medium quality, and above 65% is classified as low quality. According to this, the current NDF value of all species was categorized under medium-quality forage.

Table 8 Effect of harvesting age and crop species on chemical composition of hydroponic fodder

Fodder crop species	Parameters				
	Ash%	CP%	NDF%	ADF%	ADL%
Wheat	4.41[b]	18.86[a]	56.08[b]	30.19[b]	6.98[b]
Triticale	5.45[a]	17.2[b]	60.94[a]	38.10[a]	7.64[a]
Significant level	**	*	**	**	**
Harvesting age (days)					
10	4.09[c]	15.67[c]	55.96[c]	34.45[b]	6.81[c]
12	4.97[b]	18.25[b]	58.12[b]	31.76[c]	6.92[b]
14	5.73[a]	20.18[a]	61.46[a]	36.24[a]	8.15[a]
Significant level	**	**	**	**	**
CV%	8.57	7.46	1.97	3.64	4.19

Where: CP=crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL=acid detergent lignin **= significant at 0.01%, *= significant at 0.05% and CV= coefficient of variation

4.2.4. Acid Detergent Fiber

The ADF% was significantly affected by species and harvesting age at (P = <.001) presented in Table 8. The higher ADF value was recorded on triticale 38.1%, and the lowest were obtained from wheat 30.19%. which was in line with the current investigation during the late harvesting age, the ADF content rises as a result of the increase in structural cell wall components as the plant matures. This is due to the conversion of photosynthesis components into structural components, causing a reduction in soluble carbohydrates (Lamidi, Ingweye *et al.,* 2022). The current result in agreement with Upreti, Ghimire *et al.* (2023) reported that the

ADF value of hydroponic wheat fodder on the 11th day of harvest is 29.63. On the other hand, the current result was higher than the result of Alemnew and Mekuriaw (2023), who reported 21.25% of ADF, was recorded on barely variety on the 12th day of harvest. Variations may be due to differences in genetic makeup of variety, management, temperature, and harvesting stage.

Moreover, Naik, Swain *et al.* (2015) also reported that the rise in the content of CF, NDF, and ADF, along with the decline in nitrogen-free extract and non-fibrous carbohydrates, could be linked to the growth in both the quantity and dimensions of cell walls for the production of structural carbohydrates (cellulose and hemicellulose). According to Robert (2023), ADF values in < 35% are high-quality forages, 35-40% are medium, and above 40% are low. Therefore, in the current study, wheat was categorized as high-quality green feed, and triticale was medium-quality feed.

4.2.5. Acid Detergent Lignin

The ADL content was significantly influenced ($P < 0.01$) by the interaction effect, harvesting stage, and variety presented on table 7. A higher percentage of ADL was recorded on triticale (6.71%, 7.55%, and 8.64%), and a lower value was obtained on wheat (6.91%, 6.29%, and 7.66%) on the 10th, 12th, and 14th days of harvest. The current study is in agreement with the results reported by Bulcha, Diriba *et al*. (2022): the ADL content of wheat is 6.35% on local barley landrace at the 10th day of harvest. And also, it is in line with the result of Alemnew and Mekuriaw (2023), who reported that at the 12th day of harvest, the ADL content of local barley fodder is 8.44%. Similarly, it is in line with the 6-9% range of ADL as reported by Girma, Diriba *et al*. (2018) on different oat varieties. On the other hand, the current result is lower than the result of Upreti, Ghimre *et al.* (2023), who reported 8.17% ADL content of wheat fodder at 11th day of harvest. The difference might be due to environment, seed rate, and nutrient solution.

5. CONCLUSION AND RECOMMENDATION

One of the quick and soilless forage development methods is hydroponic fodder production. Thus, the purpose of the study was to assess how the species of fodder crops and harvesting age affected the biomass output and nutrient composition of hydroponic fodder. The study on the effect of harvesting stage on biomass yield and quality of wheat and triticale fodder under hydroponic conditions has provided valuable insights into optimizing fodder production for livestock.

The results of the study indicated that the harvesting stage significantly influenced the biomass yield, growth parameters, and chemical composition of wheat and triticale fodder.

The highest values of growth parameters and fresh biomass yield were obtained when harvested on the 14th day, whereas the highest values of DM% (14.34) and the lowest value of ADF% (31.76) were obtained at the 10th and 12th days of harvesting, respectively.

Concerning crop species, the highest values of plant height, leaf length, number of leaves per plant, fresh biomass yield, conversion factor, and crude protein percentage were obtained for wheat, whereas the highest values of root length, number of roots per plant, ash%, ADF%, NDF, and ADL% were recorded for triticale. On the other hand, both wheat and triticale have the same stem length on the 12^{th} and 14^{th} days of harvest.

Based on the parameters analyzed in the study, wheat appears to be the better option for hydroponic fodder production compared to triticale.

Recommendation

Based on the findings of this study, the following recommendations are made:

- ✓ Wheat had better choice for hydroponic fodder production because of higher growth parameters, biomass yield and better nutritional value indicators, including higher crude protein and lower crude fiber.
- ✓ Harvesting on the 14th day after planting is recommend because it allows the plants to reach their full growth potential. At this stage, the plants have sufficient time to develop all growth parameters leading to an increase in fresh biomass yield.

