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FOREWORD

I am honoured to introduce this latest issue to the International Journal of Environment, Agriculture and Biotechnology (IJEAB). Our journal is dedicated to disseminating high-quality research and innovative findings that contribute to advancing knowledge in these critical fields.

In this issue, we present a collection of papers that exemplify the diversity and depth of contemporary environmental, agriculture, and biotechnology research. The articles include various topics, from sustainable agricultural practices and environmental conservation strategies to cutting-edge biotechnological innovations. Each contribution has undergone a rigorous peer-review process, ensuring the publication of only the most significant and original research.

Our commitment at IJEAB is to provide a robust platform for researchers, academicians, and practitioners to share their work and engage with a global audience. By fostering an interdisciplinary approach, we aim to bridge the gaps between different areas of study and promote holistic understanding and solutions to the challenges we face in these domains.

We are grateful to our dedicated authors, whose hard work and intellectual rigour are the backbone of our journal. We also extend our appreciation to our reviewers and editorial board members, whose expertise and diligence ensure the high standards of our publication. Finally, we thank our readers for their continued support and engagement.

We hope you find the articles insightful and inspiring as you explore this issue. We encourage you to contribute your research to future issues and join us in our mission to advance knowledge and drive positive change in the environment, agriculture, and biotechnology fields.

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Impact of bio stimulants on growth parameters of capsicum (*Capsicum annum* L.)

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Abstract— *In recent years, there has been a growing interest in the cultivation and consumption of peppers, prompting efforts to identify optimal conditions for their growth and development. This study aimed to assess the impact of biostimulants on the growth and yield of capsicum. The experiment involved twelve treatments, including an absolute control, and was designed using a Randomized Block Design with four replications. The underlying hypothesis suggested that biostimulants could enhance the yield of pepper fruits. The study was conducted in a polyhouse at the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar, during the Rabi seasons of 2022-23 and 2023-24, using the PSM-1 variety as the experimental material. The result showed that treatment T_3 (RDF + Seaweed extract 2.5 ml/L) recorded highest plant height (103.22 cm), leaf area (370.63 cm²) and no. of branches per plant (11.63).*

Keywords— ***Biostimulants, Capsicum, Growth, Yield, Polyhouse***

I. INTRODUCTION

Capsicum (*Capsicum annum* L.) commonly known as bell pepper, sweet pepper or shimla mirch is a tropical and subtropical vegetable and spice from family Solanaceae with chromosome no. 2n = 24 and is popular for its delicious taste, pleasant flavor and nutritional quality. Bell pepper is a native to Mexico with secondary centre of origin in Gautemala (Heiser and Smith, 1953). In India, it was introduced by the Britishers in the 19th century in Shimla Hills (Singh *et al*., 1993). Globally, *Capsicum annuum* is the most widely cultivated species, along with four other domesticated species: *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens*. It is extensively grown worldwide due to its high consumption, nutritional benefits, and commercial value for both farmers and consumers in developed and developing nations. Conservation of chilli biodiversity and sustainable cultivation practices hold immense importance given the crop's global significance.

Biostimulant is a substance or microorganism applied to plants to enhance nutrient efficiency, abiotic stress tolerance and overall crop quality (Sun *et al.*, 2023). Major categories of biostimulants include humic and fulvic acids, protein hydrolysates and nitrogen-containing compounds, seaweed extracts, botanicals, chitosan and other biopolymers, inorganic compounds, and beneficial fungi and bacteria (Du Jardin, 2015). These biostimulants improve plant growth, resilience and productivity by promoting natural physiological processes. Despite significant advancements in improving bell pepper quality through mineral nutrition, research on the application of biostimulants for the same purpose remains limited.

Chitosan, a biodegradable derivative of chitin found in fungal walls and crustacean shells, enhances plant growth, pest resistance, stress tolerance, and post-harvest quality. It improves traits like plant height, leaf area, chlorophyll content, and photosynthesis in crops (Lustriane *et al.*, 2018; Malerba *et al.*, 2016), and supports soil microbiota diversity for better nutrient absorption (Rabbi *et al.*, 2016). Humic acid, an organic compound, promotes nutrient uptake, root growth, and stress tolerance. Polyamines like putrescine regulate growth and stress responses, extending shelf life and maintaining fruit texture through foliar application (El-Tohamy *et al.*, 2008; Khosroshahi *et al.*, 2007). Salicylic acid (SA) regulates growth, stress tolerance, and post-harvest decay in crops like strawberries and tomatoes (Kazemi, 2014; Asghari *et al.*, 2009), boosting yield and quality at low concentrations (Canakci, 2011). Seaweed extracts, rich in plant growth regulators (auxins, cytokinins), improve growth, flowering, yield, and shelf life (Yao *et al.*, 2020). Seaweed-derived gels and sprays enhance soil structure, water retention, and microbial activity, offering eco-friendly preservation and growth-promoting benefits (Thivy, 1961; Ramani *et al.*, 2020).

The present study aimed to determine the impact of biostimulants on growth and yield of capsicum.

II. MATERIALS AND METHODS

The present research experiment was conducted at Polyhouse of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar during *Rabi* season of 2022-23 & 2023-24 by using capsicum *cv.* PSM-1. The experiment was conducted at polyhouse located near Ram Dhan Seed Farm (RDS), CCS Haryana Agricultural University, Hisar, which is located in semi-arid, subtropical climate zone at 29° 09' to 14.28" north latitude and 75° 43' to 02.84" east longitude at an elevation of 215 m above mean sea level on South western border of Haryana state. The field experiment was laid out in Randomized Block Design (RBD) by using four replication of each twelve biostimulants treatments. Treatments details are:

T_1: RDF (Control)

T_2: 87.5 % RDF

T_3: RDF + Seaweeds extract (2.5 ml/L)

T_4: 87.5 % RDF + Seaweeds extract (2.5 ml/L)

T_5: RDF + Salicylic acid (2 g/L)

T_6: 87.5 % RDF + Salicylic acid (2 g/L)

T_7: RDF + Chitosan 0.5 %

T_8: 87.5 % RDF + Chitosan 0.5 %

T_9: RDF + Putrescine 0.1 g/L

T_{10}: 87.5 % RDF + Putrescine 0.1 g/L

T_{11}: RDF + Humic acid (5 ml/L)

T_{12}: 87.5 % RDF + Humic acid (5 ml/L)

The observation for plant growth and yield attributes wer recorded on randomly selected plant five competetive plant per treatment in each replication. Observation recorded are plant height (cm) at harvest, leaf area (cm^2) and no. of branches per plant, The experiment was laid out in Randomized Block Design with four replication. The data obtained from the experiment conducted in RBD were analyzed as per standard methods suggested by Panse and Sukhatme (1967). The data observed for various characters during the study were statistically analyzed following the technique of analysis of variance (ANOVA).

III. RESULT AND DISCUSSION

Plant height (cm)

Plant height is a critical growth parameter and a vital indicator of plant development. It is closely associated with lateral branch formation, flower and fruit production, and ultimately crop yield. This parameter not only influences plant architecture but is also an essential agronomic trait contributing to overall productivity. In the study, the pooled plant height over two years ranged from 87.20 cm to 103.22 cm. The tallest plants (103.22 cm) were recorded in treatment T_3 (100% RDF + Seaweed extract at 2.5 ml/L), comparable to T_{11} (100% RDF + Humic acid). The shortest plants (87.20 cm) were observed in treatment T_2 (87.5% RDF). The enhanced plant height in 100% RDF treatments is attributed to increased nitrogen and phosphorus levels, promoting cell division and elongation. Optimal nitrogen availability in the root zone supports better nutrient uptake and vegetative growth, consistent with the findings of Fawzy *et al.* (2012). Seaweed extract application likely boosted plant height due to its rich content of growth-promoting substances, including auxins, gibberellins, cytokinins, micronutrients, vitamins, and amino acids (Hamed *et al.*, 2018). These results align with studies by Sridhar and Rengasamy (2012), Ozbay and Demirkiran (2019), Vijayakumar *et al.* (2019), Ashour *et al.* (2021), and Azzam *et al.* (2022) on capsicum. Humic acid also significantly influenced plant height by improving soil fertility and nutrient availability. Its application enhanced plant growth and yield, particularly in vegetable crops, while mitigating stress-related damage (Doran *et al.*, 2003).

Leaf area (cm^2)

The pooled value of both the years of experimental study, significantly the maximum leaf area (370.63 cm^2) was recorded in treatment T_3 (RDF + Seaweed extract 2.5 ml/L), whereas, the minimum leaf area (285.10 cm^2) was observed in treatment T_2 (87.5 % RDF). In this present study, leaf area was significantly increased in the bell pepper plants with 100% RDF along with foliar application of various biostimulants.

The increase in leaf area is a positive indication of response of growth factors in many of the nutritional investigation and also directly indicates the increase in photosynthetic activity of a plant producing more of photosynthates and more metabolic activity. Their combination produced more leaf area due to proper utilization of nutrition. The leaf area increased gradually with 100% RDF at all the growth stages due to better N and K nutrients availability and absorption by the plants resulted in more number of leaves and higher leaf area. These findings were in agreement with Mounika (2016) in paprika, Nanda and Mahapatra (2004) in tomato and Sahoo *et al*. (2002) in tomato, Santos *et al*. (2003) in capsicum.

Expanding the leaf area often through a higher concentration of such seaweed extract possibly due to micronutrients in the supplement, which include potassium, improves the plant's metabolism, the production of amino acids and proteins, as well as the emergence of photosynthetic pigments that further improved the performance of the leaf area (Kularathne *et al*., 2021). These results are also in accordance with Sridhar and Rengasamy (2012); Ozbay and Demirkiran (2019); Vijayakumar *et al.* (2019) and Azzam *et al.* (2022) in capsicum.

Number of branches per plant

The number of branches per plant plays an important role in plant morphogenesis and is important agronomic characters that determine the fruit quality and yield. The effective branches also determine the number of flowers cluster or no. of fruits per plant that decide the total yield and quality of bell pepper fruit.

The pooled value of both the years of experimental study showed that for number of branches per plant was maximum (11.63) in treatment T_3 (100 % RDF + Seaweed extract 2.5 ml/L)**,** which was at par with treatment T_{11} (RDF + Humic acid), whereas the minimum (9.63) was observed in treatment T_2 (87.5 % RDF).

There was increase in branches per plant might be due to increase in nutrient use efficiency and synergistic effect of nitrogen and potash, there was increase in number of primary branches. Availability and uptake of nutrient and vigorous growth character facilitates a greater number of branches per plant and moreover potassium plays a major role in cell division and elongation and metabolism of carbohydrates and protein compounds (Gouthami *et al.*, 2022). Similar results were observed by Manna *et al*., (2012) with the application of Biozyme (seaweed extract) as foliar fertilizer increased the mean number of branches per plant of chilli. Thus, it is amply clear that the biozyme (seaweed extract) which consisted of precursors of auxin, enzyme, protein and micronutrients was responsible for the improved vegetative growth of chilli. These results are also in accordance with Sridhar and Rengasamy (2012); Vijayakumar *et al.* (2019); Ashour *et al.* (2021) and Azzam *et al.* (2022) in capsicum. Humic acid rises the chlorophyll and leaf N, P, K content and K concentration increased number of branches was also reported by Kazemi, M (2013) on cucumber. Similar findings were also reported by Fathima *et al*., (2013) in chilli, Kumar *et al*., (2015) in Okra.

Table 1: Effect of various biostimulants on plant height (cm), leaf area (cm^2) and no. of branches per plant of capsicum cv. PSM-1 under polyhouse

Treatments	Plant height (cm)			Leaf area (cm^2)			No. of branches per plant		
	2022-23	2023-24	Pooled mean	2022-23	2023-24	Pooled mean	2022-23	2023-24	Pooled mean
T_1	89.74	90.48	90.11	288.62	291.84	290.23	9.50	10.25	9.88
T_2	86.72	87.68	87.20	283.46	286.74	285.10	9.25	10.00	9.63
T_3	101.55	104.89	103.22	368.85	372.41	370.63	11.00	12.25	11.63
T_4	93.40	97.92	95.66	311.49	317.93	314.71	10.25	11.00	10.63
T_5	93.89	97.33	95.61	319.18	321.46	320.32	10.75	11.25	11.00
T_6	88.12	91.44	89.78	291.88	295.16	293.52	9.75	10.50	10.13
T_7	98.96	100.48	99.72	337.46	343.12	340.29	10.50	11.75	11.13
T_8	92.12	93.90	93.01	300.24	303.54	301.89	9.75	10.75	10.25
T_9	95.05	99.01	97.03	326.97	330.67	328.82	10.50	11.50	11.00
T_{10}	90.30	92.96	91.63	296.11	299.43	297.77	9.25	10.75	10.00

T_{11}	99.83	103.37	101.60	350.26	355.94	353.10	11.00	12.00	11.50
T_{12}	94.54	96.10	95.32	307.79	312.67	310.23	10.00	10.75	10.38
C.D.	2.46	2.76	1.70	9.26	9.61	7.79	0.31	0.34	0.20

IV. CONCLUSION

The study highlighted the positive effect of biostimulants on growth and parameters of capsicum. Plant treated with Seaweed extract recorded highest plant height (103.22 cm), leaf area (370.63 cm²) and no. of branches per plant (11.63).

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The Vegetable Garden for All: Twenty Years of Horticultural Therapy Experiences at the "Animal Farm" in Ladispoli (Rome, Italy)

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Abstract**—** *Contact with nature has always been recognized as having a positive and relaxing effect on people; horticultural therapy is one of the latest forms of unconventional therapy, which uses plants to improve physical and mental condition. Horticultural therapy activities, after a long experimental phase dating back to the 1960s, are now a consolidated practice in the USA, Canada and Europe. In Italy, social farming has developed in a more organic way since the early 2000'S: there are no pre-established models and the various social agriculture projects, in recent years, have aimed to develop good practices starting from personal experience in the field rather than from codified models. The Animal Farm, social farm in Ladispoli (Rome, Italy), has developed a functional model based on twenty years of experience in the period 2003 – 2024, which is reported in the present work. The mixed experience of informative educational activities and rehabilitation activities allowed farm's visitors to come into contact with the participants in the workshop and this increased people's awareness of the problems of people with disabilities. The workshops are organized in daily activities where the various local institutions bring their users (either individuals or groups) to carry out agricultural activities and practical workshops. The path followed is aimed at people with medium and severe mental disabilities. The workshop is structured in two levels of activity: routine works and creative work. The experiments implemented within the horticultural therapy paths in the Animal Farm of Ladispoli (Rome, Italy) confirm the key role of agricultural activities in rehabilitation programs for disabled people and in the present work the positive effects observed in the workshops are reported.*

Keywords— ***Horticultural therapy, good practice model, multifunctional agriculture, rehabilitative workshop, social farm.***

I. INTRODUCTION

The positive influence of nature on human health and life has long been known, and contact with nature has always been recognised as having a positive and relaxing effect on people (Ulrich 1979, 1984; Zawiślak, 2015).

Horticultural therapy (garden therapy, horticultural medicine, from the Latin *hortus* that means vegetable garden) is one of the latest forms of unconventional therapy, which uses plants to improve a person's physical and mental condition. Horticultural therapy can be passive, when it involves walking, standing in the garden among plants, looking at them, smelling them, touching them; therapy can also take an active form, which involves the active participation of man in gardening work (preparing the soil, sowing seeds, transplanting seedlings, planting plants and bulbs, weeding, watering, picking fruit, vegetables and flowers) (Zawiślak, 2015; Haller & Capra, 2016).

Generally, scientists have shown that spending time in nature, for everyone and not only for vulnerable or disabled people, dedicating oneself to gardening and picking vegetables and fruit stimulates the brain to release dopamine, the so-called happiness hormone, a substance that is responsible, among other things, for well-being and concentration; furthermore, children in the developmental growth phase are the main ones to enjoy the benefits of outdoors activities (OLIVERIO FERRARIS & OLIVERIO).

Horticultural therapy activities, after a long experimental phase dating back to the 60's are now a consolidated practice in the USA, Canada and Europe (BURLINGAME & WATSON, 1960). In the European model, called "green care" or "farming for health", it is foreseen, in addition to the places typically linked to therapies such as hospitals (CZAŁCZYŃSKA – PODOLSKA & RZESZOTARSKA – PAŁKA, 2016), the development of a dedicated agriculture in farms, with the involvement of the two worlds of farmers and doctors and health workers; a combination that, on the one hand, provides a healthy and optimal environment for disadvantaged people, on the other hand, offers economic support for small farms, often in economic difficulty (HASSINK & VAN DIJK, 2006; GÓRSKA-KŁĘK *ET AL.*, 2013). Agriculture has therefore taken on, in recent decades, an increasingly evident "social function", meaning that all activities related to agriculture have an impact on society by contributing to the cultural and civil growth of its members (MUGANO *ET AL.*, 2010). The European Union encourages the growth of multi-functionality activities in agriculture, which includes all activities that increase the social role of the agricultural sector (DI IACOVO & O'CONNOR, 2009).

Educational farms are realities in the multi-functionality evolution of farm in Italy, developed especially in the last two decades; these are farms where people can visit and learn about domestic animals and breeding cycles, getting in touch with the rural world now so far removed from the daily activities of most of the population, accustomed to urban contexts. (SOFO & NATILE, 2013)

In addition to the Educational farm in recent years, taking the experiences already developed in the US and in the Nordic countries of Europe, begin to appear on the Italian scene the social farms, farms where one of the main activities, if not all, is conducting therapeutic rehabilitation activities aimed at people with disabilities; often disabled people are included in the production process. (HASSINK & VAN DIJK, 2006; VAN ELSEN *ET AL.*, 2014). A social farm is characterized by both a productive and a social component; in the latter case, horticultural practices can find a wide application in the activities of the so-called "wellness farms" for the rehabilitation of people with addictions (alcohol, drugs, etc.) or for the support and care of the elderly or physically or mentally disabled people. In this typology of farm, work management and training can be influenced by the use of chemical substances, which can limit the activity of the people involved. In this case, the possibility of using organic farming techniques avoid the use and contact with toxic substances and would guarantee an improvement in the human/plant interaction and a simplified management of agronomic practices compared to conventional methods (DAVIS, 1995, MUGANO *ET AL.*, 2010; PIZZUTI PICCOLI & KACZMARCZYK, 2016).

In Italy, social farming has developed in a more organic way since the early 2000'S; only in 2015 a national law on social agriculture was approved, now in the implementation phase. There are no pre-established models and the various social agriculture projects, in recent years, have tried to develop good practices starting from personal experience in the field rather than from codified models (FINUOLA & PASCALE, 2008; ARSIAL, 2011).

At "Animal Farm", a social farm in Ladispoli (Rome, Italy), a functional model has been developed and consists of the simultaneous activities of educational and social farm; an integral part of the model is the performance of horticultural therapy activities, which are discussed in this work.

II. MATERIAL AND METHODS

The "Animal Farm" is an experimental farm, developed on an area of 2 ha, where animals belonging to breeds in danger of extinction are raised and where plant species are grown according to natural methods without the use of chemical substances used in traditional agriculture. The activities of the farm, in addition to breeding, are developed in two main activities: environmental education activities for schools (about 4000 students and visitors per year) and workshops aimed at disabled and disadvantaged people (PIZZUTI PICCOLI & KACZMARCZYK, 2016).

The farm, since 2003, brings to to developing a good practice model in horticultural therapy, proposed in this work, which can be exported and implemented in other situations; the farm staff consists of agronomists, psychotherapists, ethologists, farmers who work together as a team in the implementation of educational and rehabilitation activities. All the structures present at the farm have been created by disabled individuals who have participated in the various workshops over the years. The workshops are organized in daily activities where the various institutions of the territory (rehabilitation centers for disables, hospitals, etc.) bring their users (individual assets or groups) to carry out horticultural activities and practical workshops. The designed path type is aimed at people with medium and severe mental disabilities.

Activities are conducted, at the beginning, always with the presence, as well as of the operators of farm, by operators of rehabilitation services who daily work with the involved disabled people. This is a facilitation providing security in an initially unfamiliar environment for the participants. Over time the role of the farm operator becomes increasingly prominent as participants gain familiarity for the spaces of the farm.

The proposed workshops aim at recovery of psycho-physical well-being of those who participate, o promote a sense of responsibility, autonomy, and socialization opportunities. During practical workshops, participants can decide on the time and space needed to perform the required tasks (for instance to check if weeding is needed, if irrigation is necessary, etc.), developing a sense of autonomy and the ability to make decisions. The attempt is to stimulate users to make proposals regarding the execution of work, in particular those relating to the creation of structures for the farm (arks for sowing seeds on the ground, raised structures for wheelchair people, etc.). Decisions are not imposed from above, but they are involved in the choice of materials, the order in which the work is to be carried out, and operational strategies. Initially, participants will be supervised and guided in practical activities by the operators, and gradually they will be encouraged to carry out phases of vegetable garden and olive tree grove management independently. The importance is undoubtedly, in the rehabilitation phase, of operational autonomy and awareness of own abilities, which the users can then express in new and different work environments.

The workshop is structured according to two levels of activity: routine work and creative work.

Routine work.

The first type includes work on the care and management of the vegetable garden, the olive tree grove and the widespread orchard (the orchard consists of around 40 fruit trees arranged in rows or small groups throughout the farm). The routine work is used to put the participants in confidence with the farm's places and facilities, giving them a sense of security and encouraging their independence. The activities proposed in the routine phase are structured so that they can be carried out in the daily time of permanence of the person in the farm; routine jobs, such as weeding flowerbeds or watering plants in the vegetable garden, must be structured to be able to finish within the time of two or maximum three hours and give the perception of the finished work. This promotes a sense of gratification for a job started and completed in the defined time frame.

Creative work

The second phase involves participants in the construction of facilities for the farm (greenhouse, benches, scarecrows, etc.), first conceived and designed, then built together; the activities will end in several days of work, on each day, participants work on building and completing a single part of the structure. This level gives the idea of something finite, realized in all its phases of construction by the participants, participants who work will have contributed to improving the capabilities of the farm; this gives a sense of belonging and increases self-esteem. Even the creative work, which necessarily takes longer, usually set at two to three months, is organized in daily or weekly phases that give a sense of the contribution made to its realization.

The working day is structured into three phases:

- Preparation of participants and initial meeting with the definition of assets and assignment of duties and organization of the times;
- working activities, interrupted by a break for a snack;
- final meeting of the day with feedback comments.

As part of the daily workshops they are inserted obstacle factors that contribute to maintaining the functions of the person involved and to increase motor and psychic abilities. Of course all the activities proposed are carried out safely and in accordance with hygienic standards corresponding to the parameters of the law currently in force.

Great care has been taken in the choice of species to be cultivated. For seasonal production, preference has been given to short-cycle species, propagated by seed or agamic reproduction, such as tomatoes, beans, eggplants and various aromatic species; for the tree component, in addition to the olive tree grove, rare and little-used fruit plants have been chosen (including European medlar *Mespilus germanica* L., jujube *Ziziphus jujuba* Mill., sorb *Sorbus domestica* L.) in order to promote the conservation of these ancient species and cultivars (GUIDI, 2017).

Regarding work organization, cultivation tasks were identified both for individual responsibility (irrigation, plant protection) and for group work (sowing, transplanting and harvesting). Spring and summer operations were carried out in shaded nurseries and in the open field, while winter operations were carried out in the farm's greenhouse. Agricultural management of cultivation was carried out with the aid of materials and technical means used professionally and in compliance with the organic production method.

Fig.1. Ground benches used in horticultural therapy programs.

Fig.2. Raised benches that allow work to disabled people in wheelchairs.

Compost and manure from farm animals were used to fertilize the soil and nourish plants, eliminating the use of synthetic mineral fertilizers. Furthermore, as regards phytosanitary strategies, natural methods were employed to control various pests. As regards the specific structures, useful for the implementation of horticultural therapy programs, ground benches have proven to be very useful (Fig.1), these structures delimit a finished space in the vegetable garden and allow the participants to have the perception in time and space of the work that must be carried out and finished, with an increase in the personal gratification. During creative work, people with difficulties were guided in producing functional structures to improve the enjoyment of the workshops for other disabled people; an example is the raised benches that enable work for individuals in wheelchairs (Fig. 2); this aspect has proven extremely important in boosting participants' self-esteem in the workshops. An attempt was also made to stimulate imagination and creativity through the creation of some structures to complete the garden (an example is the scarecrow, with which participants can give vent to their imagination).

III. RESULTS

Horticultural therapy workshops have been running at the farm since 2003 and are still ongoing, allowing approximately 1873 people to participate over the years, with an average of 89 people per year (Table 1); in 2020 the COVID – 19 pandemic slowed down activities from March to May of the same year but the workshops were carried out nonetheless. The mixed experience of informative educational activities and rehabilitation activities allowed the farm's visitors (approximately 70.000 estimated in the period 2003 – 2024) to come into contact with the participants in the workshop and this increased public awareness of the challenges faced by disabled individuals. The same type of workshops was carried out by the farm staff, from 2007 to 2019 at "Parco degli Angeli" in Cerveteri (Rome, Italy), and from 2020 to 2024 at the "Giardino di Annalisa" in Ladispoli (Rome, Italy).

Table 1: Participants in horticultural therapy workshops in the period 2003 – 2023.

Year	***Number of disabled participants***	***Disability category***
2003	55	Autism spectrum disorders, moderate and severe mental illness, Down's syndrome, motor deficits, sensory deficits.
2004	70	
2005	35	
2006	45	
2007	52	
2008	65	
2009	78	
2010	65	
2011	93	
2012	101	
2013	123	
2014	112	
2015	121	
2016	118	
2017	89	
2018	95	
2019	110	
2020	102	
2021	108	
2022	115	
2023	120	

IV. DISCUSSION AND CONCLUSIONS

The experiences of horticultural therapy carried out at the Animal Farm confirm the importance of the natural environment and of agricultural work in the open air as a fundamental part of the rehabilitation activities for disabled people. These benefits for humans have been documented in all the social farms that are today present in Europe and in the American continent (Hassink & Van Dijk, 2006).

It is essential to emphasize that horticultural therapy should be conducted by a multidisciplinary team of professionals and therapists, in a working context suitably adapted to the needs of each individual user (Nowak, 2012).

According to other authors, application in work is a fundamental moment in a therapeutic-rehabilitative program whose aim is to allowing for tasks suitable for each participant to be found maximum level of psychological, social, physical and economic independence (Hassink & Van Dijk, 2006; Górska-Kłęk *et al.*, 2013; Zawiślak, 2015; Haller & Capra, 2016).

The planning of the workshops has always been based on the choice of agricultural work suitable for everyone and easy to perform: of fundamental importance is the organization of the work in modules, to allow the activities to be divided into small actions with different levels of difficulty and involvement, allowing to find a work suitable for each participant. Agricultural work is often repetitive and therefore easier to follow and remember; the simple execution of some actions (watering, harvesting the products, sowing in pots) therefore allows people with limited physical or mental abilities to be involved.

Over the years we have seen an increase in the overall well-being of participants. The condition of disability implies that others take care of disabled persons; in farming activities, this condition is reversed: it is people with disabilities or other forms of disadvantage who take care of other organisms. There is a sort of positive feedback that helps to strengthen the sense of individual responsibility and consolidates self-esteem. Any agricultural activity carried out in the care of a vegetable garden or an orchard requires decision-making effort; for example, in the case of watering plants, decisions are required, such as deciding the right amount of water for each plant. The agricultural activity, therefore, stimulates judging and calculation skills and, by offering moments of participatory planning, encourages the person to make proposals on the work to be done.

Not secondary is the fact that working in a farm, to manage and treat plants and structures, allows participants to stay outdoors, with very wide possibilities of movement, favoring the physical activity and decreasing the sense of constriction given by the closed spaces. To carry out activities related to plants management multiple motor functions are necessary: they are, in fact, required unilateral movements, bilateral movements (involving both arms or both legs), bimanual movements (one hand performs the action and the other helps), bending, stretching, rhythmic or/and automatic movements, the coordination of movements and global purposes, the hand-eye coordination, muscular strength and endurance, the learning of the strength dosage, the ability to maintain an upright position for a certain period of time.

The activities that are carried out on the farm also allow all the human senses to be stimulated: sight, touch, hearing, smell and taste are stimulated in the various phases of the cultivation processes. These are sensorial stimuli that can be particularly useful in the rehabilitation of people affected by pathologies that generate a high degree of isolation from the outside world. Contact with the earth, observing the shapes and colors of plants, transmit relaxing sensations and stimulate perceptive abilities activated by taking care of plants. The times during which agricultural processes develop represent another important aspect in rehabilitation activities. The various agricultural phases (sowing, flowering, harvesting) require us to understand and organize time: obtaining products requires processes that develop over a period of time, which is never short. The rhythms of agricultural work, which are never pressing and such as to generate stressful situations, help individuals who have difficulty dealing with reality to rebuild a relationship with time, observing and participating in the continuous transformations of biological organisms.

The activities, even the simplest ones, developed in the workshops, are generally conducted in groups of two or more people. Contact allows the establishment of closer interactions, promoting communication and socialization. Furthermore, the possibility of interacting with visitors to the farm helps reduce social isolation, which often affects people with mental, psychological, or behavioral deficits.

Finally, the product of work provides a decisive reward: the plants 'react' to the care of man and 'reward' him by producing new leaves, flowers and fruits. A positive feedback occurs and this contributes to strengthening the individual's sense of responsibility and to consolidating his self-esteem. Even obtaining a product that is 'useful' for the community (or sometimes just for the family), as in the case of vegetables or flowers, contributes contributes to the individual's self-esteem as a participant in the local community, contributing to its well-being.

In conclusion, the results obtained in twenty years of activity represent a standardized experience of horticultural therapy that has led to the development of a repeatable format. The format can represent a reference for many farms that can carry out experiences of social agriculture and, more generally, can serve as a repeatable model with significant social impact, encouraging the participation of disadvantaged individuals in work and rehabilitation programs.

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Production economics and marketing of finger millet in Mugu district

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Abstract— *Mugu district in Nepal, despite facing geographical constraints, hold immense potential for finger millet production, which can improve the living standard of its residents. A study conducted in Mugu district evaluated economics of production and marketing which includes cost return analysis, marketing dynamics, constraints and recommendations associated with finger millet cultivation. Drawing from the sample of 120 farmers from Khatyad Rural Municipality and Chayanath Rara Municipality, where finger millet is extensively grown. Household survey was carried out to collect primary information from growers conducting interviews supplemented by secondary data from various sources. The cost-return analysis underscores the profitability of finger millet cultivation, with a per-hectare cost estimated at NPR 43,127.71, gross returns reaching NPR 50,790, resulting in net returns of NPR 7,662.29 with NPR 28.80 of cost per kg of production. The productivity was 1497 Kg/Ha and benefit cost ratio of 1.18. Factors such as labor cost and cost of fertilizer were statistically significant coefficients suggesting change in labor cost and cost of fertilizer influence annual finger millet income. Direct marketing of finger millet from producers to consumers was most frequent, for which the producer receives NPR 0.98 out of NPR 1.00 paid by consumer. Attack of pests such as rats and blast disease followed by lack of infrastructures and market intelligence were the major production problems. Growers highly suggests to have technical support for producing beverages along with availability of modern production technology.*

Keywords— ***Finger millet, linear regression, Benefit-Cost ratio, Marketing channel, Garett ranking***

I. INTRODUCTION

The Poaceae family's finger millet (Eleusine coracana (L.) Gaertn.), commonly referred to as Kodo in Nepal, is a significant crop used for food, fodder, and industrial goods. The Nepalese mid-hills have a high diversity of finger millet (Kandel et al., 2019). In terms of acreage and productivity, finger millet, ranks fourth among the major crops grown in Nepal, behind rice, maize, and wheat. According to Ghimire et al. (2017), the main districts in Nepal that produce this crop are Khotang, Sindhupalchok, Baglung, Syangja, Kaski, Gorkha, and Sindhuli. Finger millet (*Eleusine coracana* (L.) Gaertn.) is one of the important crops of Nepal with area of production of 265,401 hectares. In the fiscal year 2020/2021, 326,443 tons of finger millet were produced with a productivity of 1.23 Mt/Ha. Of this, 207,52 tons were produced in Karnali province with a production of 1.09 Mt/Ha, and 4196 tons were produced in Mugu district alone with a productivity of 0.98 Mt/Ha (MoALD, 2022). In Nepal's hills and mountains, millet plays a significant role in providing smallholder farmers and marginalized populations with food and nutrition security. In terms of acreage and productivity, finger millet is the most important crop in the districts of Humla and Mugu, although it ranks second in

Jumla, Khotang, and Sindhupalchok. The largest area and production of finger millet in Nepal is found in the Baglung district of Gandaki Province (Gairhe et al., 2021).

Finger millet is usually converted into flour and made into Roti (cakes), Dhindo (puddings) and Khole (thin porridge). It is also popular for making fermented beverages among certain communities of the country which is needed for their religious and cultural rituals. The straw of finger millet is an important animal fodder particularly, during the feed deficit months and helps to sustain animal management, improved compost application, soil fertility and yield (Adhikari, 2012). Health benefit of millet includes, helps to protect against heart diseases, and lowers bad cholesterol levels, beneficial in detoxifying the body, prevents type II diabetes, prevents onset of breast cancer, beneficial in lowering blood pressure and enhancing the function of the kidneys, liver, and immune system (Devika, 2017). As members of the Poaceae family, millets are considered to be ancient staple foods that originated in the tropical regions of Asia and Africa. With a 41 percent global share, India is the world's top producer of millet, with Africa coming in second. Millets are sometimes called "super foods," and growing them is a way to practice sustainable agriculture (Rawat, 2022). The economics of production and profitability of finger millet cultivation in Mugu district remains largely unexplored. There is insufficient information and analysis regarding the economic aspects of Finger millet. Due to lack of informed strategies and interventions aimed at improving farmer livelihoods it is difficult in promoting sustainable agricultural practices, enhancing market integration and overall economic development in the region. In recent times, because of nutritive value of finger millet hype is increased and different nations have implemented policies to promote the cultivation of finger millet. Exploring the present socio-economic situation and analyzing the profitability of finger millet in Nepal is highly required. By examining the economics of finger millet cultivation, this research aims to provide valuable insights into the viability and profitability at the farm level and exploration of market dynamics at the market level. Finger millet holds a pivot role as a staple crop in Mugu district, contributing significantly to local food security and survival. Understanding its economic aspects is essential for enhancing agricultural productivity, improving rural livelihoods and ensuring sustainable food production. The study aims at pinpointing the production and marketing aspects such as cost of inputs, cost of production, returns, marketing practices, problems of production and marketing, etc. Therefore, the objective of this study is to access the economic prospects of finger millet production and marketing in Mugu district in Nepal.

II. METHODOLOGY

Mugu district was purposively selected for this study based on coverage area of Finger millet production, marketing value and demand of consumers. The study was conducted in Khatyad Rural Municipality and Chayanath Rara Municipality based on the farmers and traders involved in Finger millet production and marketing. A total of 120 farmers and traders were selected as samples for enumeration. Simple random sampling method was used in choosing the sample. Consequently, 60 households from both Khatyad Rural Municipality and Chayanath Rara Municipality were selected.

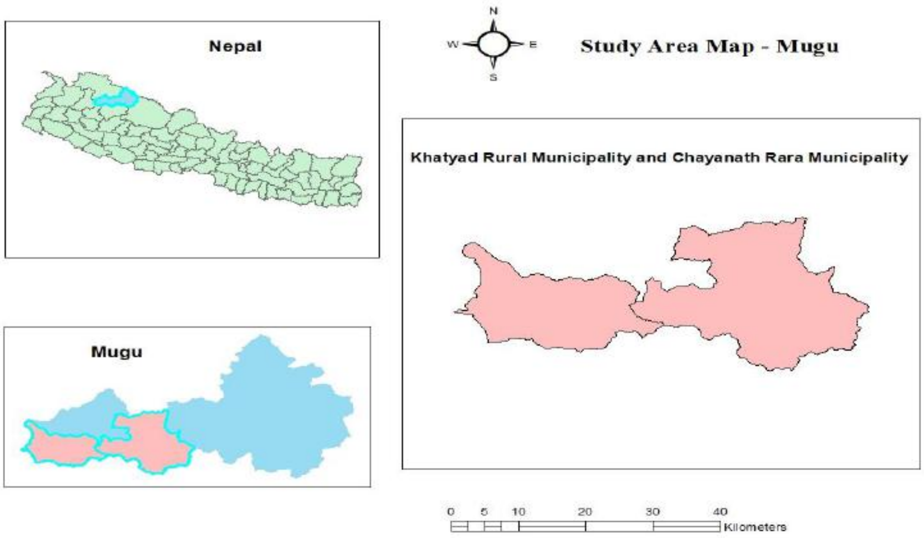

Fig.1. Map depicting the location of the study area

Primary information was collected by using pre-tested interview schedule by applying face–to–face interview method. The collected information was first tabulated, coded and entered into the computer. Data analyses were done by using the computer software packages like Microsoft Excel and Statistical Package for Social Science (SPSS).

2.1. Operational cost: Operational costs in agriculture include the value of hired and family labor, animal and machine labor (both hired and owned), seeds, manures, fertilizers, depreciation, irrigation charges, land revenue, interest on working capital, and miscellaneous expenses.

2.2. Cost of production: The cost of production is calculated by using following formula:

$$\text{Average cost of production} = \frac{\text{Cost of cultivation}}{\text{Total production}}$$

2.3. Income measures:

Following income measures were used.

2.4. Gross income: It is the total value of main product.

GI = {Qm × Pm}

Where;

GI = Gross Income

Qm = Quantity of main product

Pm = Price of main product

2.5. Farm business income (FBI):

FBI = Gross income – Cost A

Where:

Cost A = Operational cost – value of owned labor

2.6. Family labor income (FLI) and management:

FLI = Gross income – Cost B

Where:

Cost B = Cost A + interest on FC + depreciation

2.7. Net income (NI):

NI = Gross income – Cost of cultivation

2.8. Returns per rupee (RPR):

RPR=Gross Income/Cost of cultivation

2.9. Return on investment (ROI)

Return on investment is a technique to evaluate the profitability or efficiency of an investment relative to its cost. The ROI formula calculates the ratio of the net return or gain from an investment to the initial cost of investments.

$$\text{ROI} = \left(\frac{\text{Net return}}{\text{Initial cost}}\right) \times 100\%$$

2.10. Return on labor

Return on labor is a measure of the efficiency and effectiveness of labor input in generating output or income. It evaluates the return or value generated per unit of labor cost.

$$\text{Return on labor (ROL)} = \left(\frac{\text{Net profit+value of family labor}}{\text{Total income}}\right) \times 100\%$$

2.11. Net Profit

It is the net earnings after subtracting all the expenses not included in the calculation of gross margin. It was calculated by deducting fixed cost and marketing cost from gross margin as shown in equation:

Net profit = gross margin –marketing cost- total fixed cost

2.12. B: C ratio

It is the benefit of the farm business relative to inputs cost, expressed both in monetary value. The benefit-cost ratio is calculated by taking the ratio of total revenue and total cost. It is calculated by using the following formula:

$$\text{B/C ratio} = \frac{\text{Gross return}}{\text{Total cost}}$$

If the B/C ratio is greater than 1, the farm business is profitable.

If the B/C ratio is less than 1, the farm business is unprofitable.

If the B/C ratio is equals to 1, the farm business can neither be considered profitable nor unprofitable.

2.13. Gross margin analysis

The gross margin provides simple and quick method for analyzing farm business which is the difference between the gross return and the total variable cost incurred that is:

Gross margin = Gross return - total variable cost

Where, Gross return = $\sum Gross\ return$ = return from main product + return from by products

Total variable cost = $\sum$ cost of all variable inputs used for the production.

2.14. Linear regression

Linear regression is a statistical method used to model the relationship between a dependent variable (often denoted as Y) and one or more independent variables (often denoted as X). Linear regression was used to estimate the factors of share to total income. The equation for the model is represented by:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon$$

Where:

Y is Annual finger millet income

X_1, X_2, X_3, X_4 are the independent variables, cost of labor, cost of seeds, cost of ploughing, cost of fertilizers

β_0 is the intercept, representing the income when all costs are zero.

$\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients, representing the change in income for a one unit change in each respective cost variable, holding other variable constant.

ϵ is the error term, representing the difference between the observed and predicted income values.

2.15. Marketing Channel

The path or route followed by the commodity which connects the producer with the final consumer is known as marketing channel. Marketing channel consists of various market middleman who perform the various marketing activities in sequence as the produce moves from the producers to ultimate consumers.

2.16. Price spread

Price spread is calculated by the difference between net price paid by the consumer and price received by the producer for an equivalent quantity of farm product.

$$P_s = C_f - P_f$$

Where:

C_f = Consumers price

P_f = Price received by farmer

2.17. Producers share

$$P_s = \left(\frac{\text{Price received by producer}}{\text{Price paid by consumer}}\right) \times 100\%$$

2.18. Marketing margin

The marketing margin at any stages of marketing has been calculated as follows:

$$MM_i = SP_i - (PP_i + MC_i)$$

Where:

MM_i = Marketing margin of the i-th middleman

SP_i = Selling price of the i-th middleman

PP_i = Purchasing price of the i-th middleman

MC_i = Marketing cost incurred by the i-th middleman

2.19. Garrett's ranking technique

Garrett's ranking technique was used to rank the constraints and recommendation indicated by the respondents on different factors. As per this method, respondents have been asked to assign the rank for all factors and the outcomes of such ranking have been converted into score value. This technique was used for analyzing constraints in production and marketing of finger millet, and recommendation for speeding up the growth of finger millet production and these ranks were converted to scores by referring to Garrett's table.

$$\text{Percent position} = \frac{100*(Rij-0.50)}{N}$$

Where:

Rij = Rank given for ith item by a jth individual

Nj = Number of items ranked by jth individual

The per cent position of each rank was converted to scores by referring to tables given by Henry Garrett. Then for each factor, the scores of individual respondents were added together and divided by the total number of respondents for whom the scores were added. These mean scores for all the factors were arranged in the order of their ranks and inferences were drawn.

III. RESULTS AND DISCUSSIONS

3.1. Socio - demographic characteristics of respondents

The study revealed that the sample of 120 farmers had an equal gender distribution, with 50% female and 50% male farmers. The age distribution showed that 62.5% of farmers were within the age group of 36-55, representing the middle-aged demographic, while a significant proportion were aged 56 and above, indicating the presence of experienced farmers. Regarding family size, 69.1% of households had up to 5 members, 23.4% were medium-sized families with 6-9 members, and a smaller proportion had larger households with 10 or more members. Educational status revealed that 43.4% of respondents were illiterate, 13.3% were literate, 21.6% had completed primary education, 12.5% had attained secondary education, 8.4% had higher secondary education, and only 0.8% had a university education. Agriculture emerged as the primary occupation for 72.5% of respondents, while a smaller proportion engaged in dual occupations combining agriculture with business, government jobs, private jobs, or social employment. In terms of household income, 90.8% of farmers earned an annual income above NPR 200,000, while 9.2% earned between NPR 100,000 and NPR 200,000. Regarding finger millet production, 78.3% of farmers produced over 200 kg annually, 20.8% produced between 50 and 200 kg, and only 0.8% produced less than 50 kg.

Table 1. Socio - demographic characteristics of respondents

Demographics	Number of respondents (N=120)	Percentage
Gender		
Male	60	50
Female	60	50
Age group		
Below 25	3	2.5
26 – 35	25	20.8
36 – 55	75	62.5
56 and above	17	14.2
Family type (no. of members)		
Small size (up to 5)	83	69.1
Medium size (6 - 9)	28	23.4
large size (above 10)	9	7.5
Education		
Illiterate	52	43.4
Primary education	26	21.6
Secondary education	15	12.5
Higher secondary education	10	8.4
University	1	0.8
Literate	16	13.3
Occupation		
Agriculture as main occupation	87	72.5
Agriculture as subsidiary occupation	33	27.5
Household income		
Less than NPR 200000	11	9.2
More than NPR 200000	109	90.8
Annual finger millet production (Kg)		
Less than 50	1	0.8
50 – 200	25	20.8
More than 200	94	78.3

Table 2. Reasons for selecting finger millet production among respondents

Reason for finger millet farming	**Frequency**	**Percent**
Highly nutritive plant	120	100
Drought tolerance	14	11.7
Easy cultivation,	1	.8
Other	2	1.7

The table 2 shows that 100% of farmers in Mugu district cultivate finger millet primarily because of its highly nutritive value. Drought tolerance was mentioned by 11.7% of respondents, while only a small percentage cited easy cultivation and other reasons. This indicates that nutrition is the main driver for finger millet farming in the region

3.2. Marketing channel preferences

The finger millet sample farmers' preferences for marketing channels, accounting for 92.5% of respondents, prefer "Direct selling," indicating a preference for selling their produce directly to consumers or end-users. Only a small proportion, 6.7%, opt for selling through "Retailers and wholesalers," suggesting limited reliance on intermediaries in the marketing process. Additionally, a negligible percentage (0.8%) chooses "Middlemen and local traders" as their preferred marketing channel. These findings emphasize farmers' inclination towards direct engagement with consumers.

Table 3. Preferences for marketing channels among respondents

Preferences for marketing channel	**Frequency**	**Percent**
Direct selling	111	92.5
Middlemen and local traders	1	.8
Retailers and wholesalers	8	6.7
Total	**120**	**100.0**

Key aspects of finger millet farming

Table 4. Production and distribution of finger millet among respondents

Particular	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Area for finger millet farming (Gada)	120	2	12	6.69	1.931
Household consumption (Kg)	120	50	700	195.96	72.649
Selling amount (Kg)	120	0	300	90.83	53.837

The descriptive statistics highlight key aspects of finger millet farming respondents in Mugu District. Farmers allocate an average area of approximately 6.69 Gada for cultivation, each gada representing at least 300m^2 in area with variations ranging from 2 to 12 Gada. Household consumption of finger millet varies widely, with households consuming an average of 195.96 Kg annually, ranging from 50 to 700 Kg. Similarly, the amount of finger millet sold by farmers varies, with an average of 90.83 Kg sold, ranging from 0 to 300 Kg.

3.3. Cost structure in finger millet production

The total cost of cultivation per hectare was found to be NPR 43127.71. The breakup of total cost into operational and fixed costs indicated that the operational costs were NPR 38232.71 (88.65%) and fixed costs were NPR 4895.00 (11.35%).

Table 5. Cost (NPR /Ha) of finger millet production in the study area

S. N	Particulars	Value (NPR)	%Total cost
1	Operational costs		
a.	Human labor	12,951.43	30.03
	Owned	7,770.6	18.01
	Hired	5,180.83	12.01
b.	Seeds	747.20	1.73
c.	Ploughing	9,921.13	23.00
d.	Farm Yard Manure	11,311.75	26.23
e.	Miscellaneous Cost	800.00	1.85

f.	Total working capital (Σ a to e)	35,731.51	82.85
g.	Interest on working capital @7%	2,501.21	5.80
	Total operational costs (Cost A)	38,232.71	88.65
2	Fixed costs		
a.	Land revenue	-	-
b.	Rental value of owned land	4,000.00	9.27
C	Interest on fixed capital @10%	445.00	1.03
d.	Depreciation	450.00	1.04
	Total fixed costs	4,895.00	11.35
	Total costs	**43,127.71**	**100.00**

The majority of the operational cost are attributed to human labor, ploughing, farm yard manure, seeds, miscellaneous cost and interest on working capital constituting 88.65% of the total costs. Fixed cost that contains rental value of owned land, interest on fixed capital and depreciation contribute 11.35% to the total cost.

3.4. Cost breakdown of agricultural activities in finger millet cultivation

The pie chart illustrates that human labor is required to perform various cultural practices viz., land preparation, transplantation, application of manures and fertilizers, weeding, irrigation and harvesting. Of the total costs, human labor was the highest item of cost in the cultivation of finger millet. The expenditure incurred towards human labor was NPR 12951.43 per hectare accounting for 30.03 per cent of the total costs. The expenditure towards ploughing was NPR 9921.13 (23.00%). Seedlings of finger millet were transplanted. The seed cost was NPR 747.20 accounting for 1.73 per cent of total cost.

Plant nutrient management is an important factor for getting good crop yields. The balanced supply of plant nutrients would also help to maintain disease free conditions to a larger extent. The farmers had spent NPR 11311.75 on organic fertilizers such as farm yard manure for 26.23 percent of the total cost and inorganic fertilizers were not incorporated as Karnali province being organic province. Among the fixed costs, rental value of owned land was the major item, it was NPR 4000 per hectare.

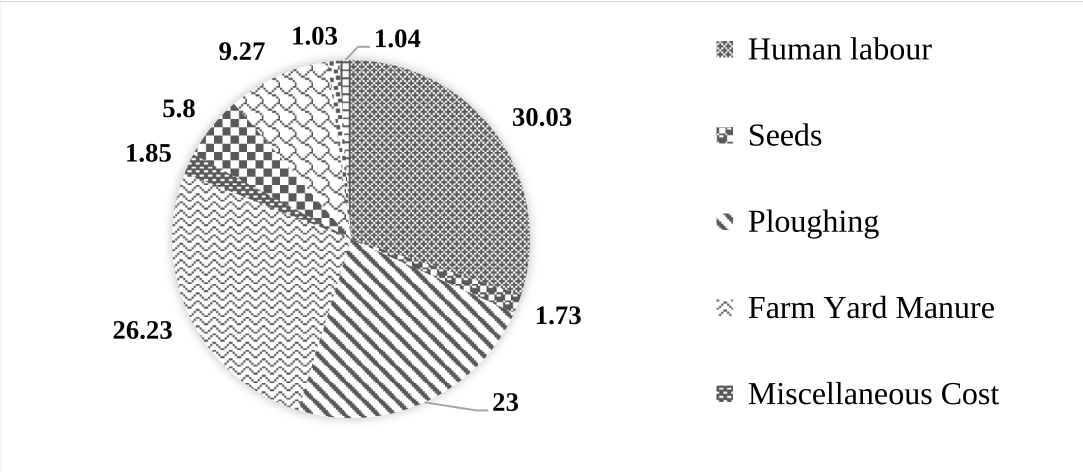

Figure 2. Percentage distribution of expenditure on finger millet production

3.5. Yield and revenue of finger millet production

The details of physical output and returns per hectare from the production of finger millet are presented in Table 10. On an average, the yield of main product was 1.49 Mt, while that of by-product was 1 Mt. To produce value added product wine average amount of 0.48 Mt of finger millet is used, which in return produces 48 liter of beverage The monetary yield for main product having NPR 30/Kg results in return of NPR 44910. 1 Mt by product straw gives return of NPR 1000 and 48 liters of value-added product wine gives return of NPR 4880. The sample farmers, on an average realized a total income of NPR 50790 per hectare. The net returns were estimated at NPR 7662.29 per hectare. The Benefit Cost ratio in the cultivation of finger millet was estimated to be 1.18.

Table 6. Output and return per hectare of finger millet cultivation

S. N	Particulars	Units	Output and returns
1	Yield in physical units		
A	Main product	Mt	1.49
B	By product (Straw)	Mt	1
C	For value added product (wine)	Mt	0.48
2	Yield in monetary terms		
A	Main product	NPR	44910
B	By product (Straw)	NPR	1000
C	Value added product (wine)	NPR	4880
3	Gross return	NPR	50790
4	Cost of cultivation	NPR	43127.71
5	Net returns	NPR	7662.29
6	B:C ratio		1.18

3.6. Income from finger millet production

Various farm efficiency measures such as farm business income, family labor income, net income and farm investment income and returns per rupee of expenditure were worked out.

The gross income realized in the cultivation of finger millet was estimated at NPR 50790 per hectare. Though the gross income is a measure to analyze the efficiency of farm business, but it alone does not help us to judge the success of farm business. Therefore, another measure namely net income which represents surplus over the total costs was estimated. Higher net income reflects the degree of success of farm business. Finger millet farmers in the study area realized a net income of NPR 7662.29 per hectare.

Farm business income is a measure which indicates return for owned resources like land, labor and capital and this amounted to NPR 19877.89 per hectare. Family labor income is another measure of farm efficiency which represents the returns to farmers owned labor and family labor and this amounted to NPR 15432.89 per hectare. Farmers were able to secure a net income of 1.18 per every rupee spent in finger millet cultivation. Return on investment is 17.76% which indicates the investment has yielded a profit of 17.76% relative to initial investment amount. The return on labor is 30.38% which indicates for every unit of labor cost there is a return of approximately 30.38% in profit.

Table 7. Farm income per hectare of finger millet production

S. N	Particulars	Farm income (NPR)
1	Gross income (GI)	50,790.00
2	Farm business income (FBI)	19,877.89
3	Family labor income (FLI)	15,432.89
4	Return on investment (ROI)	17.76%
5	Gross margin	12,557.29
6	Return on labor (ROL)	30.38%
7	Net income (NI)	7,662.29
8	Cost of production per Kg	28.80
9	Average price per Kg	30
10	B: C ratio	1.18

In our study we found that the cost of production per hectare of finger millet NPR 43127.71 was significantly closer compared to previous research by Kaushal and Choudhary, (2020) which was INR 33336.02 and higher than Adhikari, (2012) which was NPR 23847.65 at Kalabang site and NPR 21005.57 at Begans. Our cost of production was slightly higher compared to Tandel, (2017) in the study economic analysis of south Gujrat revealed to be INR 23752.15. The productivity of finger millet according to research of Adhikari, (2012) was 1.15 Mt/Ha in Kalabang and 0.98 Mt/Ha in begnas similarly 1.09 Mt/Ha was in the study of Tandel, (2017) which is quite significant with our result of 1.4 Mt/Ha.

The research (Tandel, 2017) estimated net return of INR 2181.71 and B:C ratio of 1.10 and the study (Adhikari, 2012) estimated B:C ratio of 1.04 at Kalabang and 1.05 at Begnas which aligns with our findings of net return of NPR 7662.29 and B:C ratio of 1.18.

3.7. Factors of annual income from finger millet production

The model summary provides statistical information about the regression model used to analyze the relationship between various predictors (cost of fertilizer, labor cost, cost of seeds, cost of ploughing) and the dependent variable, annual finger millet income (NPR), in the context of research on finger millet production in Mugu district. The R Square value (coefficient of determination) of 0.347 indicates that approximately 34.7% of the variability in annual finger millet income can be explained by the predictors included in the model. The F Change value of 15.292 is associated with a significant p-value of .000 (Sig. F Change), indicating that the overall regression model is statistically significant at the 0.05 level.