Future Prospects

- ✓ Evaluating hydroponic green forage production's cost-benefit analysis to the conventional one.
- ✓ Assessing the long-term impacts of chemicals used to sterilize grain seeds on animal health
- ✓ Develop educational program to train farmers in hydroponic technique, crop selection and harvesting techniques.
- ✓ Evaluate the impact of hydroponic fodder produced at different harvesting stages on animal growth, milk production, and health.

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7. **APPENDIX**

List of Appendix Table

Appendix table 1 Analysis of variance (ANOVA) showing mean squares for morphological parameters influenced by harvesting age and species

		Mean squares								
Source of variation	df	PH	LL	SL	RL	NLPP	NRPP	FBY	CF	DMY
Species	1	14.06**	16.72**	1.44**	119.50**	0.20**	1.38**	1462.86*	0.11*	104.83**
Harvesting age	2	76.11**	23.21**	3.94**	11.12**	0.18**	0.54**	14959.50**	1.14**	282.24**
SP*HA	2	0.50 Ns	0.07 Ns	0.22 ns	0.21ns	0.003ns	0.027ns	55.36ns	0.004 ns	2.95ns
Error	12	0.59	0.85	0.14	0.41	0.003	0.045	184.71	0.014	3.82
CV (%)		4.22	10.66	8.10	5.52	3.25	3.20	7.08	9.58	7.16
LSD (0.05)		1.38	1.64	0.68	1.15	0.1	0.38	24.18	0.212	3.47

Where, DF= Degree of freedom; PH=Plant height; SL=Stem length; LL=Leaf length; RL=Root length NLPP=Number of leaf per plant; NRPP=Number of root per plant; FBY=Fresh biomass yield; CF=Conversion factor; DMY=Dry matter yield; SP=species; HA=Harvesting age; **= significant at 1% level probability, *= significant at 5% level of probability, ns= non-significant

Appendix table 2 Effect of harvesting stage and grain varieties on the chemical composition of wheat and triticale hydroponic fodder

		Mean square					
Source of variation	df	DM%	Ash%	CP%	NDF%	ADF%	ADL%
Species	1	5.70**	4.85 **	12.35*	106.19**	281.00**	2.09**
Harvesting age	2	0.07**	4.04**	30.58**	45.94**	30.48**	3.31**
SP*HA	2	0.002**	0.06 Ns	1.08Ns	1.04Ns	1.31Ns	0.89*
Error	12	0.0002	0.17	1.81	1.34	1.54	0.09
CV (%)		0.10	8.57	7.46	1.97	3.64	4.19
LSD (0.05)		0.026	0.75	2.39	2.06	2.21	0.54

Where, SP= Species; HA= Harvesting age; DM% =Dry matter percentage; ASH%=Ash percentage; CP%= crude protein percentage; NDF%=Neutral detergent fiber; ADF%=Acid detergent fiber ADL%=Acid detergent lignin; DF=degrees of freedom; CV=Coefficient of Variation; **= significant at 1% probability level, *= significant at 5% probability level, ns= non-significant at 5% probability level

List of Appendix Figure





Appendix figure 1 seed cleaning and seed of Triticale (figure on the left) and seed of wheat (on the right)

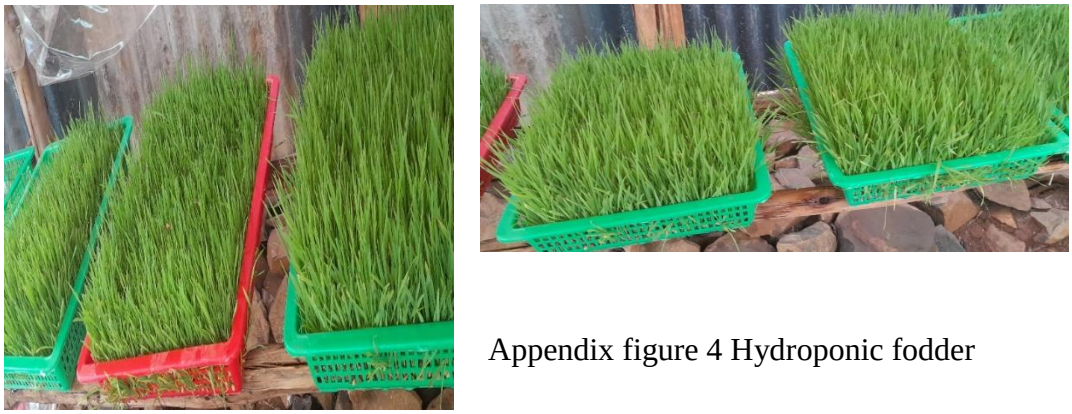




Appendix figure 2 seed washing and soaking and tray cleaning



Appendix figure 3 fodder production in a hydroponic unit



Appendix figure 4 Hydroponic fodder







Appendix figure 5 wheat (W) and Triticale (T) fodder on the 10th (HA1), 12th (HA2), and 14th (HA3) days of harvest in hydroponic conditions



Appendix figure 6 Root part of hydroponic fodder





Appendix figure 7 Root length and collecting agronomic data