Table 8. Model summary for annual finger millet income prediction

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	Sig. F Change
1	.589[a]	.347	.325	.379	.347	15.292	.000
a. Predictors: (Constant), cost of fertilizer, labor cost, cost of seeds, cost of ploughing							
b. Dependent Variable: annual finger millet income (NPR)							

The table 9 presents the coefficients for the predictors (labor cost, cost of seeds, cost of ploughing, cost of fertilizer) in the regression model predicting Annual finger millet income (NPR) in Mugu district. Among the predictors, only "Labor cost" and "Cost of fertilizer" have statistically significant coefficients. "Labor cost" has a coefficient of 0.211 with a significance level of 0.034, and "Cost of fertilizer" has a coefficient of 0.374 with a significance level of 0.000. This suggests that changes in labor cost and cost of fertilizer significantly influence annual finger millet income in Mugu district. However, "Cost of seeds" and "Cost of ploughing" do not show significant effects on annual finger millet income at the 0.05 significance level. Here the regression coefficient is less than 1, it indicates decreasing returns to scale, meaning that increasing the amount of capital invested results in proportionately less output.

Table 9. Model summary for annual finger millet income prediction

Model	Standardized Coefficients		T	Sig.
	Std. Error	Beta		
(Constant)	.142		5.512	.000
Labor cost	.000	.211	2.146	.034
Cost of seeds	.000	.135	1.648	.102
Cost of ploughing	.000	.176	1.780	.078
Cost of fertilizer	.000	.374	4.409	.000
a. Dependent Variable: Annual finger millet income (NPR)				
b. Return to scale (∑ bi): .896				

3.8. Marketing channel of finger millet

The finger millets are non-perishable commodity that can be sold throughout the year. Farmers were found selling-out finger millets mainly through three channels in the study area. The study revealed that majority of finger millet were marketed directly from producers to consumers. Consumers were local buyers of finger millet. Little amount of finger millet was traded through middleman. Most of the finger millet produced in study sites was consumed at the same production site. Direct selling of finger millet from producers to consumers was observed as the strongest marketing channel having 47.80 percent finger millet marketed solely. 10.35 percent of finger millet was marketed through local trader or miller solely. However, medium amount was found to be taken by Neighbor farmer/local traders (millers) and consumer combined. 11.95 percent of finger millet were channeled through consumer, local trader and collector combined.

Table 10. Major channels, based on no. of households engaged and the volume channelized, of finger millet marketing in the study area

Marketing channel	No. of respondents	Frequency	Sold quantity (Kg)	Percent of total sold quantity
Channel I	65 (54.2%)	103	6000	47.80
Channel II	14 (11.6%)	52	1300	10.35
Channel III	3(2.5%)	9	650	5.17
Channel I, Channel II	32 (26.7%)	38	3750	29.88
Channel I, Channel II, Channel III	6 (5%)	120	850	6.77
Grand Total	**120**	**322**	**12550**	**100**

The marketing of finger millet through major channel have been presented based on the data collected from farmers and market functionaries. The channels identified in the study area were:

Channel-I: Producer → Consumer

Channel-II: Producer → Neighbor farmer/Local trader/Miller → Consumer

Channel-III: Producer → Collector → Wholesaler → Retailer → Consumer

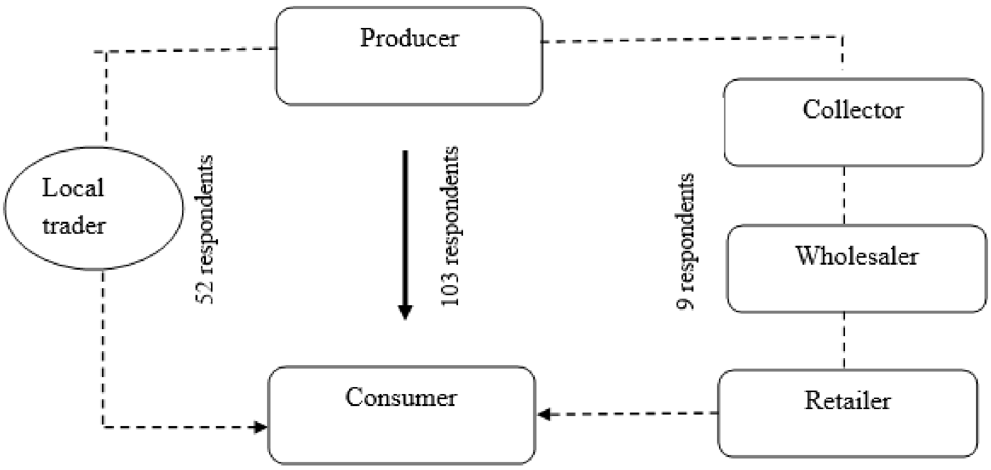

Fig.3. Marketing channel of finger millet in Mugu district

Reddy *et al*. (2015) and Tandel (2017) insights about having 3 important marketing channels of finger millet first being producer to consumer followed by producer to retailer to consumer and producer to local trader or local mandi to retailer to consumer. These findings align with our findings which is more similar to the marketing channel findings of Adhikari (2012) majority of growers channeling produce directly to the consumer and then through local trader or miller to the consumer and by collector to wholesaler to retailer and finally to the consumers.

Marketing costs, marketing margin and price spread of finger millet

The channel of marketing of finger millet from producer to consumer varies from area to area. The average price spread was worked out on per quintal basis. Marketing cost, margin and price spread were calculated for three channels separately.

Marketing cost, margin and price spread of finger millet in channel – I

The producer received the price of NPR 3000 per quintal which is 98.16 percent of consumer's rupee. The cost incurred by producer on transportation, loading, unloading, weighing, and miscellaneous charges etc. was NPR 56 per quintal which is 1.83 percent of consumer's rupee.

Marketing cost, margins and price spread of finger millet in channel – II

The producer received the price of NPR 3000 per quintal which is 91.01 percent of consumer's rupee. The cost incurred by producer on transportation, loading, unloading weighing and miscellaneous charges etc. was NPR 56 per quintal which is 1.69 percent of consumer's rupee. Producer sold the produce to the local trader or miller at NPR 3056 which is 92.71 percent of consumer's rupee. The local trader sold directly to the consumer at NPR 3296 per quintal. The cost incurred by local trader was NPR 40 per quintal which is 1.21 percent of consumer's rupee. Thus, the margin retained by the local trader amounted to NPR 200 per quintal which is 6.06 percent of consumers rupee. The price spread was NPR 296 per quintal.

Marketing cost, margin and price spread of finger millet in channel – III

The producer received the price of NPR 3000 per quintal which is 66.56 percent of consumer's rupee. The major cost incurred by the producers are loading, unloading, weighing a32nd miscellaneous charges accounted to NPR 35.5 per quintal. The price at which the producer sold to the collector is NPR 3035.5 which is 67.34 percent of consumer's rupee. The cost incurred by collector is NPR 38 which accounted for 0.84 percent of consumer's rupee. The collector selling price to wholesaler was NPR 3373.5 with profit margin of NPR 300. The cost incurred by wholesaler was NPR 41 and the wholesaler selling price to retailer was NPR 3914.5 with margin of NPR 500 which is 11.09 percent of consumer's rupee. The cost incurred by retailer was NPR 43. The margin that retailer received is NPR 550 per quintal which is 12.20 percent of consumer's rupee. The price that the ultimate consumer pays is NPR 4507.5 per quintal. The price spread was NPR 1507.5 per quintal.

Table 11. Marketing cost, margin and price spread of finger millet in different marketing channels of study area

(NPR/qtl)

S. N	Particulars	Channel – I	Channel – II	Channel - III
1	Producer's net price	3000 (98.16)	3000 (91.01)	3000 (66.56)
2	Cost incurred by			
A	Producer	56 (1.83)	56 (1.69)	35.5 (0.79)
B	Local trader or miller		40 (1.21)	
C	Collector			38 (0.84)
D	Wholesaler			41 (0.91)
E	Retailer			43 (0.95)
	Total cost	56 (1.83)	96 (2.90)	157.5 (3.49)
3	Margin earned by			
A	Local trader or miller		200 (6.06)	
B	Collector			300 (6.66)
C	Wholesaler			500 (11.09)
D	Retailer			550 (12.20)
	Total margin		200 (6.06)	1350 (29.95)
4	Consumer's price	3056 (100.00)	3296 (100.00)	4507.5 (100.00)
5	Price spread	56	296	1507.5
6	Producer's share	98.16 %	91.01 %	66.56 %

Note: Figures in parentheses indicate percent share in consumer's price

3.9. Analyzing constraints in production and marketing of finger millet and suggestion from growers

Garrett's ranking technique was used to rank the constraints identified in finger millet production and marketing. By using Garrett's formula, the per cent position was obtained. These were converted into scores by relating to Garrett's table. The mean score values were obtained and the constraint having the highest score value was identified as the most important.

Table 12. Percentage positions and their corresponding Garett table values

Rank	% position 100(R-0.5)/120	Garett Value
1	100(R-0.5)/120 =0.42	96
2	100(R-0.5)/120 =1.25	92
3	100(R-0.5)/120 =2.08	88
4	100(R-0.5)/120 =2.91	86
5	100(R-0.5)/120 =3.75	84

Above table 12 includes the rank assigned to each item, the Garett value calculated for each rank, the percentage position of each item, and the final Garett value assigned to each item. Lower Garett values indicate higher ranks, and the percentage position offers context on each item's relative position within the total set of items being ranked.

Table 13. Ranking problems associated to finger millet production and marketing in study area

Problems	**F1**	**F2**	**F3**	**F4**	**F5**	**Total respondents**	**Total score**	**Average score**	**Rank**
Low level of education and training	18	3	17	34	48	120	10456	87.13	5
Problems due to pests	21	65	17	11	6	120	10942	91.18	1
Lack of market intelligence	8	35	61	15	1	120	10730	89.41	3
Lack of quality seeds	19	13	5	57	26	120	10546	87.88	4
Lack of infrastructures	54	4	20	3	39	120	10846	90.38	2

Problems due to pests was the most severe production constraint in finger millet, with Garrett score of 91.18. Similarly, the second severe most constraint was found to be lack of infrastructures having a Garrett score of 90.38. In finger millet production lack of market intelligence were ranked third (89.41) and fourth (87.88) most severe constraints faced by the farmers were lack of quality seeds and low level of education and training having 87.13 ranking fifth were the constraints of finger millet production and marketing.

From the study, attack of pests such as rat to the standing crop was the most serious production problem followed by lack of infrastructures. Lack of infrastructure such as transportation was one of the major constraints followed by low quality seeds and low level of education and training. Adhikari, (2012) also came out with same constraint. Still majority of the finger millet growers using own farm local varieties for seed purpose and unavailability of good quality seed and lack of improved variety was major constraints for little millet growers in compare with finger millet growers. This is in line with the research (Kaushal and Choudhary, 2020).

Suggestions given by finger millet growers

Table 14. Ranking suggestions associated to finger millet production and marketing in study area

Suggestions	**F1**	**F2**	**F3**	**F4**	**F5**	**Total responders**	**Total scores**	**Average score**	**Rank**
Technical education should be made available	45	1	1	6	67	120	10644	88.7	4
Availability of timely inputs	7	27	22	63	1	120	10594	88.28	5

Modern production technology should be easily adaptable in the field	10	21	75	13	1	120	10694	89.11	2
Technical support for brewery industry	14	69	19	17	1	120	10910	90.91	1
Program for increasing nutritional awareness	44	2	3	21	50	120	10678	88.98	3

The suggestions were ranked with the help of Garett ranking method. Brewery management was the major problem in cultivation of finger millet; hence to mitigate this with 90.91 score growers gives a suggestion to provide technical support for brewery industry and to provide modern production technology easily adaptable in the field with 89.11 score from growers to rank second followed by providing program for increasing nutritional awareness to the farmers of Mugu district so that they could engage in production and marketing of finger millet actively. The next important problem was unavailability of technical education for farm operation therefore 88.7 score from growers was suggested to provide technical education available. The next constraint was lack of timely inputs of manures and quality seeds. Therefore with 88.28 scores growers suggested facilitating availability of timely inputs made available to the growers. More research and development activities suggested to release good quality seeds and varieties.

IV. CONCLUSION

This study conducted in Mugu district shed light on the economic dynamics, demographic characteristics, and marketing strategies associated with finger millet cultivation. Through a comprehensive cost-return analysis, it became evident that while the cultivation of finger millet entails significant costs, it also yielded favorable returns, indicating its potential as a profitable venture for farmers in the region. The regression analysis for factor share to total output of production found labour cost and fertilizer cost significantly impact income. However, challenges such as damage from pests, lack of market intelligence, and inadequate infrastructure were constraints to both production and marketing processes. Furthermore, the demographic profile of finger millet growers revealed a predominantly middle-aged population with limited formal education, highlighting the need for targeted interventions to enhance agricultural knowledge and skills. The identification of three primary marketing channels underscores the importance of understanding local trade dynamics for optimizing market access. Grower's recommendations, including support for the brewery industry, adoption of modern technologies, and improved access to education and inputs, offer valuable insights for enhancing productivity and market competitiveness. Addressing the challenges and leveraging the opportunities identified in the study can contribute to the sustainable development of finger millet cultivation in Mugu district, benefiting both farmers and the wider community.

Technical support for the brewery industry should be provided as some of the farmers or growers from Mugu district mainly rely on income generated from brewery produced from finger millet. Cost-return analysis of this study revealed that finger millet cultivation involves substantial cost yet yields favorable returns, highlighting its viability as a profitable venture, so providing more favorable conditions to attract more farmers towards finger millet cultivation should be done. Regression analysis suggests improving labor cost efficiency through better training, skill development, and adoption of labor-saving technologies could optimize the cost-effectiveness of labor inputs. Promoting effective fertilizer use is crucial, as its significant effect on income highlights the importance of timely access and proper application. Re-evaluating investments in seeds and ploughing could help reduce unnecessary costs without affecting output. The regression coefficient being less than 1 indicates decreasing returns to scale, suggesting the need for improved management practices and strategic investments to ensure additional inputs yield proportionate increases in output. Supporting innovation and technology adoption, such as introducing advanced farming techniques and improved technologies for seed and ploughing, is also important. Policymakers should consider these findings when developing agricultural support programs, providing subsidies for fertilizers and labor-saving tools along with technical assistance to significantly improve farmers' incomes in Mugu district. Finger millet, being a highly nutritive crop, necessitates programs for increasing nutritional awareness in the Mugu district. Growers suggest that technical education should be provided to the growers and the upcoming generation of the study area. Being a remote area of the country deprived of timely inputs, growers suggest providing inputs on time. Urban consumers in Nepal are willing to pay a premium price for local finger millets, so strengthening marketing channels for finger millet can help connect producers with urban consumers, indicating a potential market for this crop, which will improve the smallholder livelihoods of growers in the Mugu district.

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Profitability Performance of Broiler Chicken Farming Partnership Pattern in North Minahasa Regency

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Abstract**—** *The study aims to analyze the influence of performance factors on the profitability of broiler chicken farming using partnership patterns in North Minahasa Regency. The method used is a survey method, using a purposive random sampling technique. Data collected through used the questionnaires. Data analysis used multiple linear regression analysis. The results showed that the profitability obtained by broiler chicken farmers using a partnership pattern was IDR 623,844,148 with an average per respondent of IDR 20,794,805. While the influence each independent variable have a very significant effect on the partnership pattern broiler farming profitability. The results of the regression coefficient analysis show that if the Performance Index (IP) increases by IDR 1, profitability will increase by IDR 2.29, these results indicate that farmers have succeeded in achieving the performance of lifeweight and efficiency of feed and medicine/vaccine use. However, Feed Conversion Ratio (FCR) increases by IDR 1, profitability will decrease by IDR 1.13, meaning it is necessary to improve maintenance management to increase feed conversion into additional bodyweight. Likewise, the Mortality rate increases by IDR 1, then profitability tends to decrease by IDR 0.68, which means the depletion or mortality rate needs to be reduced through more intensive maintenance management.*

Keywords**—** ***Broiler, Chicken, Partnership Pattern, Performance, Profitability.***

I. INTRODUCTION

The nutritious food program that will soon be implemented by the Indonesian government needs to be supported by a livestock production development program, to provide meat, milk, and eggs as part of an effort to increase the availability of animal protein in Indonesia (Ministry of Agriculture, 2024). Meat and eggs from chickens are sources of protein that are easy to find and have affordable prices (Prasetyo, 2018).

Chickens farmed for meat are called broilers. Globally, the billions broiler chickens are farmed each year to meet consumer demand. Broiler chickens as one source of animal protein from livestock are very popular among various levels of society. Chicken delivers vital, under-consumed nutrients of public health importance for all age groups. Chicken meat is a favorite meat because almost everyone, and the increasing public awareness of the importance of consuming nutritious food has caused the demand for chicken meat to continue to increase every year (Swamilaksita and Sukandar, 2022; and Tamaluddin, 2016).

The demand or need for broiler chicken meat is driven by several factors, including a fast lifestyle and changes in people's consumption patterns. People tend to choose foods that are quick to process and have the right taste, such as chicken meat as the main choice of food ingredients for the community. Broiler chicken meat has become a favoured choice among consumers due to its high content of nutritions as proteins and minerals, and its affordable price. Processed chicken meat is also easy to find in various outlets, from restaurants to food shops, also playing an important role in increasing demand (Sattyananda, 2024).

On the other hand, the supply of broiler chickens are influenced by various factors, including chicken farming management to increase production efficiency, where the management technology that has been applied, especially for broiler chicken farming businesses, is the partnership pattern.

Partnership in livestock business is cooperation between livestock businesses based on the principles of mutual need, strengthening, benefit, respect, responsibility, and dependence, where the partnership agreement is made in the form of a written agreement (Ministry of Agriculture, 2017). Partner farmers (plasma actors) are generally evaluated for their performance by partner companies (core actors) by looking at the performance of achieving body weight, production age, feed conversion ratio, mortality rate, and performance index (Pandey et al., 2022 and Ministry of Agriculture, 2017).

In North Sulawesi, Indonesia, broiler chicken farming has developed since the 1978 Bimas (Community Guidance) Program for broiler chickens, and has implemented a broiler partnership pattern since the 1990s through partner companies, namely PT Charoen Pokphand Indonesia (Animal Feedmill) and PT Java Pelletizing Factory Ltd (PT Japfa Comfeed), each of which later developed with several subsidiaries as partner companies. Partner companies PT Ciomas Adisatwa and PT Bintang Sejahtera Bersama (BSB) as the core companies of partner farmers studied in North Minahasa Regency.

The partner company (core) evaluates the performance of partner farmers (plasma) of broiler chickens expressed in the performance or appearance of broiler chicken production which can be measured through three indicators, namely the index of performance (IP), feed conversion ratio (FCR), and mortality rate. The performance of the three performance indicators at the partner farmer level (plasma) is appreciated by the partner company (core) through the provision of performance index (IP) incentives, feed conversion ratio (FCR) incentives, and mortality rate incentives. For this reason, it is necessary to know the influence of each of the three indicators on business profitability, so that it will be known which performance indicators need to be maintained or improved.

II. RESEARCH METHODS

The study was conducted in North Minahasa Regency in the sub-districts that have the most partnership broiler farmers, namely Dimembe Sub-district and Talawaan Sub-district. The method used was a survey method with a purposive random sampling technique for determining respondent samples with research criteria, namely a minimum of 3 years of experience in partnership broiler farming and using conventional cage construction (open house).

Data were collected through direct observation and interviews with broiler farmers using a partnership pattern using a questionnaire. This study only selected 30 partner farmers as a minimum number, where according to Sugiyono (2019) the sample size should be 30 to 500 samples.

Data analysis used a multiple linear regression analysis model, to test the effect of independent variables, namely performance index incentives (X1), feed conversion ratio incentives (X2), and mortality incentives (X3) on the dependent variable of broiler business profitability (Y). The variables were analyzed using multiple regression using the formula according to Basuki (2015) and Sugiyono (2014):

$$Y= a + b_1X_1 + b_2X_2 + b_3X_3 + e$$

Definition of variables and coefficients of this study, namely:

- Y is the profitability or profit level of broiler chicken farming
- X_1 is the amount of performance index (IP) incentives for broiler chicken farming
- X_2 is the amount of feed conversion ratio (FCR) incentives for broiler chicken farming
- X_3 is the mortality (depletion) incentive for broiler chicken farming
- a is the constant coefficient
- b_1 is the regression coefficient of the performance index (IP) incentive variable
- b_2 is the regression coefficient of the feed conversion ratio (FCR) incentive variable
- b_3 is the regression coefficient of the mortality (depletion) incentive variable
- e is the standard error coefficient.

Through multiple linear regression analysis, regression coefficient (R) and determination coefficient (R2) analysis were carried out to determine the level of relationship and percentage of influence of all independent variables with the profitability variable of the broiler business. Then the F test was carried out to test the multiple linear regression model of the influence of independent variables (Xi) simultaneously on the profitability of the broiler farming. Furthermore, the t test was used to determine the partial influence of each independent variable (X_i) on the profitability of the broiler business. Then the results of the regression coefficient analysis were interpreted according to the regression coefficient value of each variable, namely the performance index incentive (X_1), feed conversion ratio incentive (X_2), and low mortality incentive (X_3) on the profitability variable or profit of the broiler chicken business (Y) of partner farmers. The analysis used the SPSS 23 application.

III. RESULTS AND DISCUSSION

Revenue of broiler farming with a partnership pattern in North Minahasa Regency is obtained from total broiler sales, partner company incentives, namely IP (Index on Performance) incentives, FCR (Feed Conversion Ratio) incentives, and LM (Low Mortality) incentives. The higher the IP (Index of Performance) value, the better the performance (Suwianggadana, et al., 2013). FCR (Feed Conversion Ratio) is a measure of feed use, the lower the FCR value, the more efficient it is (Siregar et al. 2017). While the mortality value as a percentage is calculated by dividing the number of dead chickens by the chicken population during maintenance and then multiplying it by 100 percent (Zulfan and Zulfikar, 2020).

Table 1. Revenue, costs and profits of sample farmers per period

No	Description	Amount (IDR/Period)	Average (IDR/Period)
(1)	**Revenue:**		
	a) Chicken Sales	10,626,702,600	354.223.420
	b) Performance Incentives/Bonuses from Core Company:		
	▫ Index of Performance (IP) Incentive	50,049,847	1,668,328
	▫ Feed Conversion Ratio (FCR) Incentive	47,838,302	1,594,610
	▫ Low Mortality (LM) Incentives	49,982,299	1,666,077
	Total Revenue	**10,774,573,048**	**359,152,435**
(2)	**Cost:**		
	▪ Purchase of Inputs (chicks/DOC, feed and medical chemical vaccines (MCV)	9,635,378,900	321,179,297
	▪ Electricity and water/PDAM bills	187,250,000	6,241,667
	▪ Labor Wages	282,500,000	9,416,667
	▪ Taxes (land and building tax, levies)	45,600,000	1,520,000
	Total Cost	**10,150,728,900**	**338,357,630**
(3)	**Profit = (1) – (2)**	**623,844,148**	**20,794,805**

Table 1 shows that the total income obtained by partner farmers in one period was IDR 10,774,573,048 with an average per period of IDR 359,152,435 for each partner farmer. While the total cost for one period was IDR 10,150,728,900 with an average of IDR 338,357,630 per period for each partner farmer. So the profit obtained by partner farmers per period was IDR 623,844,148 with an average of IDR 20,794,805 for each partner farmer. Factors that influence the amount of profit obtained are the allocation of production costs, besides the factor of how to regulate the use of farm production factors (Murti, et al., 2020).

Table 2. Results of correlation and determination coefficient tests

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*
1	.931	.867	.852	.12139

R is the correlation coefficient

R Square or R2 is the determination coefficient

Data processed, 2024

Table 2 shows the results of the correlation coefficient test of 0.931, which means that there is a very close relationship between the dependent variable of profitability or profit level (Y) with the independent variables of the amount of performance index incentives/bonuses (X1), the amount of feed conversion ratio incentives/bonuses (X2) and mortality incentives/bonuses (X3). Likewise, the results of the determination coefficient test obtained an adjusted R square value of 0.867, this means that the influence given by the performance index incentive variables, feed conversion ratio incentives and mortality incentives on profitability performance is 86.7%; while 13.3% is influenced by other variables. The determination coefficient (R2) is useful for measuring the level of accuracy which is the proportion or percentage of Xi's contribution to the variation in the rise and fall of Y (Mubarak, 2021 and Sahir, 2021). This determination coefficient test is carried out with the aim of measuring the model's ability to explain how much the independent variables simultaneously influence the dependent variable, which can be indicated by the adjusted R-Square value (Ghozali, 2016).

Table 3. F test results

	Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
1	*Regression*	2.507	3	.836	56.719	.000**
	Residual	.383	26	.015		
	Total	2.890	29			

a. Superscript **) indicates a significant level of p<0.01 or very significant

b. Data processed, 2024

Based on the results of the F test in Table 3, the independent variables simultaneously, namely performance index incentives (X_1), feed conversion ratio incentives (X_2), and mortality incentives (X_3) have a very significant effect (p <0.01) on the dependent variable of broiler business profitability (Y) of broiler chicken farming for farmers with a partnership pattern. These results indicate that the three performance variables most influence the level of profit, so partner farmers must pay attention to these three factors. In improving production performance and profits, broiler plasma farmers are expected to improve maintenance management (Mahardika, et al., 2020). Analysis of the influence of each independent variable, namely the amount of performance index incentives/bonuses (X_1), the amount of feed conversion ratio incentives/bonuses (X_2) and mortality incentives/bonuses (X_3) on the dependent variable of broiler chicken farming profitability (Y), is presented in **Table 4**.

Table 4. T-test results

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*Beta*		
a (Constant)	-.316	2.085		-.152	.881
X_1	2.924	.230	1.524	12.728	.000**
X_2	-1.135	.282	-.772	-4.027	.000**
X_3	-.617	.218	-.471	-2.837	.009**

Dependent Variable:

Y = profitability or level of profit of broiler chicken business

Predictors:

a is a constant

X1 is the amount of performance index (IP) incentives for broiler chicken businesses

X2 is the amount of feed conversion ratio (FCR) incentives for broiler chicken businesses

X3 is the low mortality (depletion) incentive for broiler chicken businesses

*Superscript **) indicates a significant level of p<0.01 or very significant*

Data processed, 2024

Table 4 shows the results of the partial influence test or each independent variable also has a very significant influence (p <0.01) on the dependent variable of broiler business profitability (Y) of broiler chicken farming for farmers with a partnership pattern, so that partner farmers must pay attention to these three factors, especially variables that show negative regression coefficients, namely feed conversion ratio (X2) and mortality rate (X3). Based on Table 4, the multiple linear regression equation is obtained:

$$Y = -0{,}316 + 2{,}924\, X_1 - 1{,}135\, X_2 - 0{,}617\, X_3$$

The results of the regression coefficient analysis in the equation show that if the Performance Index (IP) increases by IDR 1, profitability will increase by IDR 2.29, this result means that farmers have succeeded in achieving the performance of lifeweight and efficiency of feed and drug/vaccine use. Variations in the production index indicate fluctuations in production efficiency that require improvement to increase profit margins (Bahari, et al., 2024).

However, if the Feed Conversion Ratio (FCR) increases by IDR 1, profitability will actually decrease by IDR 1.13, meaning that it is necessary to improve maintenance management to increase the conversion of feed into additional livestock weight. Feed Conversion Ratio (FCR) is a comparison between the amount of feed used and the amount of chicken weight that can be produced. The smaller the FCR value indicates better business conditions (other factors being equal). This shows that the addition of a certain amount of feed can result in an increase in chicken weight with a greater proportion. As with the addition of feed, for the addition of other inputs, the addition of the input in question is said to have a good effect on FCR if the addition of certain inputs with a certain proportion causes broiler chickens to transfer a certain amount of feed to increase chicken weight with a greater proportion (Suwarta, 2012). Ridwan et al. (2019) reported that the profits obtained by plasma farmers each period are fluctuating, where there is an influence of the Feed Conversion Ratio (FCR) on the profits of broiler chicken farmers in the partnership pattern. The effect is inversely proportional, if the Feed Conversion Ratio (FCR) is smaller, the profit of broiler farmers will be greater, and vice versa.

Likewise, the Mortality rate increases by IDR 1, then profitability tends to decrease by 0.68 rupiah, which means that the mortality rate or depletion (including livestock that died/was removed due to poor growth) needs to be reduced through more intensive and effective maintenance management. It is also necessary to mitigate extreme weather events that often occur, which greatly affect the level of feed consumption and increase the mortality rate of broiler chickens. The results of the study showed a very significant effect on the level of profit, so it needs to be given serious attention. This result is different from the results of the study by Ratnasari et al. (2015) that the effect of mortality on income levels was not significant because mortality did not have a real effect on the income level of broiler chicken farmers due to the level of cage density.

IV. CONCLUSION

The profitability obtained by broiler chicken farmers in partnership pattern in North Minahasa Regency is IDR 623,844,148 per period with an average per respondent of IDR 20,794,805 per period.

Each of the performance variables of Performance Index (IP) and Feed Conversion Ratio (FCR) needs to be improved, while the level of depletion or mortality needs to be reduced through more intensive and effective maintenance management.

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Solar Drip Irrigation Kit (SDIK) Sustaining the Mulberry Productivity under Rainfed Sericulture

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Abstract— *In recent years, mulberry becomes one of the important cash crops in India and it is the only sole food crop to feed the silkworm (Bombyx mori).Water scarcity creates significant impact on quality mulberry leaf production which in turn determines the silk productivity. Importantly, rainfed sericulture contributes majorly to the overall silk production in the country. But inconsistence and erratic rainfall pattern greatly affects the mulberry productivity and its sustainability. Maintaining adequate soil moisture in the plant root zone is one of the important agronomic practices in order to obtain higher mulberry productivity in rainfed sericulture. In this context, run-off rain water in the farm can be collected and stored in the surface tank or farm pond for future supplemental irrigation during non-rainy season. A device with solar pump based drumkit drip irrigation system has been developed for effective irrigation management in the rainfed mulberry cultivation. It is an eco-friendly and efficient system to supply the water and nutrients directly at the plant root zone. The study was undertaken at Central Sericultural Research and Training Institute, Berhampore with an objective to explore the effect of solar drip irrigation technology on mulberry productivity. Solar drip irrigation system was established in the experimental garden as follows: a) a water drum of approximately 1000 litre capacity was placed at a height of 5 feet from the above ground level b) From the water drum, water was conveyed to the main field using PVC pipes after filtering through screen filter c) One conventional inline drip lateral (12 mm OD; 2.4 lph) was fixed in every mulberry row with a lateral spacing of 90 cm d)Surface storage tank was constructed to collect and store the run-off rainwater. e) 0.25 HP solar based nano pump was used for lifting water from surface tank to the overhead water tank. f) 80 Wp solar photovoltaic panel was installed to generate solar electricity in order to run the solar nano pump. The experiment consisted of three irrigation systems: Solar Drip Irrigation Kit (SDIK), Conventional Drip Irrigation (CDI) and Surface Irrigation (SI). SDIK system was performed at par with CDI system in terms of mulberry growth and yield attributes. There was 37% improvement in SDIK in leaf yield against SI. Moreover, when water applied through SDIK resulted in the water saving by 24% as compared to that of SI. Besides, significant improvement in water productivity by 44% was recorded in comparison to SI. The present study clearly indicated that SDIK is an innovative approach for efficient irrigation management in order to sustain the mulberry productivity in the rainfed areas. This system would be highly suitable and affordable to small and marginal rainfed sericulture farmers.*

***Keywords*— Solar drip irrigation kit; leaf yield; water productivity; water saving; mulberry**

I. INTRODUCTION

Mulberry is one of the most important commercial crops grown extensively as food plant for silkworm. In India, mulberry is cultivated in about three lakh hectares in different agro climatic conditions varying from temperate to tropical. Sericulture is mainly depends on the quantity and quality of mulberry leaf. India is the second largest producer of silk in the world. Importantly, rainfed sericulture contributes significantly to the total raw silk production in the country which primarily depends on the monsoon rainfall (June–October). However, distribution of rainfall pattern plays a vital role on the rainfed crop productivity. Because of uncertainty in rainfall, delay in onset of monsoon and prolonged dry spells between two rainfall often creates deficit soil moisture in the rainfed mulberry garden which reflects on leaf productivity. Therefore, limited crop yield and inadequate availability of water coupled with uncertain rainfall steers for sustainable water management strategies in rainfed regions to enhance the mulberry productivity. Rain water harvesting in small ponds and recycled as life saving irrigation/supplemental irrigation is a common practice followed to attain sufficient soil moisture for successful rainfed crop production (Oweis et al. 1999). However, the major constraint in recycling of water is lifting of water from the pond and distributes the same in to the field. Importantly, the majority of small farm holders lives in rural areas and have limited access to fuel and electricity. This means they require solar power source for lifting water for irrigation.

Solar drip irrigation kit (SDIK) is one of the most promising technologies for sustainable water management to the small farm holder in the rainfed areas. It is an effective and efficient method of irrigation for higher water use efficiency and water productivity besides energy saving(Roblin, 2016). Several studies suggested as drip irrigation increased crop yield by 20-40% (Banana, Guava and Tomato); saved water by 20-30%; improved water use efficiency by 50% (Sivanappan, 1994). Increasing sustainable, efficient irrigation methods among small farm holders can enable them to increase crop productivity and household incomes (Fiona et al. 2022). In order to achieve sustainable mulberry leaf productivity, there is a need to adopt solar powered drip irrigation in rainfed sericulture farming. Therefore, the aim of this study was to evaluate the impact of solar drip irrigation kit on mulberry productivity.

II. MATERIALS AND METHOD

The present study was carried out at CSRTI, Berhampore (Latitude 24º 05' N and Longitude88º 15' E), West Bengal, India. The experimental site lies in the Gangetic alluvial plains with tropical wet and dry climate with an annual mean temperature of 27°C and monthly mean temperature ranged between 19°C and 35°C. The average annual rainfall and temperature stand at 1344 mm and 26.2°C, respectively, in Berhampore, Murshidabad. The experimental plot initial soil nutrient status was recorded as pH (7.50), EC (0.94 dS m^{-1}), organic carbon(1.44 %), available nitrogen (355 kg ha^{-1}), available phosphorous (78 kg ha^{-1}) and available potassium (660 kg ha^{-1}).

Experimental details

12 year-old S1635 mulberry garden was utilized with 90cm×90 cm spacing. A total of eight crops were harvested in different seasons(June–August2017;September–November2017;January–March 2018; March–May 2018; June–August 2018; September–November 2018; January–March2019;April–June2019).The experiment consists of three irrigation systems: Solar Drip Irrigation Kit(SDIK), Conventional Drip Irrigation(CDI) and surface irrigation(SI).

a. Solar Drip irrigation Kit (SDIK)

Under this system, a small surface tank was constructed in order to store the rain water. Two solar photovoltaic panels (40 Wp) were installed near the surface tank to generate the solar electricity. 0.25 HP solar nano pump was used for lifting water from the surface tank to a overhead tank (1000 litres) placed at1.8 m height on a platform. From the overhead tank, water was conveyed to the main field using PVC pipes after filtering through screen filter. From the mainline, sub mains of 40 mm diameter PVC pipes were connected. Conventional inline drip lateralsof12 mm OD was fixed in the submains with alateralspacingof3feet.One inline drip lateral was placed at 10 cm depth from the surface in every mulberry row. Drip laterals had emitting point spaced at 30 cm apart with a discharge rate of 2.4 lph. Laterals end were closed with end cap. Water was applied to mulberry plantation through drip irrigation by gravity method.

b. Conventional Drip Irrigation (CDI)

Under this system, water was pumped from bore well using electric motor pump and conveyed to the main field using PVC pipes after filtering through screen filter. From the mainline, sub mains of 40 mm diameter PVC pipes were connected. Drip tape laterals of 16 mm OD (250 micron wall thickness of seamless tube) was fixed in the sub mains with a lateral spacing of 90 cm. One drip tape lateral(16mm)was placed at10cm depth from the surface in every

mulberry row. Drip tape laterals had emitting point spaced at 45 cm apart with a discharge rate of 8 litres per hour. Laterals end were closed with end cap. Water was applied to mulberry plantation through drip irrigation by electrical pump pressure.

Mulberry garden maintenance

Bottom pruning (Stump height: 15–20 cm from the ground level) were adopted as per the recommended practices for Eastern India (Setua 2006). Weed control was achieved through light digging and cleaning at periodical intervals. The recommended FYM(8 t ac^{-1}) was applied after digging and properly incorporated in the soil. Drip irrigation was scheduled on every alternate day with 100% Pan Evaporation. Whereas, surface irrigation was given once in ten days at the rate of 1.5 acre inch.

Data collection

Yield and quality attributes

Yield and quality attributes were recorded at 70 days after pruning from the ten randomly selected plants. Number of leaves per shoot and number of shoots per plant was counted and expressed in numbers. Maximum shoot length was measured from the base of the plant to the base of the fully opened leaves and expressed in cm. Leaf yield (g plant^{-1}) was estimated by plucking out all the leaves from each plant and the green leaves were weighed by using electronic balance. Leaf yield (t ac^{-1} yr^{-1}) was

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obtained by multiplying leaf weight per plant and total number of plants per acre.

Water productivity

Water productivity (WP) is quantity of water required to produce one kilogram of mulberry leaf (Viets1962) and calculated as water productivity (lit kg^{-1}leaf) = Volume of water (lit) (1acmm)/ Leaf yield (kg ac^{-1})

Statistical analysis

The mean data of eight crops were subjected to statistical analysis by analysis of variance method. Wherever the treatment differences were found significant (F test), critical difference was worked out at 5% probability level. In case the treatment differences were not significant, denoted as NS.

III. RESULT AND DISCUSSION

Drip irrigation delivers water directly to the roots of plants, thereby improving soil moisture conditions; in many studies, this has resulted in yield gains of up to 50-100% (Mahesh et al. 2013),water savings of up to40–80% (Maheshetal.2016),water productivity enhancement by 60-120% (Yang et al. 2023) and associated fertilizer, pesticide, and labour savings over surface irrigation systems. However,solar drip irrigation kitis an appropriate technology that Can promote sustainable crop productivity in the rainfed areas (Kumar et al. 2015); this study quantifies the impacts of SDIK on leaf yield and water productivity in mulberry.

Different growth and yield parameters like number of shoots, maximum shoot length, number of leaves and leaf yield per plant were markedly influenced by various treatments in the present study. The values of these growth and yield attributes were higher in SDIK and CDI treatments than SI. Further, SDIK significantly improved the growth and yield parameters than SI but it was comparable with CDI. These results are in agreement with Seenappa et al. (2015) who reported that drip irrigation recorded higher yield attributes in mulberry than surface irrigation. Aruna devi et al. (2016) reported that drip irrigation significantly improved the plant height, number of branches per plant and number of leaves per branch compared to that of surface irrigation. The increments in shoot number, shoot length and number of leaves were45 & 50%, 30 & 29% and 37 & 36%, respectively in SDIK and CDI than SI in the present study. Better performance of mulberry under drip irrigation might be due to maintenance optimum soil moisture around the root zone through the cropping period which might facilitated for better water uptake led into quick plant growth and development.

Irrigation with SDIK and CDI recorded the highest leaf yield and the least yield was obtained from the SI in all the seasons. Increment in mean leaf yield was 37 and 36%higherin SDIK and CDI, respectively as compared to SI. Dingre et al. (2012) reported that drip irrigation enhanced the onion crop productivity by 12% over to that of SI. According to Naik et al. (2021), solar pump with drip irrigation system increased Chilli yield by 23%, reduced energy consumption by 545 kWh and also increased net income of the farmer in Karnataka.

The improvements in leaf yield under SDIK and CDI systems was mainly due to irrigating the crop as per its requirement at different growth stages might have maintained the soil with optimum soil moisture and higher oxygen concentration in the active root zone which led into results of better water utilization, higher nutrients uptake and crop yield. Jennifer et al. (2010) reported that solar powered drip irrigation significantly augments water intake, crop yield and household income during the dry season. Further, leaf yield was not statistically differed between SDIK and CDI in the present study. This showed that SDIK is an appropriate technology in order to sustain the mulberry productivity in the rainfed areas.

Table1.Effect of irrigation systems on growth,leaf yield and water productivity in mulberry

Treatments	Number of shoots per plant	Shoot length (cm)	No. of leaves Per plant	Leaf yield (g $plant^{-1}$)	Leaf yield (kgacre^{-1} yr^{-1})	Total water use (mm)	Water productivity (litkg^{-1}leaf)
SDIK	11.07	132.72	18.92	597	14.75	1204	326
CDI	11.50	133.13	19.38	596	14.72	1204	327
SI	7.63	103.13	15.08	437	10.79	1575	584
CD	1.26	12.93	2.06	67.94	1.26	-	45
SDIK-Solar Drip Irrigation Kit; CDI-Conventional Drip Irrigation; SI-Surface Irrigation							

In general, mulberry is a high water consuming crop and it requires around 1600-2000 mm of water annually under surface irrigation method. In the present study, irrigation water requirement for mulberry was only 1204mmin both SDIK and CDI which resulted water saving of 24% as compared to that of SI (1575 mm). Water losses through soil evaporation and percolation are very limited in drip irrigation which could facilitate to save the water. Alaofe et al. (2016) reported that solar drip irrigation improves the farmer's income by enhancing crop yield and water uptake. Water saving of drip system was reported by Mahesh et al. (2022), which is up to 24% as compared to the surface system.

Water productivity is an indicator for the efficiency of irrigation systems. Ran et al. (2018) and Huang et al. (2022) reported that drip irrigation could enhance crop water productivity when compared to furrow irrigation and flooding irrigation methods. WP was found significantly increased under SDIK and CDI systems in the present study. The mean water productivity of mulberry leaf was increased by 56% under SDIK and CDI when compared to that of SI. In this study, both SDIK and CDI methods utilizes only 380 litres of water to produce one kg of mulberry leaf whereas it was 700 litres of water in case of SI method. This indicates both SDIK and CDI are very efficient systems for irrigating water to the mulberry plantation. Drip irrigation system doubled the water productivity in comparison to surface irrigation due to better utilization of water and nutrients which in turn resulted in higher yield and lesser total water used.

IV. CONCLUSION

Rainfed sericulture's contributions for the domestic and global silk demand are unavoidable. But, the mulberry productivity in the rainfed areas is very limited due erratic rainfall patterns under changing climatic conditions. Therefore, recycling of rain water for supplemental irrigation to the rainfed mulberry crop is need of the hour in order to enhance the mulberry leaf productivity. In this connection, the impact of SDIK on rainfed mulberry leaf productivity was studied. SDIK resulted improvement in leaf yield by 37% and water productivity by 44% as compared to surface irrigation. Thus the above mentioned facts establish that SDIK could be an appropriate technology for sustainable mulberry productivity to the small-scale sericulture farmers in the rainfed areas.

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Impact of micronutrient spray on growth, bulb yield and economics of onion

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***Abstract*— *Present experiment was conducted as on-farm testing at farmers' field during Rabi season of 2022-23 and 2023-24 to assess the impact of micronutrient spray on growth, bulb yield and economics of onion crop. Two treatments i.e. T_1- Farmers' practice (without spray) and T_2- foliar spray of micronutrient replicated at five farmers field of Jhajjar district. Micronutrients were applied through foliar spray of multiplex general liquid 2.5 ml/ litre (625 ml/ ha) which contains Zn 9%, Fe 8%, Mn 0.50%, Cu 0.50% and Bo 0.25% after one month of transplanting and at bulb formation stage of the onion. The use of micronutrient as foliar spray was found effective in T2 treatment the significantly highest plant height (68.35 & 69.10 cm), number of leaves (6.80 & 6.95), bulb weight (55.38 & 58.80 g) and bulb yield (307.90 & 311.80 q/ha) during 2022-23 and 2023-24, respectively. Maximum net return (₹ 110367 & 211270/ ha) and benefit cost ratio (1.96 & 2.82) were recorded in the treatment T2 whereas, in farmers' practices were found net return (₹ 88428 & 176530/ ha) and BC ratio (1.79 & 2.55), respectively during both the year of study. Therefore, the use of micronutrient application to be increases the production and recommended for onion cultivation.*

***Keywords*— Bulb yield, Economics, Foliar spray, Micronutrient, Onion**

I. INTRODUCTION

Onion (*Allium cepa* L.) is an important bulb crop growing the global. In India, it is consumed as vegetable and condiment since ancient times. It is a short duration vegetable crop (Brewster, 1990) grown at low latitudes. It is commonly known as "Queen of the kitchen" due to its highly valued flavor, aroma, unique taste and the medicinal properties of its flavour compounds (Selvaraj, 1976; Griffiths *et al*., 2002). Its distinctive flavour and pungency, which is the due to sulphur containing compounds Allyl-propyl-disulphide. The bio-flavonoid present in the yellow colour of the outer skin of onion bulb is due to Quercetin. It contains anti-fungal property *viz.* catechol. Onion is used throughout the year in salad, as spice in soups, curries, condiment or cooked with other vegetables, such as boiled or baked and also used in processed foods like pickles, powder, paste and flakes. India is major exporter of onion and the second largest producer in the world next to China with an area of 17.9 lakh ha with production of 302.08 lakh MT per annum with average productivity of 16.87 t/ha (Anonymous, 2023). At present, In Haryana state having an area of 2.28 lakh ha with production of 5.43 lakh MT per annum with 23.79 t/ha productivity. In the Jhajjar district, an area of 334.8 ha with production of 3000 MT and 8.96 t/ha average productivity (Anonymous, 2023). The major onion producing states in India are Maharashtra, Madhya Pradesh, Gujarat, Karnataka, Rajasthan, Bihar, West Bengal, Uttar Pradesh, Haryana, Andhra Pradesh, Tamil Nadu, Odisha, Punjab and Telangana.

Due to intensive cropping, a smaller amount of manures, micronutrients and unfair use of fertilizers so soil health is deteriorating continuously. All the essential nutrient elements are most important factors which govern the onion growth and yield. Macro and micronutrients help in increasing the yield, storage quality and fertility status of soil in onion. The macronutrient such as N, P, K, Ca, Mg, S and micronutrients such as Fe, Zn, Cu, B, Mo and Mn are beneficial in enhancing the growth, bulb yield, storage quality and fertility status of soil in onion (Singh, 2005). The soil and environment have an effect on availability of these nutrients in soil. The use of micronutrients is limited. Although, the micronutrients are required in very few quantity but important role in cell division and carbohydrates metabolism in plant growth and high crop yield (Kumar *et al*., 2021). There were evidences that micronutrients such as zinc, ferrous and boron increase the bulb size, highest plant height, bulb fresh weight, bulb diameter and yield of onion (Smriti *et al*., 2002; Shinde *et al*., 2016). In Haryana, most of the farmers use macronutrients especially nitrogen, phosphorus and potassium for more yield and quality of vegetables. The vegetable growers should carefully follow recommendations for micronutrients to avoid unnecessary costs and their toxic effects. In consideration with the above situations, an attempt has been made to study on efficacy of micronutrient spray on growth, bulb yield and economics of onion.

II. MATERIALS AND METHODS

A field experiment was conducted during *Rabi* season of 2022-23 & 2023-24 at farmer's fields in Dulina village, Jhajjar district of Haryana. Sandy loam soil was in the experiment area having pH of 7.0 and 0.35% organic carbon. Onion seed was treated with Carbendazim 2.5 g/kg seed as per package of practices. The treated seed was sown in lines in well-prepared nursery beds (3.0 x 1.0 x 0.15 m size) on 06th November during the both of experiments. Nursery management operations (Thinning, weeding, irrigation) were carried out till the seedling transplant in field. Nursery was raised commonly for both the treatments and micronutrients were applied as per treatment in the main field. About 60 days old seedling of 15 cm height were transplanted in the field on 05th January at a spacing of 15 x 10 cm. The recommended dose of fertilizer used for onion crop was 125:50:25 kg/ha NPK along with FYM 20 tonnes applied uniformly in all the treatments.

There were two treatments *i.e*., Farmer's practices (T_1) = control (without spray of micronutrients) and Assessed technology (T_2) = Use of RDF with foliar spray of micronutrients after one month of transplanting and at bulb formation stage. Micronutrients were applied through foliar spray 625 ml of multiplex in 250 litres of water/ ha which contains Zn 9%, Fe 8%, Mn 0.50%, Cu 0.50% and Bo 0.25%. Trial was conducted at five farmers' field comprising of 1.0 acre area as plot size. Ten plants were selected randomly from each treatment for recording all observations on growth and yield. Economics of onion production was calculated by keeping a record on each operation during cultivation. The t-test is statistical analysis was done using standard procedure.

Net returns = Gross returns - Variable cost

$$\text{Benefit cost ratio} = \frac{\text{Gross returns}}{\text{Variable cost}}$$

III. RESULTS AND DISCUSSION

The effect of micronutrient foliar spray was studied on the growth, bulb yield and economics of onion. The results obtained was significant differences in plants height (cm), number of leaves, bulb weight (g) and bulb yield (q/ha) due to foliar spray of micronutrients general liquid (Table 1).

Plant height (cm)

The maximum plant height (68.35 & 69.10 cm) was recorded under T2 with foliar application of micronutrient, where as the minimum plant height (56.15 & 55 cm) was recorded in T1 (control) during 2022-23 and 2023-24, respectively. The increased plant height by use of micronutrient might be due to the cell division and cell enlargement of the protoplast through water uptake. It's important role in many physiological processes and cellular function of the plants. These findings are in agreement with the findings of Abd EI- Samad *et al*. (2011); Dake *et al*. (2011) and Acharya *et al*. (2015) in onion.

Number of leaves

Significantly the maximum number of leaves/ plant (6.80 & 6.95) were recorded in the treatments T_2 (Zn 9%, Fe 8%, Mn 0.50%, Cu 0.50% & Bo 0.25%) followed by T_1 *i.e*., control (5.11 & 5.30) in 2022-23 and 2023-24, respectively. Invariably, use of micronutrients increased the production of more leaves/ plant than control. It may be due to primitive effects of micronutrients on vegetative growth which ultimately lead to more photosynthetic activities. Similar results finding by Dake *et al.* (2011); Manna *et al*. (2013); Ballabh *et al*. (2013) and Acharya *et al*. (2015).

Bulb weight (g)

Application of micronutrients *i.e.*, T_2 treatment had statistically significant of highest bulb weight (55.38 g & 58.80 g) in onion as compared to without spray of micronutrients (46.25 g & 48.75 g) during both the year of study. This might be due to the better improving of photosynthesis efficacy and increased allocation of photosynthates towards the bulb. Increased bulb weight was also due to enhanced growth and yield traits as a result of positive influence of micronutrients and PGRs. The result of present experiment well corroborates the findings of Abedin *et al*. (2012); De *et al*. (2013) and Pramanik *et al*. (2020).

Bulb yield (q/ha)

Significantly the maximum bulb yield (307.9 & 311.8 q/ha) were recorded in the treatment T2 (Zn 9%, Fe 8%, Mn 0.50%, Cu 0.50% & Bo 0.25%) where micronutrients were applied after one month of transplanting and at bulb formation stage as compared to T1 treatment (274.6 & 276.5 q/ha) *i.e*., without any micronutrients spray during both the year 2022-23 and 2023-24, respectively. It might be due the crucial role of micronutrients in strengthening the cell wall and translocation of carbohydrates from leaves to other parts of plant. The higher photosynthesis build up in the bulbs would ensure more bulb weight and bulb diameter which collectively increases the total bulb yield in onion. The similar report was observed by Trivedi and Dhamal (2013); Damse *et al*. (2014); Pramanik *et al*. (2020) and Biswas *et al*. (2020).

Economics

It is revealed from (Table 2) that the highest net return of ₹ 110367 & 211270/ ha with benefit cost ratio 1.96 & 2.82 was obtained in treatment T2 ,while the lowest net return of ₹ 88428 & 176530/ha along with benefit cost ratio of 1.79 & 2.55 was obtained in treatment T1 (Control) during 2022-23 and 2023-24, respectively. The foliar spray of micronutrients mixture applied after one month of transplanting and at bulb formation stage increased all economic parameters indicating the feasibility used of micronutrients significantly higher bulb yield and optimum profit of onion. The similar result was also reported by Nasreen *et al*. (2009) and Pramanik *et al*. (2020).

Table 1. Impact of micronutrients foliar spray on growth and bulb yield of onion

Technology	Technical observations							
	Plant height (cm)		No. of leaves		Bulb weight (g)		Bulb yield (q/ha)	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1-P.F. (No Spray)	56.15	55.0	5.11	5.30	46.25	48.75	274.6	276.5
T_2-Foliar application of Micronutrient	68.35	69.10	6.80	6.95	55.38	58.80	307.9	311.8
t-Statistic	22.51	14.78	29.13	6.98	5.43	16.58	20.18	64.09
t-Critical (P=0.05)	4.30							

Table 2. Impact of micronutrients foliar spray on economics of onion

Technology	Economics (₹/ ha)									
	Increase (%)		Variable cost (₹/ha)		Gross return (₹/ha)		Net return (₹/ha)		BC ratio	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1-P.F. (No Spray)	-	-	112030	113795	200458	290325	88428	176530	1.79	2.55
T_2-Foliar application of Micronutrient	10.82	11.32	114400	116120	224767	327390	110367	211270	1.96	2.82

Note: Onion bulbs were sold ₹ 730/ q and ₹ 1050/ q during 2022-23 & 2023-24, respectively.

IV. CONCLUSION

From the above two consecutive year of the research, it is concluded that application of micronutrients mixture (Zn 9%, Fe 8%, Mn 0.50%, Cu 0.50% & Bo 0.25%) @ 2.5 ml per litres of water after one month of transplanting and at bulb formation stage was found to be more vegetative growth, yield traits, bulb yield and economics of onion as over to control treatment.

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Agrometeorological Indices and the Weather Parameters Impact on Growth and Yield of Pearl Millet

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***Abstract*— *The experiment entitled "Studies on crop weather relation in pearl millet (Pennisetum glaucum L.) under experiment was carried out in FRBD (Factorial Random Block Design). Nine treatment combinations comprise of three sowing environments viz. crop sown on 28th June (G_1), 8th July (G_2) and 18th July (G_3) respectively along with three cultivars i.e., PC-701, HHB-67 and RHB-223 were used in the investigation. The minimum temperature and rainfall had a positive and significant effect on the grain yield. It had a strong negative correlation with evaporation and wind speed. During the research period, among cultivars the highest accumulated GDD had observed in HHB-67 from emergence to physiological maturity. The higher accumulated HTU had consumed by 18th July and lowest by 28th June and the highest HTU were observed in HHB-67 from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18th July). The Accumulated Heat use efficiency (HUE) was higher on 28th June treatment at 60 DAS. HHB-67 (0.61 g/m^2 ^{o}C/day) possess higher HUE followed by PC-701 and RHB-223 (0.50 g/m^2 ^{o}C/day).*

***Keywords*— GDD, HTU HUE, Pearl Millet.**

I. INTRODUCTION

Based on several kinds of research, in order to fulfill the demands of a growing population and changing dietary habits, the world's food supply will need to double by the year 2050 (Bruinsma, 2009; Tilman et al., 2011; OECD; Food and Agriculture Organization of the United Nations, 2012). Surface temperature is expected to increase over the 21st century under all evaluated emission scenarios, with a high probability of an increase in the severity and duration of heat waves and extreme precipitation events in many regions, according to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2023). Changes in the ordinary and extreme weather pose a major threat to governments and organizations worldwide. This study aimed to present data about the effects of meteorological factors on the development stages and yield of climate-resilient pearl millet. In this sense, millets might be selected as climate-smart crops in the future. Millets are hardy and varied crops that belong to the monocotyledon group of the Poaceae family (Maitra *et al.*, 2000, 2022). Since major cereals grown on soils that get a lot of fertilizer, irrigation, and pesticide inputs have attained an average level of productivity, the importance of millets has increased dramatically in India during the past several decades. In both rich and developing countries, millets may increase food output. Millets are a type of grain in addition to the mainstays of wheat, rice, and maize. Millions of people, especially those who live in hot, dry parts of the world, rely on millets as their main source of sustenance millions of Africans rely on millet as their main source of protein and energy. The nutritional and therapeutic advantages of millet have been documented (IIMR report 2017). Among the various types of millet, pearl millet stands out as a significant food grain cultivated in both Africa and India. As a C4 plant, it is well-suited for growth in semi-arid regions, and its unique genetic characteristics enable it to withstand high temperatures, moderate salinity, and moisture stress, making it highly adaptable (Arya *et al.*, 2014). In light of these considerations, the present study was conducted to assess the impact of crop-weather relationships on the physiological growth parameters and yield performance of pearl millet cultivars in the eastern plain zone of Uttar Pradesh.

II. MATERIAL AND METHODS

An experiment carried out during the 2023 Kharif season at the Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.). This chapter provides a detailed account of the supplies, procedures, and techniques used during the experiment.

Experiment site: The experiment was laid out at Agro-meteorological Research Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during Kharif season 2023-24 The farm is located at 26˚47′ N latitude and 82˚12′ E longitude and at an altitude of about 113 meter above the mean sea level. The field was well levelled having assured irrigation and drainage facilities.

Climatic condition of the experimental site: Geographically, the climate in this area is subtropical. This crop receives average 724.2 mm of rainfall. During the crop growing season, the average weekly maximum and lowest temperatures were 31.8 ºC to 36 ºC and 24.5 ºC to 27.6 ºC, respectively. The range of the average relative humidity was 61.05% to 91.04%, and the number of hours of bright sunshine were 1.6 to 7.8. During the study, the soil of the research plot was collected through random sampling, and the analysed physicochemical properties of the soil revealed that the experimental soil was sandy clay loam in texture with a soil pH of 8.1 and an organic carbon of 0.38%. The soil contained 189.25 kg ha-1, 18.20 kg ha-1 and 236.50 kg ha-1 of nitrogen, phosphorous and potassium respectively. The experiment was carried out in F.R.B.D (Factorial Random Block Design). Nine treatment combinations comprise of three sowing dates *viz.* 28th June (G_1); 8thJuly (G_2) and 18thJuly (G_3) respectively along with three cultivars *i.e.,* PC-701, HHB-67 and RHB-223 were used in the investigation. Pearl millet seeds were sown at a seed rate of 2-3 kg ha-1 on well-prepared seedbeds. The main field was harrowed and ploughed twice with a cultivator and rotavator and levelled with the levellers. Then, the experimental layout was divided into plots. Further, each plot was manually levelled, and one pre-planting irrigation was provided for better soil conditions during the transplanting to establish finger millet seedlings. All plots received the recommended fertilizer dose of 40:20:20 kg ha^{-1} of nitrogen, phosphate and potash, respectively.

During the experimental period, the plant height, dry matter accumulation, number of tillers and leaf area index were collected at 10-day intervals from 15 days after germination to harvest. The following equations calculated the Leaf area index, Harvest index, and relative index

Harvest index (%)- The harvest index is the ratio of grain yield and biological yield, it was calculated by following formula:

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Leaf area index-The leaf area of five plants was measured with an automatic leaf area meter at 30, 45, 60, 75, 90, and 105 DAS, as well as when the crop reached physiological maturity. The leaf area index was calculated using the formula.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Relative humidity (%)- Relative humidity is the ratio between the amount of water vapour required for saturation at a particular temperature and pressure. It can be expressed as percentage or ratio.

$$\text{RH (\%)} = \frac{\text{Water vapour present in air Relative himidity (\%)}}{\text{Water vapour required for saturation}} \times 100$$

GDD/heat units (°C Day) - were computed by summing the daily mean temperature above base temperature and expressed in day °C. For pearl millet crop, Tbase is considered as 10°C for computation of GDD (Ahmad et al., 2017). GDD was calculated for different phenological stages in pearl millet by using the following formula:

$$\text{GDD} = \sum_b^a \{\frac{Tmin.+Tmax.}{2} - Tbase\}$$

Where,

T max. is daily maximum temperature (°C)

T min is daily minimum temperature (°C)

Tb is base temperature

'a' is starting date of phenophase and 'b' is ending date of that phenophase

Base temperature for Pearl millet (kharif) crop 10-12°C

Helio-thermal units (°C Day hour)- The helio-thermal units (HTU) for a day represent the product of growing degree days and bright sunshine hours for that day and are expressed in day °C hour. The sum of HTU for each phenophase was determined by using the equation:

$$\text{HTU} = = \sum_b^a (GDD \times n)$$

Were,

n is actual sunshine hours.

GDD is growing degree day.

Heat use efficiency (HUE) (g m -2 °C Day)- the amount of dry matter produced per unit of growing degree days or thermal time and is expressed in g m-2 oC day. HUE was calculated between any two consecutive phenological stages of the crop as under

$$HUE = \frac{Total\ dry\ matter\ (g/m2)}{\sum GDD}$$

Were,

∑GDD is summation of growing degree day.

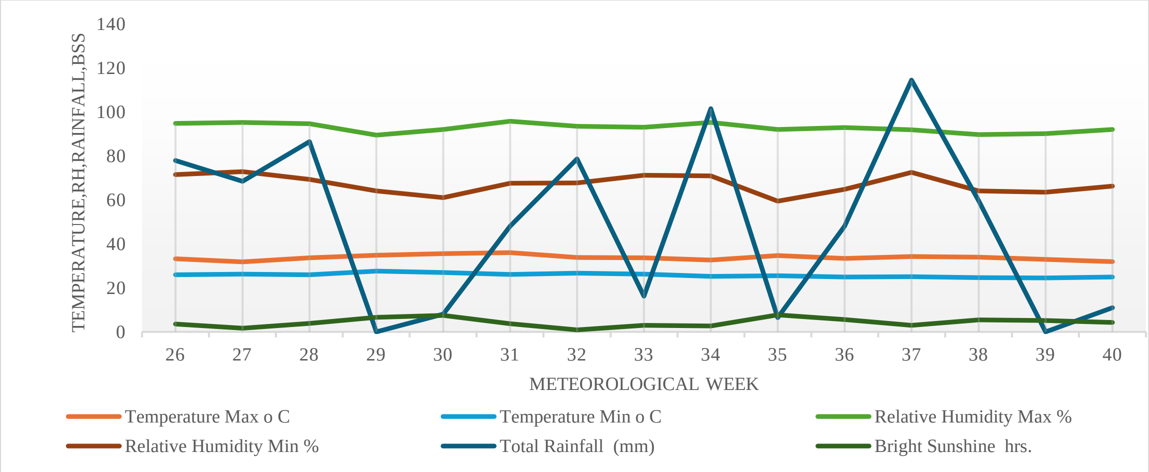

Fig.a Weather data during the experiment studies

III. RESULT AND DISCUSSION

Correlation analysis- Correlation between growth and weather parameters-shows the findings of correlation studies between meteorological parameters and growth during the vegetative and reproductive phases of pearl millet development. During the reproductive period of crop growth, there has been a strong but negative association seen between wind speed and plant height and dry matter. There is a significant positive link between the leaf area index (LAI) and the minimum temperature, and a strong negative correlation with the relative humidity in the morning.

Correlation between yield and it`s attributes with weather parameters- The minimum temperatures and rainfall have a substantial positive link with grain yield, but wind speed and evaporation have a large negative correlation. The number of effective tillers per plant was inversely connected with maximum temperature and hours of intense sunshine, and positively correlated with relative humidity in the morning and evening. The maximum and minimum temperatures and wind speed had a negative correlation with earhead length, while the two variables showed a positive correlation. Positive relationships have been observed between the test weight attribute and the lowest temperature, evening relative humidity, and rainfall; negative relationships have been observed with wind speed and evaporation. Wind speed and biological yield also had a negative correlation. Maximum temperature had a negative correlation with effective tillers per plant and a positive correlation with earhead length. The minimum temperature has been positively correlated with test weight, grain yield, and earhead length. Only the effective tillers per plant were impacted by morning relative humidity, whereas test weight and effective tillers per plant were impacted by evening relative humidity. Earhead length, test weight, grain yield, and biological yield have all been adversely affected by wind speed; also, effective tillers per plant have been found to be negatively correlated with bright daylight hours. Test weight, grain production, and the number of effective tillers per plant were all adversely affected by evaporation. Grain yield and test weight showed a favourable correlation with rainfall. There is no discernible relationship between the harvest index, earhead girth, and stover yield and meteorological data.

Agrometeorological indices - The agrometeorological observatory, located on the students' instructional farm, provided the meteorological data, which included the daily maximum and minimum air temperature, the amount of rainfall, and the number of brilliant sunshine hours. Directly recorded meteorological measurements were the source of the agrometeorological indicators. Agrometeorological indices are a highly helpful instrument for forecasting agricultural yield and determining the relationship between weather and crop productivity.

Growing Degree Days (°C Day) - Table 3 presents the data regarding the cumulative growing degree days (GDD) in relation to various treatments and phenological stages. Between the cultivars, HHB-(1241.50 °C Day) has used more GDD than PC-701 (1222.6 °C Day), RHB- 223 (1240.1°C Day), and RHB-223 has used less GDD overall at all phenological stages than PC-701 and HHB-67. Similar results had published by Andhale *et al*. (2001), and Anil Kumar *et al. (*2008).

Helio Thermal Unit (° C Day/ hours)- Table presents the information about the total number of helio-thermal units (HTU) for each treatment for each of the several phenophases. In compared to 28th June and 8th July, the crop growth environment on July 18th (PC-701) had the greatest HTU from emergence to milking stage (514.88 to 4850.40), except for the flag leaf stage, boot, dough stage, and physiological maturity stage. With each sowing delay from 28th June to 18th July, the HTU for emergence to dough stage (apart from the physiological maturity stage) rose. Among the crop growing environments for cultivar HHB-67, the 18th of July exhibited the highest HTU (518.88 to 5750.23°day/hr.) from emergence to physiological maturity, apart from the flag leaf, boot, dough, and physiological maturity stages. Another cultivar, RHB-223, is intended to be used in a range of agricultural producing settings. Every delay in seeding from 28th June to 18th July increased the HTU for physiological maturity. The 28th of June had the highest HTU values ranging from 510.75 to 5739.40 °C Day/hr. from emergence to milking stage, apart from the flag leaf stage, boot stage, dough stage, and physiological maturation as compared to 8th July and 18th July. Similar outcomes were reported by V.M.Londhe *et al.* (2020) & G. Aishwarya *et.al* (2022).

Accumulated Heat Use efficiency (HUE) **-**

Calculating the thermal usage efficiency (HUE) is crucial in determining the potential yield under various cultivars and sowing circumstances. It measures the quantity of dry matter generated every day per unit of growth degree. Table 5 presents the data that shows the HUE. The results show that as crop stages have increased, so too has the value of HUE. Maximum HUE values for the variety HHB-67 have been seen on 28th June sowing dates at all phases 15,30,45 and 60 DAS intervals, followed by 8th July and 18th July. Maximum HUE values for the cultivar PC-701 have been seen on 28th June sowing dates at all phases of 15,30,45 and 60 DAS intervals, followed by 8th July and 18th July. Another cultivar, RHB-223, exhibited the highest HUE values on 28th June sowing dates at all stages of 15,30,45 and 60 DAS, followed by 8th July and 18th July. Similar results were reported by Girijesh *et al.*in (2011), Ved Prakash *et al.*(2017), V.M.Londhe *et al.* (2020);

Table:1 Correlation coefficients of growth parameters with prevailing weather during vegetative and reproductive phases of pearl millet cultivers

Parameters	Plant height (cm)		Dry matter (g)		Leaf area index	
	Veg. phase	Rep. phase	Veg. phase	Rep. phase	Veg. phase	Rep. phase
Tmax	0.07	-0.02	0.08	-0.12	0.14	0.44
Tmin	-0.22	-0.14	-0.23	-0.32	-0.22	0.62*
RH(m)	0.04	0.21	0.03	0.34	-0.02	-0.60*
RH(e)	-0.24	0.08	-0.21	-0.14	-0.28	0.24
Wind speed	-0.08	-0.54**	-0.04	-0.50**	0.04	0.32
BSS	0.09	0.16	0.06	0.26	0.13	-0.42
Rainfall	0.05	0.2	0.02	-0.05	-0.05	0.27

Table: 2. Correlation coefficients of yield index with weather parameters in pearl millet cultivars

Parameters	Tillers/ plant	Ear head length/plant	Ear head girth/ plant	Test weight	Grain yield	Stover yield	Biological yield	Harvest index
Tmax	-0.62**	0.43*	0.14	0.06	0.16	0.15	0.19	-0.05
Tmin	-0.294	0.55**	0.11	0.46*	0.42*	0.27	0.32	0.14
RH(m)	0.56**	0.03	0.02	0.27	0.12	0.08	0.09	0.12
RH(e)	0.42*	0.25	0.04	0.44*	0.36	0.19	0.26	0.20
Wind speed	-0.05	-0.62**	-0.15	-0.55**	-0.52**	-0.37	-0.42*	-0.17
BSS	-0.55**	-0.06	0.02	-0.26	-0.16	-0.09	-0.12	-0.17
Evaporation	-0.43*	-0.41	-0.08	-0.42**	-0.41*	-0.24	-0.25	-0.23
Rainfall	0.28	0.34	0.06	0.40*	0.39*	0.22	0.24	0.20

*Significance at 1 %; **Significance at 5% Where, T_{max}= maximum temperature (°C), T_{min}= minimum temperature (°C), RH(m) = morning relative humidity (%), RH(e) = evening relative humidity (%), BSS= bright sunshine hours (hrs), Veg. phase = vegetative phase, Rep. phase= reproductive phase

Table: 3. AGDD/Heat unit at different phenophases (˚C/days) of pearl millet cultivars as affected by crop growing environments

Treatments	Emergence stage	5 leaf stage	Tillering stage	Flag leaf stage	Boot stage	50% flowering Stage	Milking stage	Dough stage	Physiological maturity stage
Crop growing environments									
PC-701									
28th June (33.2°C)	70.75	213.75	375.85	644.6	691.1	902.35	1041.1	1076.6	1222.6
8th July (31.8°C)	80	216.75	335.75	620.5	676.1	870.6	1031.6	1067.85	1196.35
18th July (34.8°C)	51	171.75	261	603.1	726.1	834.6	988.1	1019.1	1165.35
28th June (33.2°C)	70.75	213.75	375.85	644.6	691.1	902.35	1041.1	1076.6	1222.6
HHB - 67									
28th June (33.2°C)	82	221.75	367.85	638.5	726.1	910.35	1047.6	1076.6	1241.50
8th July (31.8°C)	71.25	215.75	330.75	634.6	691.1	880.6	1041.1	1062.85	1201.5
18th July (34.8°C)	67	188.75	296.25	599.1	679.1	839.6	992.4	1039.1	1175.5
RHB-223									
28th June (33.2°C)	77	212.75	365.85	640.6	736.1	899.5	1040.1	1076.6	1219.7
8th July (31.8°C)	69.75	210.75	332.75	597.1	688.1	875.5	1031.6	1067.85	1160.85
18th July (34.8°C)	51	165.5	261	610.5	679.1	844.6	988.1	1009.1	1190.5

Table: 4. Accumulated helio thermal unit (HTU) (°C /day/ hours) on different crop growing environments and cultivars

Treatments	Emergence stage	5 leaf stage	Tillering stage	Flag leaf stage	Boot stage	50% flowering stage	Milking stage	Dough stage	Physiological maturity stage
Crop growing environment									
PC -701									
28th June (33.2°C)	319.50	865.88	1261.38	3284.33	3338.33	3910.83	4298.08	4650.40	5744.40
8th July (31.8°C)	404.63	966.25	1952.88	3135.45	3233.83	3883.45	4782.65	5005.28	5604.03
18th July (34.8°C)	514.88	1626.25	2205.02	2781.20	3130.33	3910.40	4807.40	4881.90	5427.03
HHB - 67									
28th June (33.2°C)	325.50	888.50	1270.70	3280.32	3345.40	3915.25	4388.58	4690.46	5750.23

8^{th} July (31.8°C)	406.63	970.30	1960.80	3140.42	3198.25	3908.15	4800.50	5047.25	5606.05
18^{th} July (34.8°C)	518.88	1630.20	2216.20	2785.40	3150.50	3920.70	4855.23	4890.05	5430.02
RHB-223									
28^{th} June (33.2°C)	315.25	860.85	1260.75	3282.25	3340.25	3889.59	4379.75	468 5.4	5739.40
8^{th} July (31.8°C)	400.62	961.05	1905.50	3105.40	3230.25	3851.40	4777.05	4997.05	5598.25
18^{th} July (34.8°C)	510.75	1610.20	2198.05	2777.29	3129.32	3893.34	4830.20	4870.25	5420.25

Table: 5. Accumulated heat use efficiency (HUE) (g /m-2 °C /day) on different crop growing environments and cultivars

Treatments	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**
PC-701				
28^{th} June (33.2°C)	0.05	0.20	0.46	0.50
8^{th} July (31.8°C)	0.04	0.14	0.44	0.48
18^{th} July (34.8°C)	0.01	0.12	0.29	0.32
HHB-67				
28^{th} June (33.2°C)	0.06	0.20	0.54	0.61
8^{th} July (31.8°C)	0.04	0.17	0.51	0.48
18^{th} July (34.8°C)	0.02	0.14	0.35	0.36
RHB-223				
28^{th} June (33.2°C)	0.05	0.16	0.40	0.50
8^{th} July (31.8°C)	0.03	0.12	0.41	0.49
18^{th} July (34.8°C)	0.02	0.10	0.28	0.31

IV. CONCLUSIONS

During the reproductive period of pearl millet, there is a significant association between the morning relative humidity and minimum temperature and the leaf area index (LAI). Wind speed during the reproductive phase has a negative impact on plant height and dry matter. Although there was a negative correlation with wind speed and evaporation, there was a strong positive correlation between grain yield and test weight and minimum temperature and rainfall. Both evaporation and wind speed have been found to have a negative impact on grain yield and biological yield respectively. The higher accumulated GDD had consumed by 28^{th} June (1241.50 ° C/day) to attain physiological maturity among different crop growing environments then after 18^{th} July (1201.5 °C/day). 8^{th} July (1190.5°C/day) utilized minimum accumulated GDD. Among cultivars, the highest accumulated GDD had observed in HHB-67 from emergence to physiological maturity. The higher accumulated HTU had consumed by 18^{th} July and lowest by 28^{th} June among different sowing dates at different phenophases with few exceptions. Among cultivars, the highest HTU were observed in HHB-67 from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18^{th} July). The Accumulated Heat use efficiency (HUE) was higher on 28^{th} June treatment at 60 DAS. HHB-67 (0.61 g/m^2 °C/day) possess higher HUE followed by PC-701 and RHB-223 (0.50 g/m^2 °C/day). Among cultivars, the highest AGDD were Fig-b Heat use efficiency of crop growing environment observed in HHB-67 (1241.50 °C/day) from emergence to physiological maturity and least RHB-223 (1160.85 °C/day). Among cultivars, the highest AHTU were observed in HHB-67 (5750.23°C/day/ hours) from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18^{th} July). Among cultivars, HHB-67 had higher HUE (0.61 g/m^2 °C/day) followed by PC-701 and RHB-223 (0.50 g/m^2 °C/day).

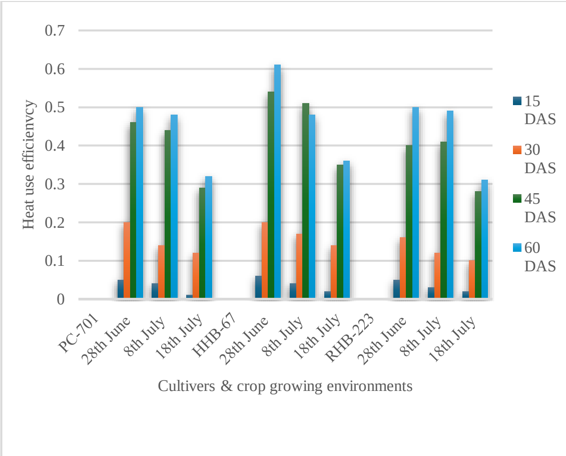

Fig-b Heat use efficiency of crop growing environment

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Evaluation of the cost of sylvo-pastoral site development operations: The case of a half-moon site in the Ouallam/ Niger department

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***Abstract*— *In Niger in general, and in its western part in particular, natural ecosystems have been undergoing continuous degradation for decades. In response, unprecedented efforts are being made to reclaim degraded land. This article assesses the cost of creating one hectare of sylvo-pastoral land in the rural communes of Simiri and Tondikiwindi (Ouallam department, Niger). Based on interviews, the cost was assessed by identifying the players involved and the equipment used. Daily remuneration, equipment depreciation, market price and load calculations were used to establish the monetary value of the cost. The people who carry out the work in the field are essentially the beneficiaries, who provide the labour and the technical supervisors. One hectare requires 105 diggers, 2 plotters and equipment. The direct and indirect monetary costs of developing one hectare of sylvo-pastoral half-moon site are estimated at 163,555 and 116,500 CFA francs respectively. The year of implementation covers the essential costs. This work has enabled us to understand the human resources and costs involved in developing a sylvo-pastoral site.*

***Keywords*— Land reclamation, cost, sylvo-pastoral, Ouallam.**

I. INTRODUCTION

As in the Sahel, the people of Niger are essentially rural (Issoufou et *al*., 2011) and are heavily dependent on natural resources to satisfy their needs, including timber and non-timber forest products (Alio et *al*., 2022). This dependence has consequences for landscape dynamics. For several decades now, the country has been experiencing a gradual degradation of its environment. The degradation of forest resources is causing physical, chemical and biological changes to ecosystems, leading to a breakdown in the services they can potentially provide (Ay et *al*., 2020 ; Moussa et *al*., 2023).

Moreover, the factors influencing the dynamics of land degradation are numerous and complex in their interactions (Moussa et *al*., 2022). To deal with this, sustainable land management (SLM) techniques are nowadays strategies for adapting to land degradation and climate change. With this in mind, Niger has embarked on a national policy to protect and restore the environment (GIZ and KFW, 2015 ; Fourera et *al*., 2019). Since then, the State, in collaboration with technical and financial partners, has been carrying out activities to restore degraded land by implementing water and soil conservation (WSC) and soil defence and restoration (SDR) techniques, in order to rehabilitate the vocations of degraded ecosystems.

Activities such as reclaiming degraded land are being carried out in a context of strengthening people's resilience. The Ouallam department has benefited from the construction of anti-erosion works, in particular half-moons. As part of the biological treatment, woody species such as *Eucalyptus camaldulensis* have been planted (Laminou et *al*., 2020 ; Moussa et *al*., 2024). The works are generally carried out on community areas, specifically on plateaux, resulting in the existence of sylvo-pastoral sites with beneficiary populations (Moussa et *al*., 2017 ; Moussa, 2018).

Developing a site therefore requires equipment and human resources, resulting in a cost that depends on the type of work, the actors involved, including the donor, and the objectives of the intervention (GIZ, 2012 ; Hamidou, 2017). The aim of this study is to assess the cost of developing one hectare of half-moon sylvo-pastoral site (DLSP). Specifically, the aim is (i) to identify the human and technical resources mobilised for implementation and (ii) to estimate the monetary cost of creating one hectare.

II. METHODOLOGY

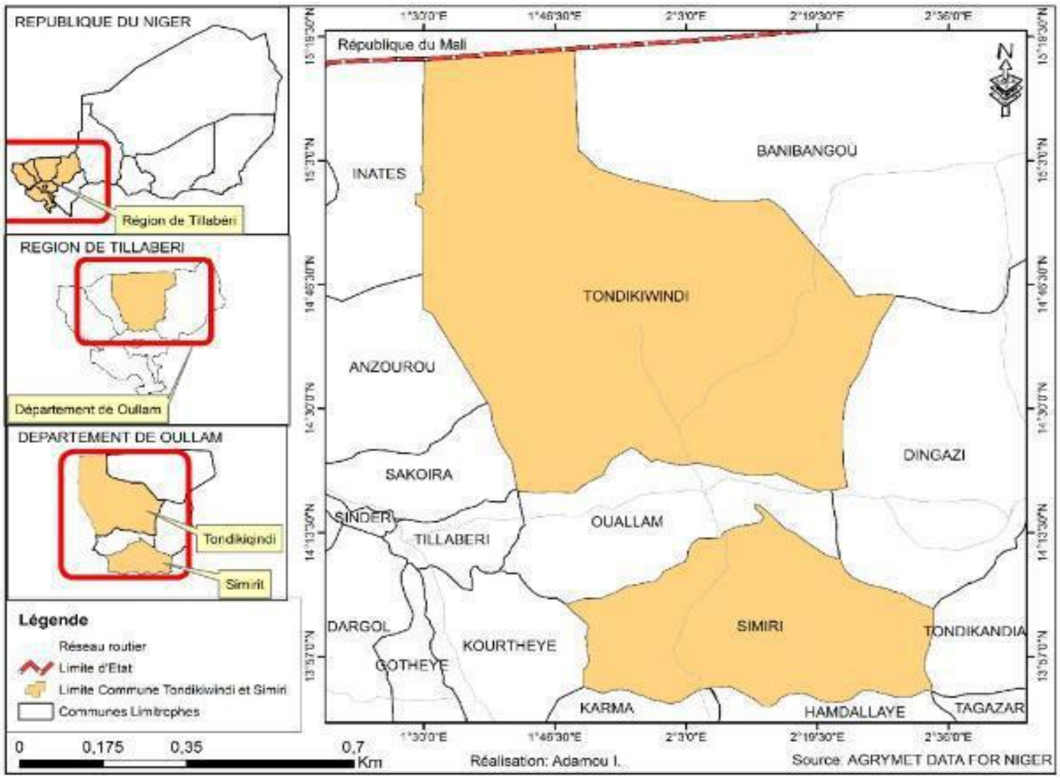

Fig. 1: Location of the communes of Simiri and Tondikiwindi

The cost evaluation was carried out using direct, semi-structured interviews with resource persons (community leaders) among the beneficiary populations, departmental government technical services, agents of the non-governmental organisation (NGO) responsible for implementing the activities and local authorities, particularly village chiefs. Table 1 shows the number of people surveyed by category.

Table 1 : Sample surveyed as part of the cost estimate

Population	Workforce
Resource persons	
Village chiefs	3
NGO agents	6
State technical services	3
Other resource persons	6
Beneficiary population	
Focus group	3 focus groups (around 10 people per focus group)

Source: Our surveys

Data was collected in the villages of Satara (Simiri rural district), Darey and Tondibiya (Tondikiwindi rural district). These villages were chosen because of the experience (more than a decade) of the local people in restoring degraded land for silvo-pastoral use. We also note the successes achieved, and the motivation and commitment of these communities to restoring and preserving their natural resources. Figure 1 shows the location of the communes of Simiri and Tondikiwindi.

The main questions asked of the people surveyed concerned the types of structures built, the role of each actor involved in building the structures and the nature of the remuneration. The evaluation methods adopted to estimate the cost of construction (Table 2) relate to one hectare of sylvo-pastoral half-moons. It should be noted that there are direct and indirect costs. The evaluation focused more on the (direct) costs of building and installing the structures.

Table 2: Parameters and methods for assessing direct cost

Operations/Materials	Valuation methods
Making the work (DLSP)	
Tracing	Daily remuneration
Digging	Daily remuneration
Tailoring equipment	Depreciation and cost of equipment
Biological enhancement	
Seeding of herbaceous plants	Market price or replacement costs
Acquisition of woody plants	Production price by the NGO
Transport of plants to the site	Cost of investment by the NGO
Planting of plants	Remuneration per planted crop

Source: Authors

The various formulas used to determine expenses are as follows:

$$\mathbf{Am} = \frac{\mathbf{Pm}}{\mathbf{Dv}}\ (A)\ ;\quad \mathbf{Rm} = \frac{\mathbf{Re}}{\mathbf{Nj}}\ (B)\ ;\quad \mathbf{Ct} = \mathbf{Pu} \times \mathbf{Np}\ (C)\ ;\quad \mathbf{Cp} = \mathbf{Pu'} \times \mathbf{Pp}\ (D)$$

- (A): Am is depreciation, Pm is the price of the equipment and Dv is the lifetime of the equipment;
- (B): Rm is the average daily remuneration, Re is the monthly remuneration and Nj is the number of days in the month;
- (C): Ct is the cost of transport, Pu is the unit price and Np is the number of plants;
- (D): Cp is the cost of planting, Pu' is the unit price at planting and Pp is the number of plants planted.

The basic requirement (direct cost) for creating one hectare of sylvo-pastoral half-moon site is essentially made up of the cost of labour, the materials used to create the half-moon and the biological treatment (Table 3). The standard norm for creating a half-moon per hectare was 313 structures (PAC, 2006). Each beneficiary is required to dig three structures per working day. It therefore takes 105 people to dig one hectare of half-moon in one working day. In practice, the beneficiary population is organised into several teams (e.g. 20 people per team).

Table 3: Requirements for creating a hectare of sylvo-pastoral half-moon site

Headings	Quantities/ha
Number of DL/hectare	313
Plotters	2 men/day
Diggers	105 men/day
Equipment (Compass, pick and shovel, etc.)	1 kit
Herbaceous seed	25 kg
Number of plants	313

Source: Our surveys

Indirect costs have been estimated on an indicative basis, as donors and stakeholders have different rates of reimbursement (a day's mission may be paid at 15,000, 25,000 or 40,000 CFA francs, depending on the organisation).

III. RESULTS

3.1. Stakeholders involved in site development

Several stakeholders are involved in site development. They are interdependent and the role of each is decisive (Table 4).

Table 4: Actors involved in the management of sylvo-pastoral sites on the plateaux

Acteurs	Roles
Beneficiary population	It provides manpower and carries out field activities under the supervision of the implementing NGO.
Implementing NGO	It is responsible for managing all the activities of the project as a whole, under the supervision of the funding body.
State technical services	They are involved in supervising and monitoring.
Funding provider	He is the authorising officer, the instructor and the project manager.

Improving the well-being of the beneficiaries is at the heart of the concerns of all these players. The cost of implementation is therefore estimated on the basis of the activities carried out by those working in the field, who are essentially the beneficiaries, supervised by the NGO's technicians. The emphasis is therefore mainly on the cost of physical activities (Table 5).

Table 5: Players' roles and working tools

Actors	**Tasks**	**Work equipment**
Plotters	They mark out the structure in accordance with the technical standards for construction, including the determination of the slope, the level lines and the excavation component of the structure, represented by a semi-circle for the half-moon.	- Compass, water level; - Stakes and ropes; - Boots and gloves.
Diggers	They scour the earth to obtain the bowl and form the bead.	Pickaxe, shovel and crowbar.
Framers	They supervise the work and ensure that it is carried out properly.	Control tools such as tape measures, plugs, etc.

The work (Figure 2) is carried out before the rainy season, generally between January and April. In most cases, the work is followed by the sowing of herbaceous plants on the ridge. The woody plants are planted during the rainy season (Figure 3).

Fig. 2: Construction of the half-pipe: a: Undeveloped area; b: the first diggings following the tracing; c: construction at an advanced level and d: Ready-made half-moon

Fig. 3: Transporting seedlings for a plantation at Simiri

3.2. Monetary cost of activities

The monetary or direct cost of developing a silvo-pastoral site in its year of establishment is 163,555 CFA francs (Table 6). Most of the management work is carried out during the year of installation. The following years are devoted to site maintenance, in particular to repairing damaged structures, replanting and caretaking.

Table 6: Direct monetary cost of creating one hectare of sylvo-pastoral half-moon

Headings	**Quantities**	**Unit amount (CFA francs)**	**Total amount (CFA francs)**
Tracing and levelling	2 men/day	1,300	2,600
Digging	105 men/day	1,200	136,500
Depreciation of equipment	1 kit	3,500	60
Herbaceous seeding	25 kg	400	10,000
Herbaceous seeding	313 plants	25	7,825
Transport of seedlings to site	313 plants	5	1,565
Planting of seedlings	313 plants	5	1,565
Total			**163,555**

However, it should be noted that there are other charges relating to the development of degraded land. These costs vary according to the funding providers. Table 7 gives some indicative values.

Table 7: Additional costs of creating a hectare of sylvo-pastoral half-moon

Headings	**Quantities**	**Unit amount (CFA francs)**	**Total amount (CFA francs)**
Training for plotters and the survey team	2/day	15,000	30,000
Site foreman's duties	1/day	1,500	1,500
Host expenses	1/day	4,000	4,000
Supervisor's duties	1/day	5,000	5,000
Site caretaker expenses	1/day	1,000	1,000

Monitoring and supervision of the funding provider	3/day	15,000	45,000
Monitoring and supervision of government technical services	2/day	15,000	30,000
Total			**116,500**

The sum of the direct cost (Table 6) and the indirect cost (Table 7) gives a monetary cost per hectare of 280,055 CFA francs (163,555 + 116,500). This cost estimate is indicative, as the amounts for the various headings vary according to the donor's financial capacity, mandate and objectives.

In addition, the State of Niger, through the Ministry of the Environment and the Fight against Desertification (ME/LD), has drawn up a compendium of technical sheets on good practice in sustainable land management (SLM). Updating this compendium in 2022 has resulted in a cost per hectare for building the sylvo-pastoral half-moon (Table 8).

Table 8: Cost of producing the sylvo-pastoral half-moon per hectare of the compendium of technical sheets on good sustainable land management (SLM) practices in Niger (ME/LD, 2022)

Headings	**Unit**	**Quantities**	**Price per unit (CFA francs)**	**Amount (CFA francs)**
Labour planning and tracing	M/d	4	2,000	8,000
Labour to make the work	M/d	105	2,000	210,000
Purchase of forestry plants	Plants	313	100	31,300
Transporting plants	Plants	313	100	31,300
Small equipment kit (daba, pickaxe, shovel, compass, level, rope, etc.)	FF[1*]	1	3,500	3,500
Personal protective equipment (PPE): Boots, gloves and masks, etc.	FF[2*]	1	300	300
Herbaceous seeding (seed)	Kg	5	5,000	25,000
Spreading	M/d	1	2,000	2,000
Regarnis in 2nd year: purchase, transport and planting	M/d	104	200	20,800
Security (over 3 years)	M/y	3	20,000	60,000
Management	M/d	1	7,000	7,000
Total investment				**399,200**

NB: These costs are indicative and may vary depending on the context.

1*: This cost is calculated on the basis that a team of 60 people uses an equipment kit (daba, pickaxe, shovel, compass, water level, rope, etc.) costing 350,000 CFA francs and will be amortised over 100 ha in one year.

2*: This cost is calculated on the basis that a team of 60 people uses PPE (boots, gloves and masks, etc.) costing 30,000 CFA francs and will be amortised over 100 ha in one year.

IV. DISCUSSIONS

In practice, the population is organised into teams, the size of which depends on the number of beneficiaries in the sector. Each team has its own players (tracers, diggers and inspectors). A beneficiary household is represented at the work by a member of the household. This member could be a woman or a man, referred to as an able-bodied arm. Nevertheless, there are beneficiary households that do not take part in the physical work. These are referred to as households without able-bodied arms (HWAA). A household without an able-bodied arm is one in which none of its members is fit to take part in the physical work, but was entitled to the same rights as the households with an able-bodied arm (HAA) that carried out the fieldwork. This consideration of disabled households is the responsibility of a donor with a humanitarian mandate. The humanitarian donor that financed the sites in this study was the World Food Programme (WFP) in collaboration with local NGOs.

The cost of creating a silvo-pastoral site includes the cost of building the structures and biological treatment (François and Souleymane, 2006). During the first years of the project, each beneficiary had to dig three structures per working day. On average, 105 people dug one hectare of half-moon. Seeds for herbaceous plants generally came from the farmers or from reclaimed sites. Woody plants for planting were also produced in village nurseries. Replanting often takes place in the first year or the following year. According to GIZ (2012), creating one hectare of forest half-moon requires a workforce of 100 people per day to mark the contour lines, draw the outline of the half-moons in staggered rows, dig the micro-basins (troughs), create the ridge, dig the planting holes, sow the ridges with herbaceous plants and plant the woody plants. GIZ (2012) estimated the quantity of plant material to be brought in at 15 kg of herbaceous seeds, 625 tree seedlings and 120 seedlings for replanting dead individuals.

In the case of this study, remuneration is generally in kind (food). This is obvious when we know that the lessor is the WFP. However, during the surveys, a few cases of cash payments were recorded, which made it possible to estimate the daily remuneration. The average daily pay for a beneficiary was 1,300 CFA francs. In their work on the socio-economic impact of the creation of sylvo-pastoral sites with half-moons and benches at Satara (Simiri commune), Moussa et *al*. (2017) reported that the production of three half-moons/day was paid at 1,300 CFA francs and planting at 25 CFA francs per plant. These results are in line with those found in the present study. On average, 104 people worked on the construction of one hectare of half-moon forest. According to Particip (2005) in GIZ and KFW (2015), the total direct unit investment cost of one hectare of forest half-moons is 147,577 CFA francs. This result is close to that of the present study, which is estimated at 163,555 CFA francs /ha in the first year (direct cost). In addition, the collection of technical sheets on good practice in sustainable land management (SLM) from the Ministry for the Environment and the Fight against Desertification (ME/LD, 2022) resulted in an indicative cost of 399,200 CFA francs. The indicative nature of the cost and the context of the intervention are at the root of the differences noted between the different costs of creating a hectare of half-moons. The financial backers do not all have the same financial capacity or mandate. For example, the World Food Programme (WFP) and a local NGO do not have the same financial capacity or mandate.

In addition, the agricultural half-moon is relatively less expensive than the sylvo-pastoral half-moon built on the plateaux. Because of the difference in soil types (between plateaux and glacis in agricultural fields), fewer able-bodied workers are needed to make the agricultural half-moon. According to GIZ (2012), 50 people a day can make a hectare of agricultural half-moon, compared with 100 to 105 people for the forest half-moon and sylvo-patorale. One person can carry out just over 6 agricultural half-moons compared with 3 forest half-moons per day. According to Jangorzo et *al*. (2019), the cost of producing one hectare of agricultural half-moon is 114,000 CFA francs, or 364 CFA francs per work.

However, it should be noted that the cost of building a site and the nature of the remuneration of the populations depended on the funding provider and the objectives targeted. In the case of a donor with a humanitarian mandate, the cost is quite high, as the population is assisted beyond their efforts. This is corroborated by the existence of households without valid arms (HWAA) who did not take part in the work, but received the same rewards as those who did. With regard to the nature of the remuneration, depending on the donor and the context, people are paid in cash (Cash For Work) or in food (Food For Asset). In the study by Hamidou (2017) on assessing the impacts of a half-moon site in Ayorou (Tillabéri-Niger), the beneficiaries of the recovery work are paid exclusively in food.

V. CONCLUSION

At the end of the assessment of the investment cost, it emerges that several players are involved in the recovery of degraded land. Each has its own role to play and uses its own means to fulfil it.

Assessing the cost is complex, as it could be estimated at several levels due to the diversity and interdependence of the players involved. The cost of creating a sylvo-pastoral site, as estimated in this study, covers both direct and indirect expenses. The latter vary according to the players involved. The cost obtained is relatively low and bearable for the donors.

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Spatio-temporal dynamics of fodder availability in Mali: Case of the Sikasso Region

Dynamique spatio-temporelle de la disponibilité fourragère au Mali : Cas de la Région de Sikasso

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Abstract— *Livestock farming contributes to more than 10% of the Gross Domestic Product (GDP) (DNPIA, 2013). However, the aerial vegetation cover that supports this livestock is subjected to severe challenges due to recurring droughts, floods, and human activities. Today in Mali, it is imperative to develop a strategy to optimize the sustainable use of pastoral resources. This necessarily involves access to information on the spatiotemporal dynamics of forage resources, a challenge faced by technicians and policymakers responsible for livestock management in Mali. The present study, initiated to characterize the spatiotemporal dynamics of forage resources in the Sikasso region, could provide stakeholders with essential information for developing an effective and sustainable management strategy. The analysis of collected data highlighted the significant variability in rainfall data from 1980 to the present and particularly from 1999 to 2012. It also provided insights into forage availability, which was largely higher than the region's needs. The surplus was estimated at 6,950,099 tons in 2020, indicating that the region could accommodate additional livestock. The spatiotemporal mapping of the Dry Matter Production (DMP) showed that the critical periods of the year are February, March, and April. This period may extend into May if rainfall is insufficient. Forecasts also indicate that forage availability will continue to decline until 2050 if no action is taken. The rate of decline is expected to be steep in July from 2025 to 2050. In conclusion, the objective of this study has been achieved, as the results presented can assist in making appropriate decisions.*

Keywords*— *Livestock farming, Forage resources, Spatiotemporal dynamics, Rainfall variability, Sustainable management

Résumé— *L'élevage contribue à plus de 10% du Produit Intérieur Brut (PIB), (DNPIA, 2013). Cependant, le couvert végétal aérien qui soutient cet élevage est soumis à de rudes épreuves liées aux sècheresses et inondations répétitives et aux activités anthropiques. Aujourd'hui au Mali, il s'avère impératif de développer une stratégie afin d'optimiser l'utilisation durable des ressources pastorales. Cela passe nécessairement par l'accès à l'information sur la dynamique spatio-temporelle des ressources fourragères, obstacle auquel les techniciens et décideurs en charges de l'élevage au Mali sont confrontés. La présente étude, initiée pour caractériser la dynamique spatio-temporelle des ressources fourragères en région de Sikasso, pourrait mettre à la disposition des acteurs des informations nécessaires au développement d'une stratégie de gestion efficace et durable. Le traitement des données collectée a permis de mettre en évidence la grande variabilité des données pluviométriques de 1980 à nos jours et la période 1999 à 2012. Il a aussi enseigné sur la disponible fourragère qui était largement supérieur au besoin de la région. L'excédent a été estimé de 6 950 099 tonnes en 2020, ce qui signifie que la région peut recevoir du bétail supplémentaire. La* *cartographie spatio-temporelle du DMP à montré que les périodes problématiques de l'année sont Févier, Mars, Avril. Il peut s'étendre à Mai si la pluviométrie est déficitaire. Les prévisions montrent aussi que les tendances de la disponibilité fourragère seront en baisse jusqu'en 2050 si rien ne s'est fait. La pente de la baisse sera forte en Juillet de 2025 à 2050. En conclusion l'objectif recherché par ce travail a été atteint car résultats représentés peuvent aider à des prises de décision idoine.*

***Mots clés* — Élevage, Ressources fourragères, Dynamique spatio-temporelle, Variabilité pluviométrique, Gestion durable**

I. INTRODUCTION

L'économie malienne est principalement basée sur l'agriculture, l'élevage et la pêche (MEADD, 2015). L'élevage contribue à plus de 10% du Produit Intérieur Brut (PIB) (DNPIA 2013). Il joue un rôle considérable dans la sécurité alimentaire en supportant la production de denrées alimentaires telles que le lait, la viande et en créant des revenus et des emplois (Makadji, 2014). II constitut aussi une source d'énergie (traction animale, biogaz), d'engrais et d'amendement de sols. Il permet d'utiliser les résidus de cultures et les plantes adventices. L'intégration de l'agriculture et l'élevage est considérée comme un important facteur de développement agricole durable. Cependant, le couvert végétal aérien qui soutient largement cet élevage est soumis à de rudes épreuves. Aujourd'hui au Mali, l'insuffisance de fourrage surtout pendant la période de soudure constitue une des principales contraintes de l'élevage (Coulibaly, 2007). La disponibilité du fourrage est fortement dépendante de la pluviométrie. La grande variabilité pluviométrique, les sècheresses et inondations répétitives (A. ICKOWICZ, V. MATHIEU, 2015, p.1) attribués aux changements climatiques et l'agrandissement continu des superficies cultivées ont eu comme conséquence la dégradation des écosystèmes pastoraux et la réduction des espaces réservés au pâturage. Inversement, le cheptel enregistre les taux de croissance les plus élevés (taux de croissance annuelle de 3% pour les bovins, et de 5% pour les ovins et caprins en 1991/92) (Cook, 1998). Et, avec l'insécurité grandissante dans le Nord et le centre du Mali (zone initialement réservée au pâturage), les éleveurs se sont trouvés dans la nécessité et/ou l'obligation de chercher un environnement propice à leur activité. Ce qui explique le déplacement d'un nombre important de bétails du Nord vers le Sud, zone la plus végétative et la plus stable du pays. Aujourd'hui il s'avère important de développer une stratégie pour optimiser l'utilisation et la gestion durable des ressources pastorales surtout fourragères dans cette zone pour la durabilité du secteur. Cependant, le principal obstacle auquel des techniciens en charge de l'élevage et décideurs sont confrontés réside dans l'absence d'information adéquate pour cerner la dynamique des ressources pastorales qui s'étendent sur de larges étendues. L'accès à l'information sur l'évolution du fourrage dans l'espace et dans le temps est primordial pour le développement d'une stratégie de gestion durable et approprié des ressources pastorales au Mali. Les images satellites et le Système d'Information Géographique, outil de traitement et d'exploitation des données multidisciplinaires offrent aux spécialistes et aux décideurs les moyens de prospection, d'étude et d'aide à la décision. L'objectif de cette étude était de contribuer à la gestion durable de l'élevage au Mali. Précisément, de caractériser la dynamique spatio-temporelle des ressources fourragères en lien avec les données pluviométriques.

II. MATERIELS ET METHODES

Site d'étude :

La figure 1 montre la localisation géographique de la région de Sikasso au Mali dans la carte des zones climatiques du Mali.

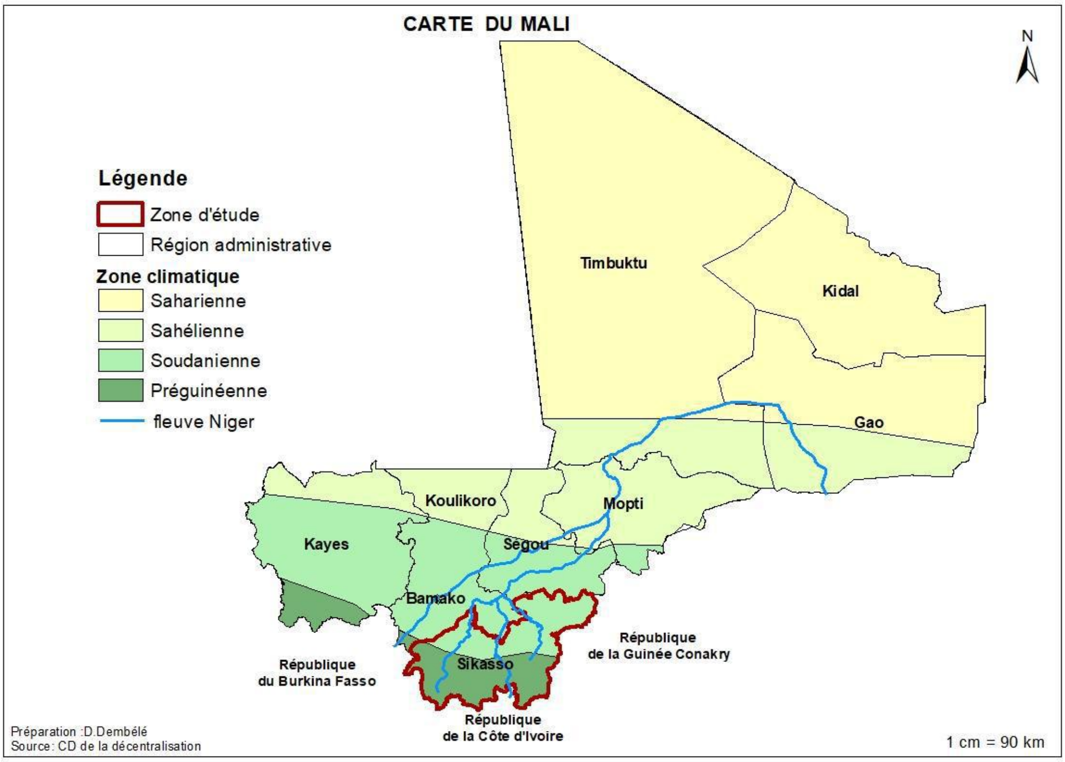


Fig.1 : carte de la situation géographique de la région de Sikasso

Les données :

Les données utilisées sont : les images satellites, les fichiers vecteurs de la zone d'étude les données pluviométriques et les données collectées à partir des enquêtes de terrain.

Images : les images utilisées sont le DMP (Dry Mater Productivity ou productivité de la matière sèche). Le DMP est un indicateur de la biomasse sèche. Il est directement lié à la NPP (Productivité Primaire Nette de Phyto-masse aérienne). Ces images ont été enregistrées par le capteur Spot végétation et archivées par le projet de surveillance environnementale pour le développement durable en Afrique (AMESD). Le DMP est exprimé en Kg/matière sèche/ha/jour. Il offre la possibilité d'estimer la production de la phyto-masse aérienne (Swinnen, 2015). Les images ont été soumises à des corrections géométriques et radiométriques dans le cadre du projet AMESD (African Monitoring of the Environment for Sustainable Development). Faute de disponibilité de données DMP pour les autres années, la période 1999 -2012 a été choisie pour analyse des données.

Données numériques : les fichiers vectoriels produits à partir de CD de décentralisation ont été utilisés pour délimiter et extraire les zones d'intérêt.

Données pluviométriques : elles ont été collectées auprès du service national de la météorologie du Mali.

Données de terrain : des échantillons de biomasse ont été prélevé dans quatre cercles représentatifs de la région de Sikasso notamment, Kolondiéba, Sikasso, Bougouni et Yanfolila. La méthode de la branchette a été utilisée pour estimer la biomasse ligneuse et celle du « point quadra » comme d'écrite par « Daget et Poissonnet » a été utilisée pour déterminer la biodiversité herbacée.

Données de résidus de récolte : elles ont été collectées auprès de la Direction Nationale de la Production Industrielle et Animale (DNPIA).

Le nombre d'UBT en 2020 a été calculé en utilisant le nombre de bétail recensé en 2019 multiplié par le taux de croissance annuel.

Traitement des données : les fichiers vecteurs de la région de Sikasso et images satellites couvrant la zone CEDEAO ont été utilisés sur Arc-GIS pour générer des images dérivées couvrant la région de Sikasso. Les données ont ensuite été classifiées. Un intervalle de 1000 kg/ha a été choisi entre les classes afin d'harmoniser et de faciliter les comparaisons. Les données pluviométriques des 30 et 14 dernières années ont été graphiquement représentées sur Excel afin de cerner la variabilité des précipitations et de faciliter le choix des périodes à étudier. La production de biomasse reçue des sites de prélèvement a été évaluée et extrapolée à l'hectare. Les relations entre la disponibilité fourragère et la pluviométrie ont été aussi analysées.

Prévision de la disponibilité en 2025 et 2050 : la différence de matière sèche entre 2002 et 2010 a été utilisée pour calculer le taux de croissance annuel. Et, ce taux de croissance à son tour été utilisé pour calculer les prévisions pour 2025 et 2050

III. RESULTATS ET DISCUSSION

3.1. Pluviométrie

Les figures 2 et 3 présentent l'évolution interannuelle de la pluviométrie totale annuelle de 1980 à 2012 et 1999 à 2012 respectivement. Les données annuelles oscillent en dents de scie indiquant la grande variabilité de la pluviométrie déjà soulignée par Mahé (1995). Les graphiques élucident les années les plus humides (1994 et 2010) et les plus sèches (1984 et 2002). Les cumules annuels pluviométrique les plus élevés étaient 1325.27mm et 1298.70 mm enregistrés en 1994 et 2010 durant les périodes 1980-2012 et 1999-2012 respectivement. Et, le cumule annuel le moins élevé était 707.86 mm mesuré en 2002 pour les deux périodes. La moyenne pluviométrique pour la période 1999-2012 (la période étudie) était 1019.256mm. La donnée pluviométrique annuelle la plus proche de cette moyenne est 1012.80mm enregistrée en 2008. Cette année 2008 a été donc choisie comme année moyenne. Ces 3 dates 2002, 2008 et 2010 ont été choisie pour l'analyse des données. Ainsi toute tendance future semblable à ces 3 dates pourra aider à une prise de décision idoine.

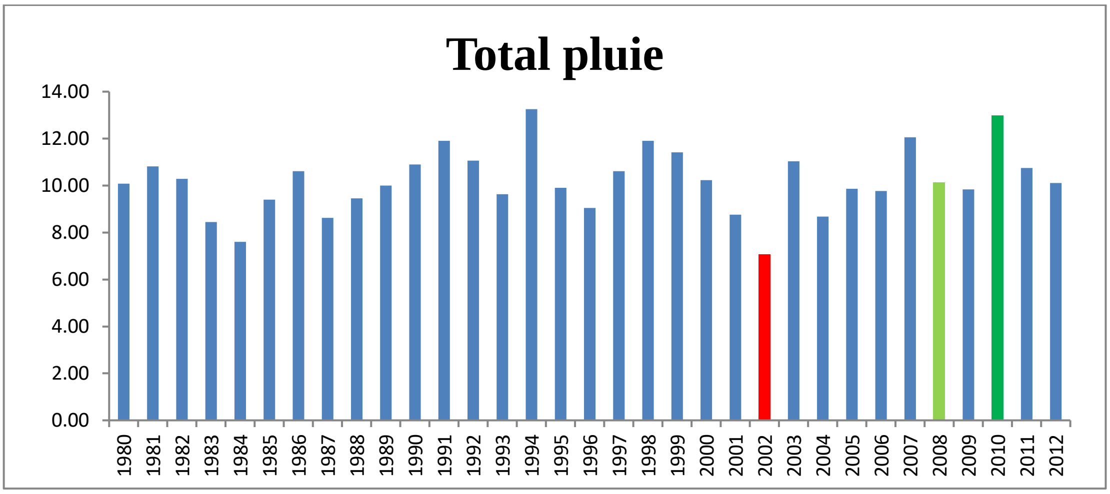


Fig.2: Evolution de la pluie totale annuel de 1980 à 2012 dans la région de Sikasso

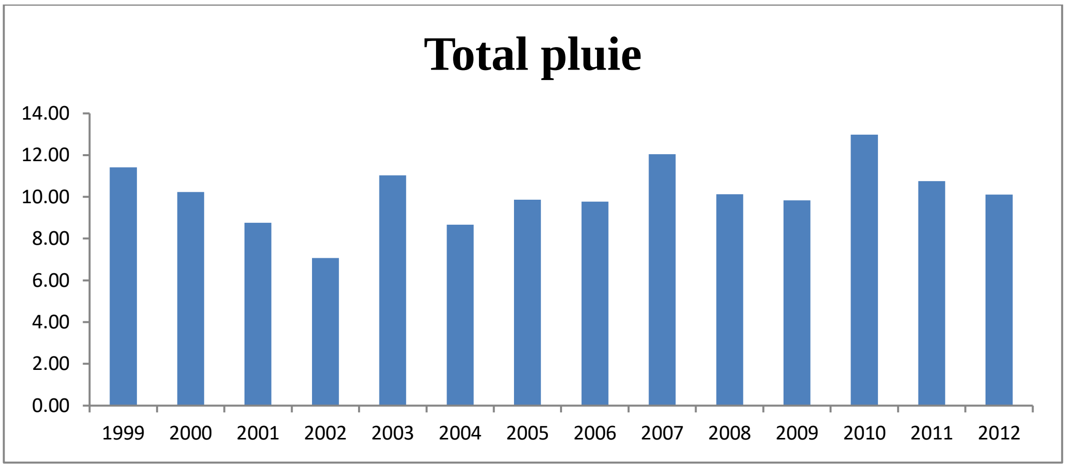


Fig.3 : Evolution de la pluie totale annuel de 1999 à 2012 dans la région de Sikasso

La figure 4 montre l'évolution inter mensuelle des pluviométries en 2002, 2008 et 2010. Le cumule le plus élevé a été enregistré en Aout en 2008 (année moyenne) et le cumule le moins élevé en juillet en 2002 (année déficitaire). L'allure de ce graphique montre encore la grande variabilité pluviométrique.

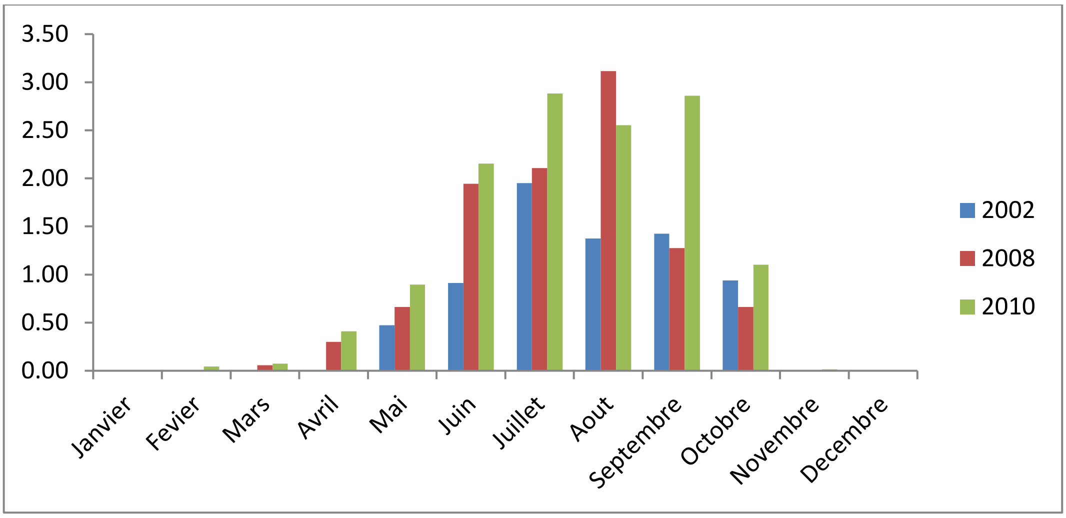


Fig.4 : Evolution des pluies totales mensuelles en 2002, 2008 et 2010 dans la région de Sikasso

3.2. Les Ressources fourragères

Le fourrage est toute substance d'origine végétale à l'exception des grains servant à la nourriture et à l'entretien du bétail en particulier plantes, tiges, feuilles et racines fraîches ou séchées de prairies naturelles ou artificielles (COLETTE Cl., 1922, p. 19).

Les sources de fourrage dont il est question dans cette étude sont constituées essentiellement des produits de pâturages naturels et des résidus de récolte.

Le pâturage naturel dans la région de Sikasso est principalement composé de la végétation de savanes claires et arbustives à herbacées annuelles et pérennes en zone soudanienne et de savanes boisées et forêts claires à herbacées pérennes en zone Nord-Guinéenne (sud de la région). Les espèces ligneuses jouent un rôle important pour combler le déficit en protéine en saison sèche.

Après les récoltes, les zones de culture libèrent chaque année d'importantes quantités de résidus consommés par le bétail (Blanchard, 2010, Kanté, 2001). Le potentiel de résidus consommable était évalué pendant la campagne 1997/1998 à 4.300.000 tonnes de matières sèches (PNDEM, 2003). Une partie est consommée au champ et l'autre est ramassée et stockée (Blanchard, 2010). Le tableau1 ci-dessous produit sous la direction de l'Institut d'Economie Rurale (IER) et de l'économie de filière ECOFIL en 1998 donne une idée sur la production de résidus de culture dans la région de Sikasso.

Tableau1: Quantité de sous-produits agricoles disponibles au cours de la campagne 1997/1998 (Unité en tonne) en région de Sikasso.

Mil	Sorgho	Riz	Maïs	Arachide	Niébé	Coton	Son céréales	Son riz	Fonio	Total
59571	176247	273223	150065	14253	4929	44341	234199	3942	5376	**966146**

Source *: IER / ECOFIL, 1998*

Le tableau2 élucide la quantité de résidus de récolte produite en 2019 en région de Sikasso. Le cercle de Sikasso avait enregistré la plus grande production. Le tableau3 montre la production de matière sèche à hectare en 2019. Le cercle de Bougouni avait produit la plus grande quantité de matière sèche.

Tableau 2 : Résidus de récolte disponible (tonne)

Cercle	Mil	Sorgho	Maïs	Fonio	Riz	Niébé	Arachide	Total
Sikasso	21 001	22 478	447 192	247	116 884	18 575	18 298	**644675**
Kolondiéba	1 662	3 026	34 860	2 347	26 902	784	7 726	77307
Bougouni	4 703	16 788	104 464	705	67 100	3 600	21 280	218640
Yanfolila	763	8 742	91 628	242	42 522	1 044	9 418	154360

Tableau 3 : Production de matière sèche en région de Sikasso (tonne/ha)

Cercle	Superficie pastorale (ha)	Production brute (TMS/ha)	Production disponible (TMS/ha)
Bougouni	2 728 090	17 096 940	**5 641 990**
Kolondieba	146 186	782 095	258 091
Sikasso	541 455	2 550 855	841 782
Yanfolila	354 440	1 837 063	606 231

TMS= Tonne de Matière Sèche

Le tableau 4 : présente le nombre d'Unité de Bétail Tropical (UBT) en 2020 dans la région de Sikasso. La disponibilité fourragère les besoins en fourrage et la différence entre le disponible et le besoin sont aussi présenté. L'analyse du tableau montre une balance excédentaire. Le fourrage disponible est largement supérieur aux besoins de la région. La zone est donc en capacité de recevoir un nombre important de bétail transhumant.

Tableau 4 : Disponibilité fourragère pour 2020

Cercles	UBT total en 2020	Fourrage disponible (TMS)	Besoin en fourrage (TMS)	Ecart (TMS)
Bougouni	481 029	5 913 294	721 543	5 191 751
Kolondiéba	167 069	338 931	250 604	88 327
Sikasso	457 007	1 741 361	685 511	1 055 850
Yanfolila	119 491	793 407	179 236	614 171
Total	**1 224 596**	**8 786 993**	**1 836 894**	**6 950 099**

TMS= Tonne de Matière Sèche ; UBT= Unité de bétail Tropical

3.3. La Disponibilité fourragère basée sur le Dry Matter Productivity (DMP)

L'information sur la disponibilité fourragère dans l'espace et dans le temps est très importante pour planifier la gestion durable des ressources pastorales. Les ressources végétales qui soutiennent principalement cette disponibilité sont essentiellement dépendantes des pluies. La quantité et la bonne répartition spatio-temporelle des pluies sont déterminent pour la croissance de la végétation et le stock de fourrage pour le reste de l'année (Garba, 2017). L'information spatio-temporelle sur le stock fourrager peut aider les éleveurs à optimiser les prises de décision pour anticiper ou retarder les mouvements de transhumance. Les zones d'accueil ont besoin aussi d'information pour faire face aux risques de surcharge et de conflits. Il est donc important de renforcer le dispositif d'évaluation de la production fourragère, d'informer et de situer les déficits fourragers dans les zones agro-pastorales.

Dans la région de Sikasso en 2002, la pluviométrie totale annuelle était de 707.87 mm et la production annuelle du fourrage a varié entre un minimum de 0 kg/ha en Mars et un maximum de 9887 kg/ha en Octobre. Cela signifie qu'en Mars 2002 le couvert végétal était totalement absent dans certaines localités de la région. En 2008, la pluviométrie totale annuelle était de 1012.80 mm et la production annuelle du fourrage a oscillé entre un minimum de 41 kg/ha mesuré en Févier et un maximum de 11725 kg/ha mesuré en Septembre. Et, en 2010, la pluviométrie totale annuelle était 1298.70 mm et la production annuelle du fourrage a balancé entre un minimum de 110 kg/ha mesuré en Févier et un maximum de 11340 kg/ha mesuré en Septembre.

Les tableaux 2, 3 et 4 ci-dessous montrent la variation mensuelle des données fourragères et pluviométriques en 2002, 2008 et 2010 respectivement. L'analyse de ces données montrent que la période déficitaire en région de Sikasso se situe entre Février et Avril. Une comparaison des 3 années montre que la pluviométrie et la disponibilité fourragère étaient plus déficitaires en 2002.

Tableau 5 : dynamique mensuelle de la disponibilité fourragère et la pluviométrie en 2002

Mois	Fourrage (kg/ha)	Pluie (mm)
Janvier	375 à 4847	0.00
Février	173 à 2858	0.00
Mars	0 à 2813	0.00
Avril	134 à 3197	0.00
Mai	123 à 5200	47.27
Juin	196 à 7498	91.13
Juillet	748 à 8549	195.20
Aout	764 à 9571	137.60
Septembre	1000 à 9491	142.60
Octobre	691 à 9887	94.07
Novembre	428 à 7038	0.00
Décembre	489 à 8141	0.00

Tableau 6 : dynamique mensuelle de la production fourragère et la pluviométrie 2008

Mois	**Fourrage** (kg/ha)	Pluie (mm)
Janvier	565 à 7531	0.00
Février	***41*** à 2128	0.00
Mars	155 à 3509	5.73
Avril	216 à 4174	29.90
Mai	274 à 7144	66.13
Juin	382 à 8726	194.57
Juillet	868 à 10953	210.80
Aout	365 à 11286	311.57
Septembre	2718 à ***11725***	157.67
Octobre	1370 à 9893	66.43
Novembre	817 à 7578	0.00
Décembre	594 à 5083	0.00

Tableau 7 : dynamique mensuelle de la production fourragère et la pluviométrie 2010

Mois	**Fourrage** (kg/ha)	Pluie (mm)
Janvier	389 à 6805	0.00
Février	166 à 4257	4.43
Mars	218 à 4152	7.33
Avril	***110*** à 5866	40.97
Mai	221 à 7475	89.53
Juin	800 à 9749	215.23
Juillet	583 à 11078	288.23
Aout	1666 à 10914	255.37
Septembre	1278 à ***11340***	285.87
Octobre	2329 à 10352	110.33
Novembre	858 à 6661	1.40
Décembre	733 à 5989	0.00

4.1. Dynamique spatiale du fourrage basé sur le Dry Matter Productivity (DMP)

Dans le but de comprendre la dynamique spatiotemporelle du fourrage en région de Sikasso, les figures numéro 5 à 17 ci-dessous ont été produites. Elles expliquent les changements au niveau du DMP dans l'espace et dans le temps sur les 3 années sélectionnées. L'analyse des figures montre que la production fourragère enregistrée était plus élevée en Septembre 2008 avec 11725 kg/ha et moins élevée en Mars 2002 avec 0 kg/ha. Elles clarifient aussi que la production fourragère augmente du Nord vers le Sud de la région en lien avec la pluviométrie qui augmente aussi dans le même sens.

Comparé aux deux autres années (2008 et 2010), 2002 a été l'année la plus déficitaire. Ce qui peut s'expliquer par le déficit pluviométrique enregistré la même année. Les graphiques en annexe montrent la distribution spatiale de la disponibilité en fourrage.

4.2. Prévision de la disponibilité du fourrage en 2025 et 2050

Le tableau 8 et la figure 5 ci-dessous montrent l'évolution des données fourragères de 2002 à 2010 et la prévision pour les années 2025 et 2050. Le constat est que le fourrage évolue de façon déficitaire notamment pendant les mois de Février, Avril et Juillet. Ce déficit est plus prononcé en juillet avec -40 kg/ha en 2050 si rien n'est fait. Ce résultat va en ligne droite avec le déficit des espaces pastorales, du couvert végétal et des productions végétales enregistrés pendant ces dernières années en générale au Mali.

Tableau 8 : Evolution prévisionnelle de la disponibilité fourragère

Mois	2002	2010	2025	2050
Janvier	375	389	403	442
Février	173	166	159	140
Mars	0	218	436	1042
Avril	134	110	86	19
Mai	123	221	319	591
Juin	196	800	1404	3082
Juillet	748	583	418	-40
Aout	764	1666	2568	5074

Septembre	1000	1278	1556	2328
Octobre	691	2329	3967	8517
Novembre	428	858	1288	2482
Décembre	489	733	977	1655

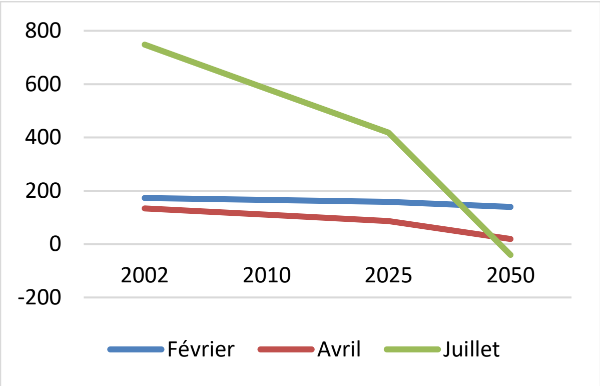
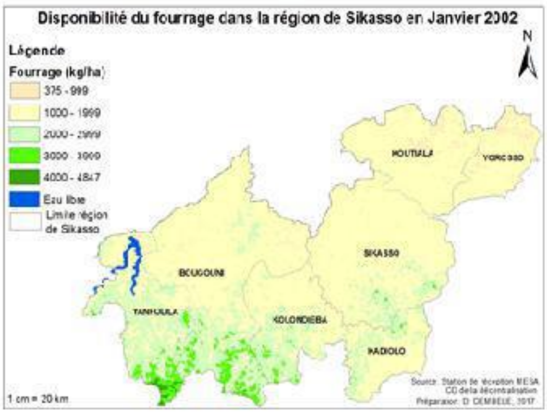


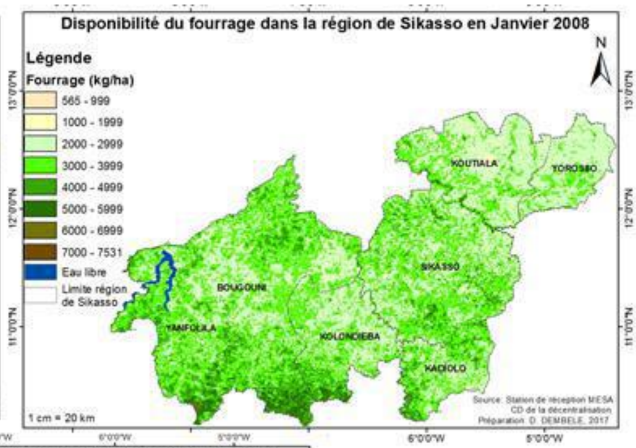
Fig.5 : Evolution de la disponibilité fourragère de 2002 à 2050

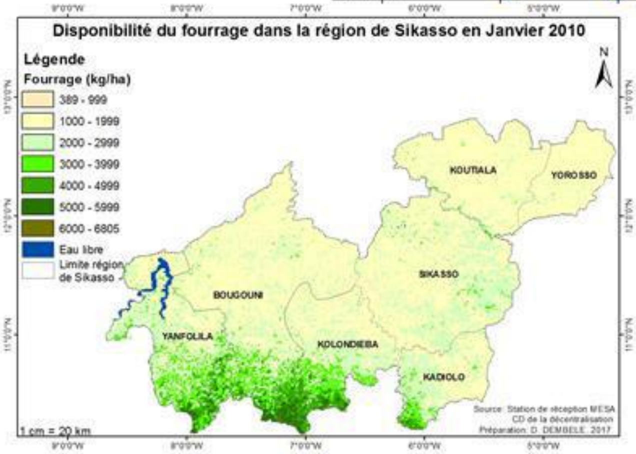
IV. CONCLUSION

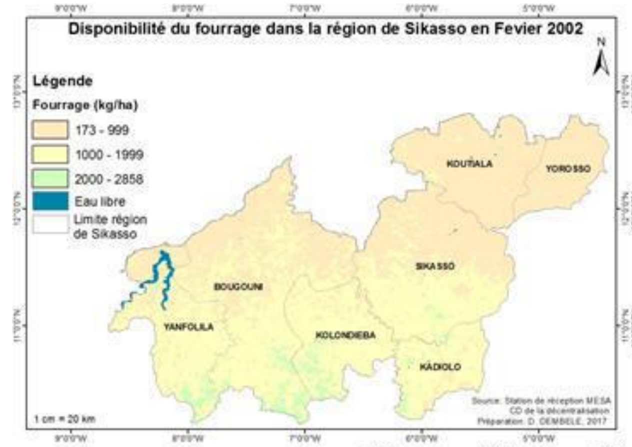
Le but principal de cette étude était de mettre à la disposition des acteurs de l'élevage de l'information spatiotemporelle sur la disponibilité fourragère pour les aider dans la prise de décision pour le développement d'une stratégie appropriée de gestion durable des ressources fourragère dans la région de Sikasso. L'utilisation combinée des données satellitaires, le SIG et les enquêtes de terrain ont facilité l'estimation, la cartographie de la distribution spatiale et la dynamique mensuelle du fourrage durant les années 2002, 2008, 2010. Il a varié en 2002 (année déficitaire en pluie avec 707.87 mm) entre **0 kg/ha et 9887** kg/ha. En 2008 (année moyenne avec 1012.80 mm) le fourrage a varié entre 41 kg/ha et 11725 kg/ha. Et en 2010 (année la plus pluvieuse avec 1298.70 mm) il s'est rangé entre 110 kg/ha et 110 kg/ha. Les variabilités spatiales sont présentées par les figures en Annexe.

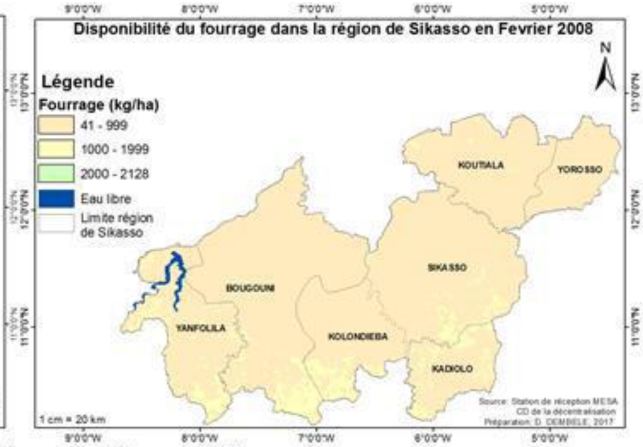
Annexe

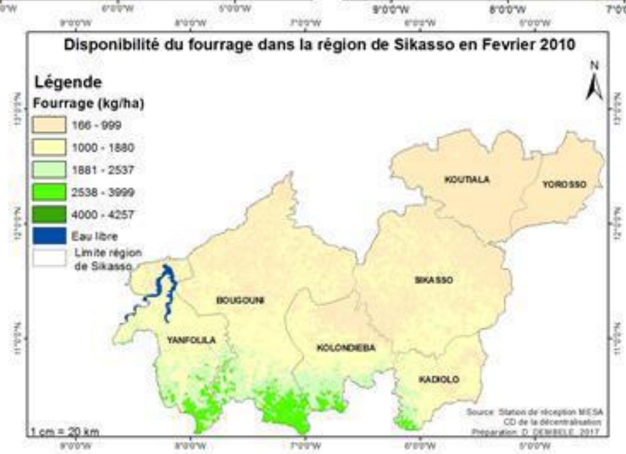






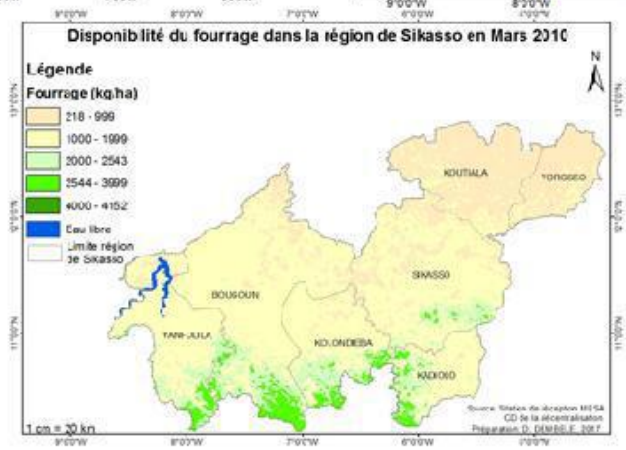

Disponibilité du fourrage dans la région de Sikasso en Fevier 2002
Légende
Fourrage (kg/ha)
173 - 999
1000 - 1999
2000 - 2858
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

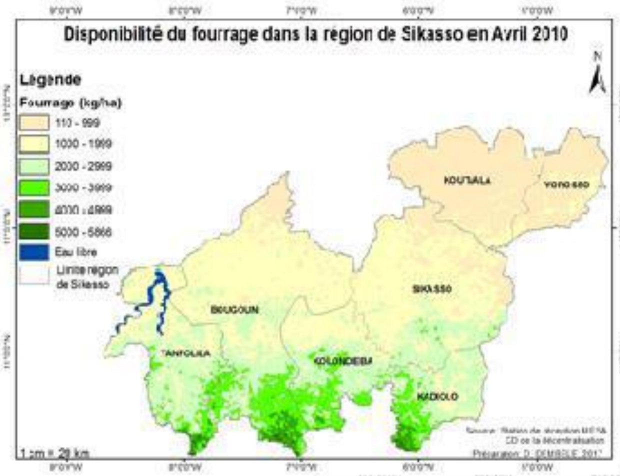

Disponibilité du fourrage dans la région de Sikasso en Fevrier 2008
Légende
Fourrage (kg/ha)
41 - 999
1000 - 1999
2000 - 2128
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

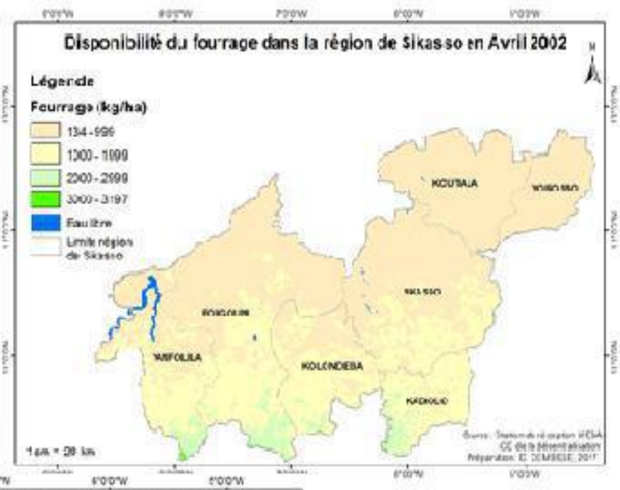

Disponibilité du fourrage dans la région de Sikasso en Fevrier 2010
Légende
Fourrage (kg/ha)
166 - 999
1000 - 1880
1881 - 2537
2538 - 3999
4000 - 4257
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

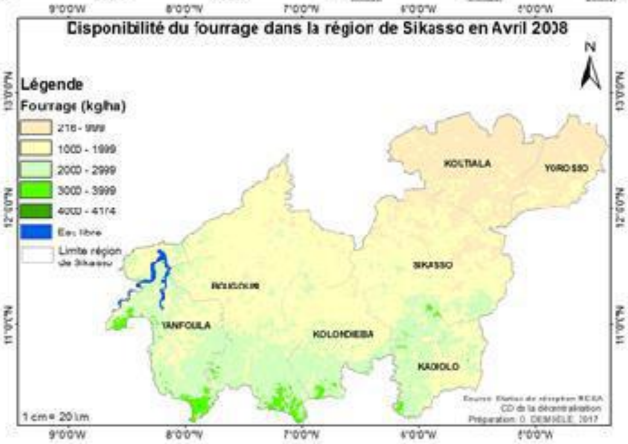

Disponibilité du fourrage dans la région de Sikasso en Mars 2002
Légende
Fourrage (kg/ha)
Eau libre
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA

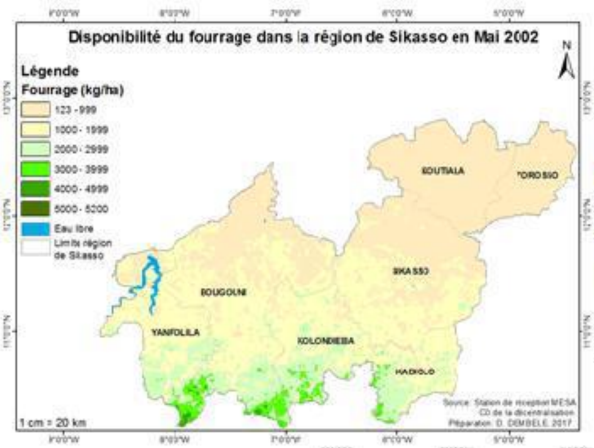

Disponibilité du fourrage dans la région de Sikasso en Mars 2008
Légende
Fourrage (kg/ha)
1000 - 1999
2000 - 2999
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

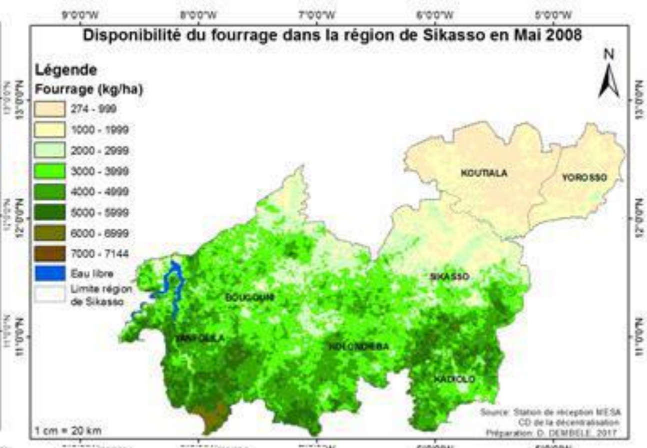

Légende
Fourrage (kg/ha)
218 - 999
1000 - 1999
2000 - 2543
Eau libre
KOUTIALA
BOUGOUNI
KOLONDIEBA

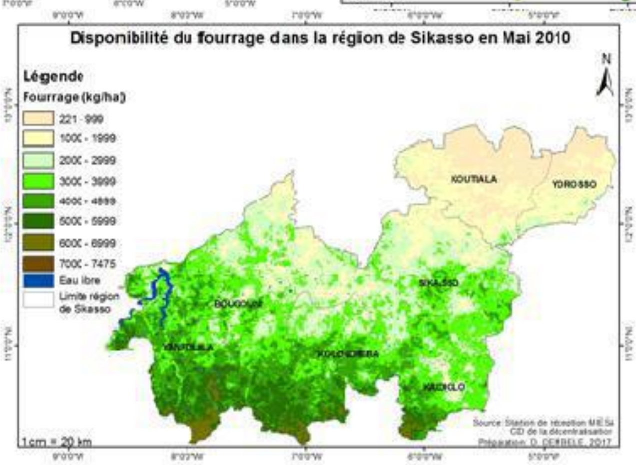

Disponibilité du fourrage dans la région de Sikasso en Avril 2010
Légende
Fourrage (kg/ha)
110 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5866
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

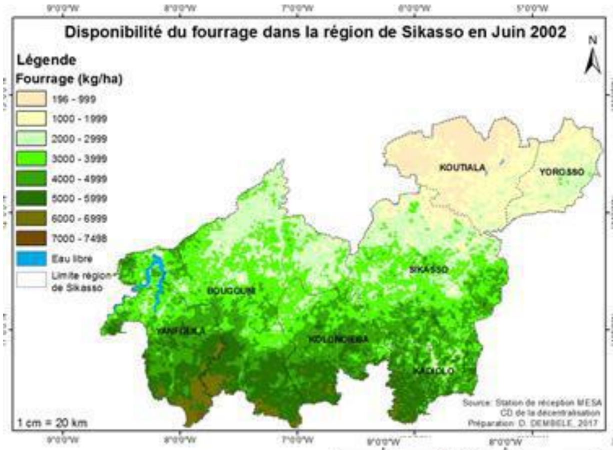

Disponibilité du fourrage dans la région de Sikasso en Avril 2002
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
KOUTIALA
SIKASSO
YANFOLILA
KOLONDIEBA
KADIOLO

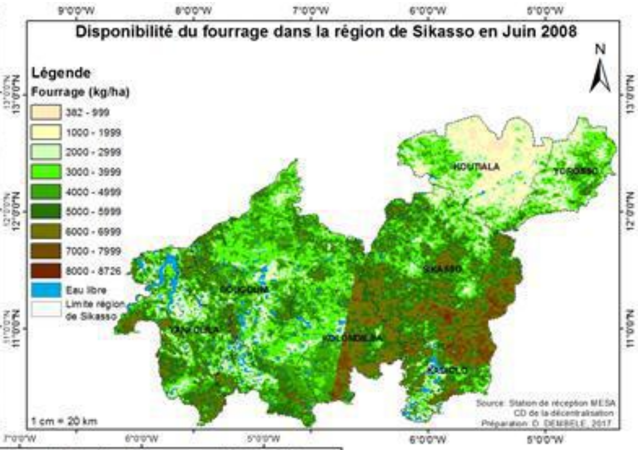

Disponibilité du fourrage dans la région de Sikasso en Avril 2008
Légende
Fourrage (kg/ha)
1000 - 1999
2000 - 2999
3000 - 3999
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Mai 2002
Légende
Fourrage (kg/ha)
123 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5200
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Mai 2008
Légende
Fourrage (kg/ha)
274 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7144
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km
Source: Station de réception MESA
CD de la décentralisation
Préparation: D. DEMBELE 2017


Disponibilité du fourrage dans la région de Sikasso en Mai 2010
Légende
Fourrage (kg/ha)
221 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7475
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Juin 2002
Légende
Fourrage (kg/ha)
196 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7498
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km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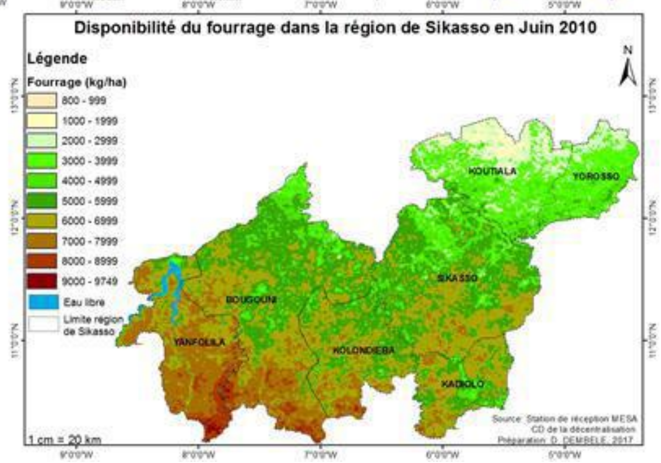
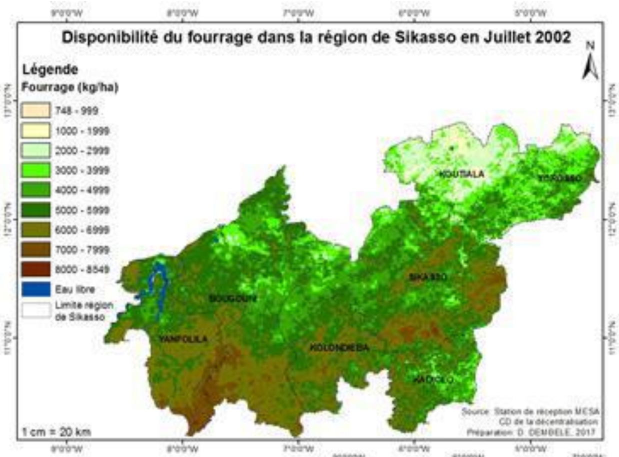
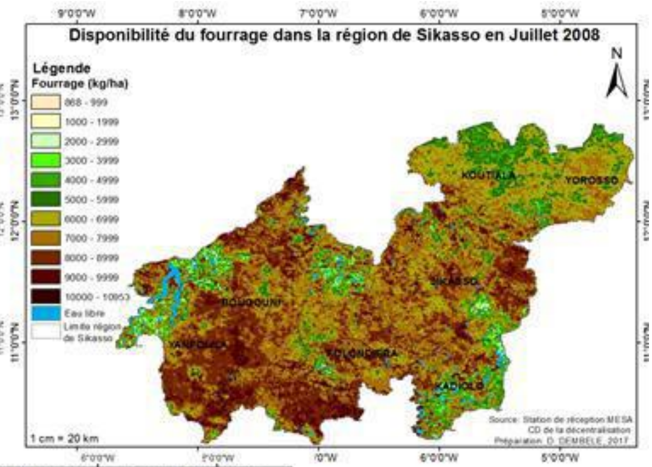
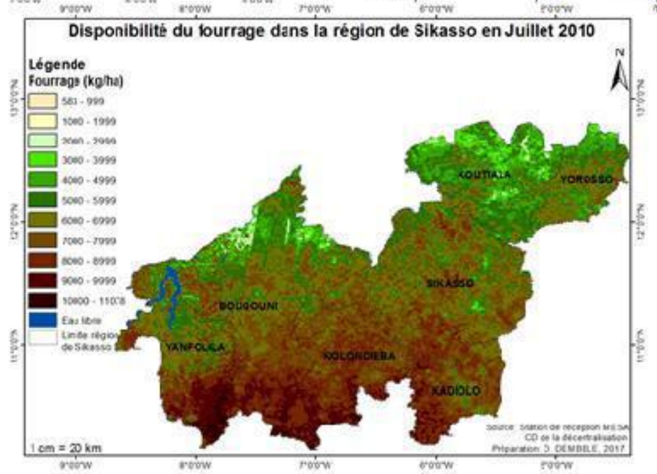
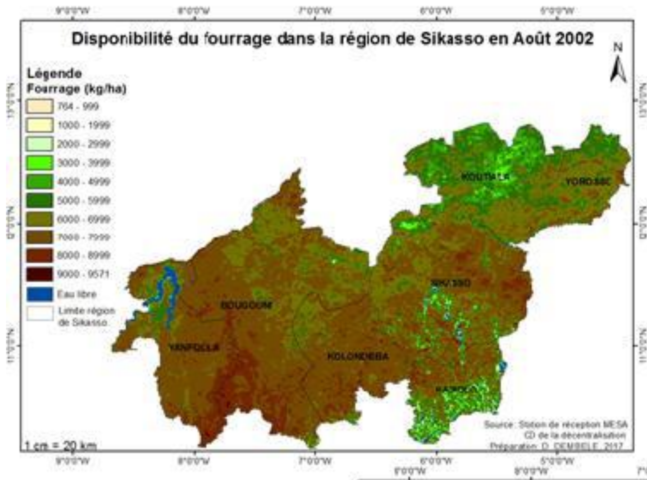
Légende
Fourrage (kg/ha)
382 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
8000 - 8726
Eau libre
Limite région de Sikasso
1 cm = 20 km

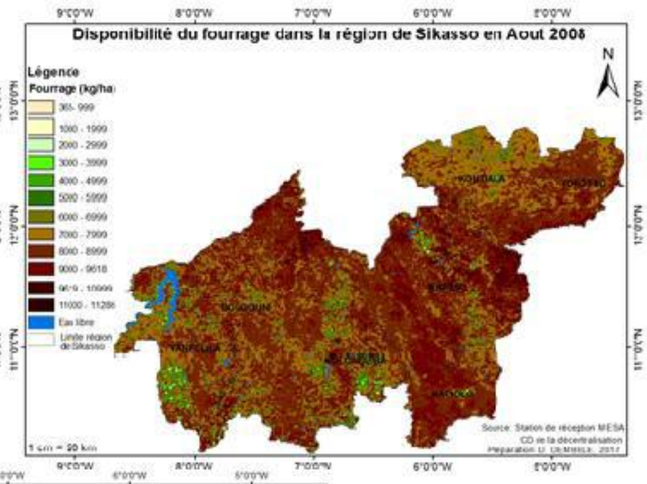

Disponibilité du fourrage dans la région de Sikasso en Juin 2010
Légende
Fourrage (kg/ha)
800 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
8000 - 8999
9000 - 9749
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

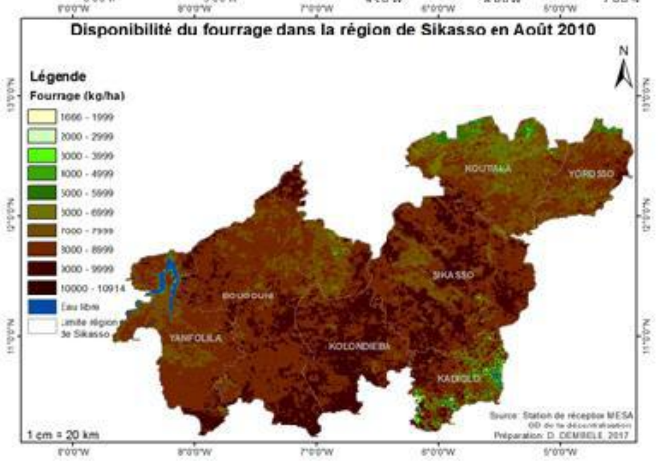

Disponibilité du fourrage dans la région de Sikasso en Juillet 2002
Légende
Fourrage (kg/ha)
748 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
8000 - 8549
Eau libre
Limite région de Sikasso
1 cm = 20 km

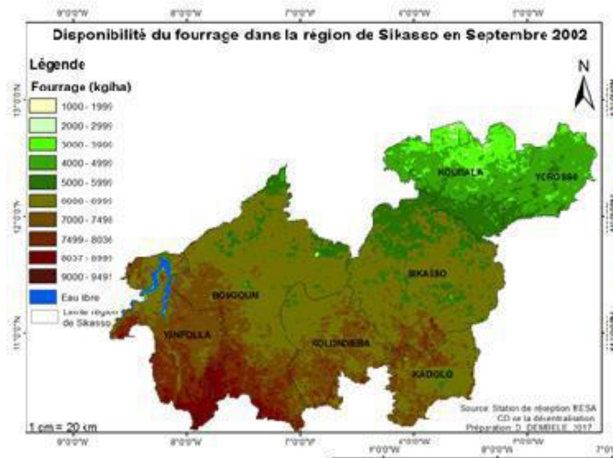

Disponibilité du fourrage dans la région de Sikasso en Juillet 2008
Légende
Fourrage (kg/ha)
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Juillet 2010
Légende
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Août 2002
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Août 2008
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
BOUGOUNI
YANFOLILA
KADIOLO


Disponibilité du fourrage dans la région de Sikasso en Août 2010
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Septembre 2002
Légende
Fourrage (kg/ha)
Eau libre
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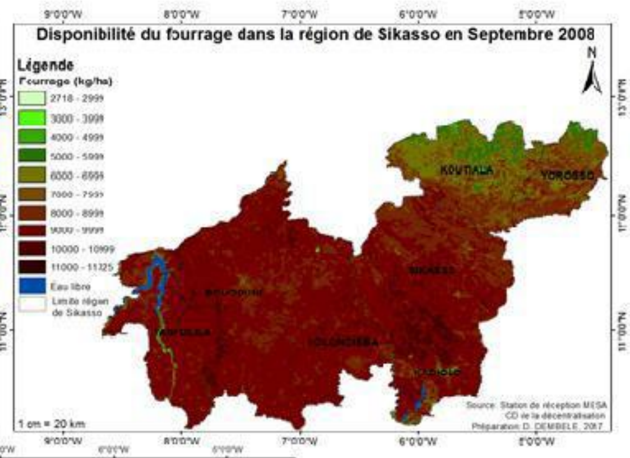
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Septembre 2008
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
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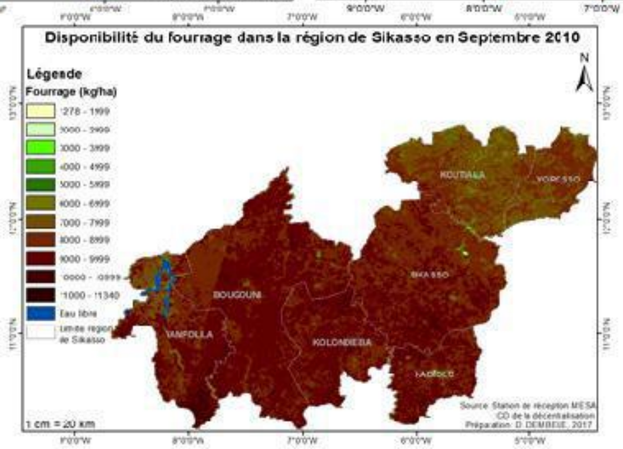
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Septembre 2010
Légende
Fourrage (kg/ha)
Eau libre
Limite région de Sikasso
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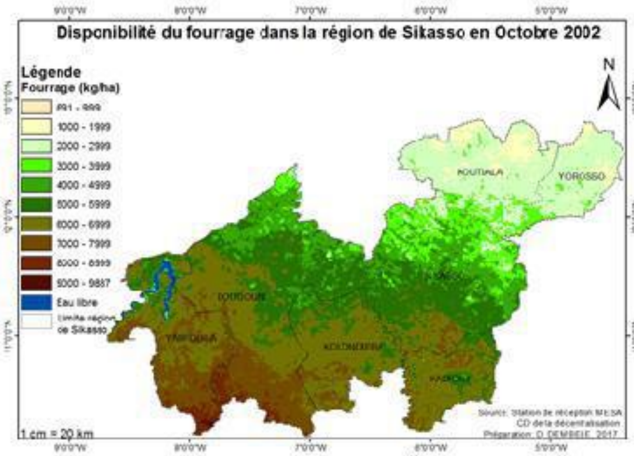
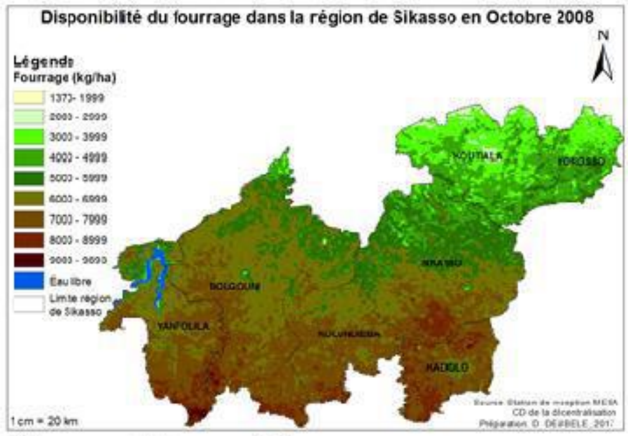
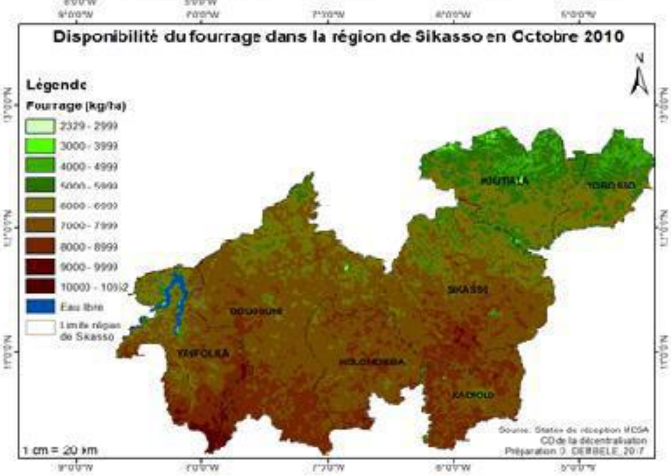
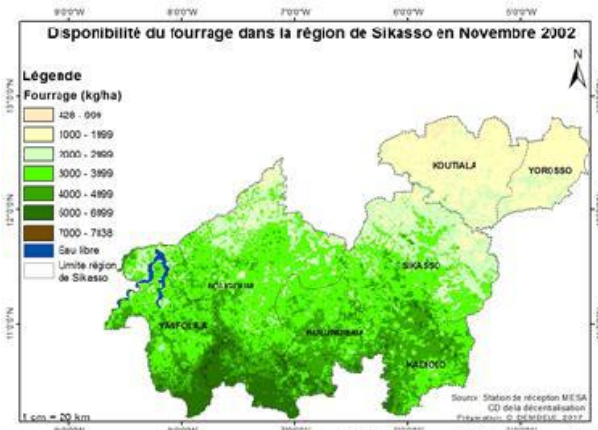
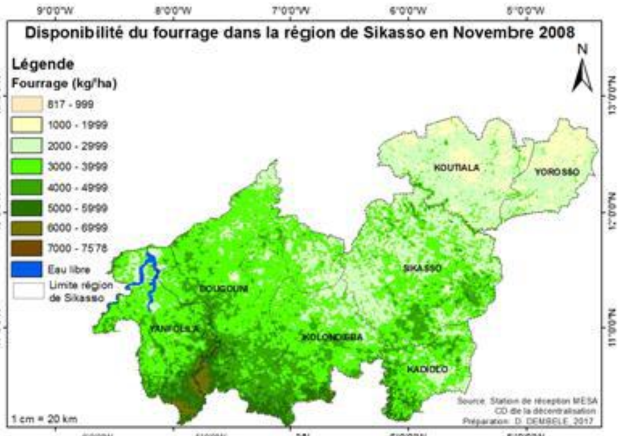
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

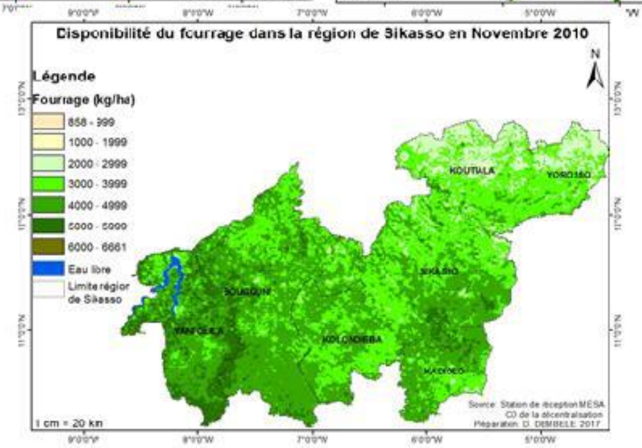

Disponibilité du fourrage dans la région de Sikasso en Octobre 2002
Légende
Fourrage (kg/ha)
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km

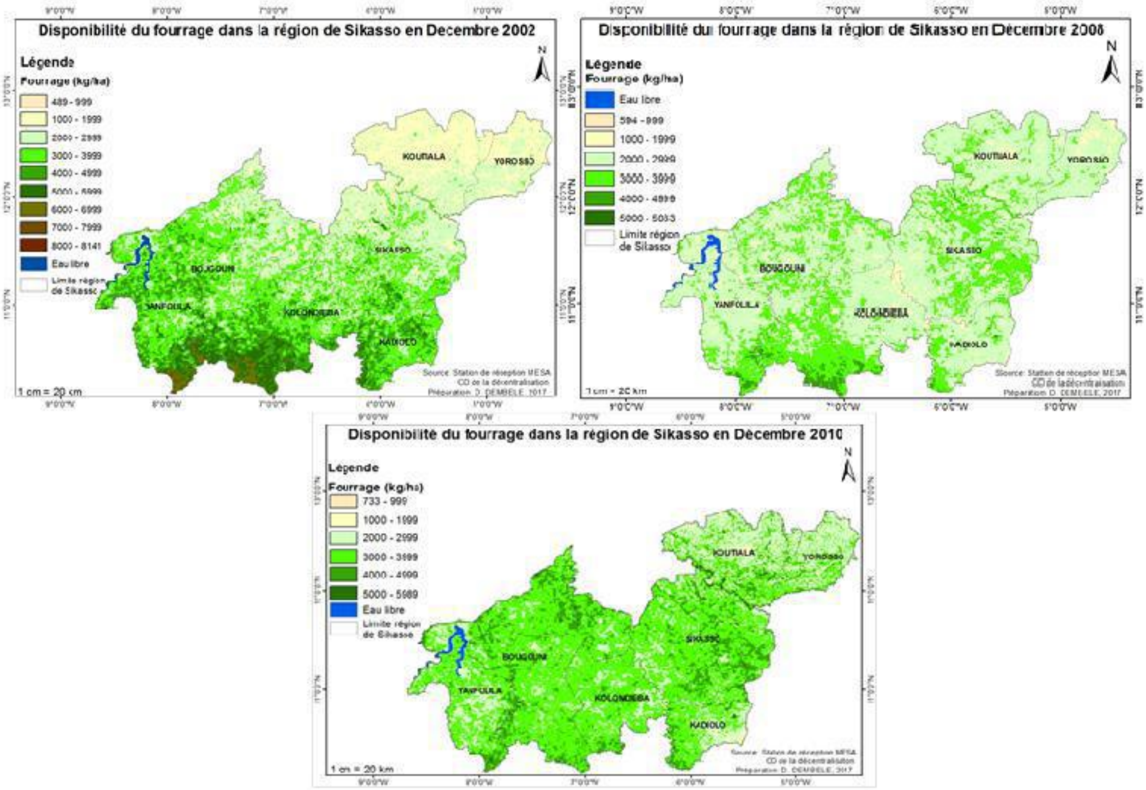

Disponibilité du fourrage dans la région de Sikasso en Octobre 2008
Légende
Fourrage (kg/ha)
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
8000 - 8999
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Octobre 2010
Légende
Fourrage (kg/ha)
2329 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7999
8000 - 8999
9000 - 9999
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km
Source: Station de réception MESA
CD de la décentralisation
Préparation: D. DEMBELE 2017


Disponibilité du fourrage dans la région de Sikasso en Novembre 2002
Légende
Fourrage (kg/ha)
1000 - 1999
3000 - 3999
4000 - 4999
5000 - 5999
7000 - 7838
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km


Disponibilité du fourrage dans la région de Sikasso en Novembre 2008
Légende
Fourrage (kg/ha)
817 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6999
7000 - 7578
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km
Source: Station de réception MESA
CD de la décentralisation
Préparation: D. DEMBELE 2017


Disponibilité du fourrage dans la région de Sikasso en Novembre 2010
Légende
Fourrage (kg/ha)
858 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
5000 - 5999
6000 - 6661
Eau libre
Limite région de Sikasso
KOUTIALA
YOROSSO
SIKASSO
BOUGOUNI
YANFOLILA
KOLONDIEBA
KADIOLO
1 cm = 20 km
Source: Station de réception MESA
CD de la décentralisation
Préparation: D. DEMBELE 2017



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Effect of Organic Fertilizers and Plant Growth-Promoting Rhizobacteria (PGPR) on Nutrient Residue and Growth of Rice (*Oryza sativa* L.)

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Abstract— *This study aims to evaluate the effects of organic fertilizers and Plant Growth-Promoting Rhizobacteria (PGPR) on rice (Oryza sativa L.) growth and fertilizer residues. The research was conducted at Jatimulyo Experimental Farm, Malang, using a split-plot design with 12 treatment combinations of organic fertilizers and PGPR. The results showed that the application of organic fertilizers increased soil organic carbon content, while PGPR contributed to improving nitrogen and potassium efficiency by reducing nutrient losses. However, the efficiency of phosphorus from inorganic fertilizers remained low, with most of the phosphorus retained in the soil and not absorbed by plants. Principal Component Analysis (PCA) revealed that plant growth parameters were more influenced by inorganic fertilizer treatments than organic ones. This research provides important insights for the development of sustainable agricultural technologies that enhance soil quality and reduce dependence on inorganic fertilizers.*

***Keywords*— organic fertilizer, PGPR, rice production, sustainable agriculture**

I. INTRODUCTION

Rice is a staple food in Indonesia, where the majority of the population depends on it as their primary food source. As the population grows, the demand for rice is expected to remain stable or even increase. In 2022, national rice production was recorded at around 55 million tons. East Java, one of the main rice production centers in Indonesia, has experienced a decline in productivity from 2020 to 2021, from 56.68 ku ha^{-1} in 2020 to 56.02 ku ha^{-1} in 2021 (BPS, 2023). This decline is an issue that needs serious attention, as it can affect food security in Indonesia.

One of the factors contributing to the decline in rice productivity is the excessive use of inorganic fertilizers by farmers. Overuse of fertilizers can result in negative impacts, such as decreased rice yields, soil degradation, greenhouse gas emissions, water pollution, and food insecurity (Smith & Siciliano, 2015). Soil, air, and water pollution caused by inorganic fertilizers can occur through leaching of nutrients, soil property degradation, and accumulation of toxic substances in water sources (Agbede, 2010). Therefore, the excessive use of inorganic fertilizers must be avoided to maintain agricultural sustainability and environmental quality.

As an alternative, the use of organic fertilizers can help improve soil conditions and provide the essential nutrients for plant growth. Organic fertilizers have the ability to enhance soil quality, improve its physical, chemical, and biological properties, and increase the population of soil microorganisms that function as decomposers. One example of organic fertilizers is manure, which contains humic acid, fulvic acid, hormones, and enzymes that are crucial for soil health and plant growth (Atmaja et al., 2019). Furthermore, utilizing baglog waste from the mushroom industry in East Java as an organic fertilizer can reduce environmental pollution caused by waste accumulation, by recycling it for agricultural use.

In recent years, the government has started to shift policies from conventional agriculture to organic farming systems. Organic farming is expected to help restore the environmental quality that has been degraded by excessive use of inorganic fertilizers. Although organic farming systems are often associated with lower productivity per unit area compared to conventional farming (Zhai et al., 2009), organic fertilizers focus more on improving soil properties rather than increasing immediate yields.

One approach to improving organic farming yields is the addition of PGPR (Plant Growth-Promoting Rhizobacteria), which are natural bacteria that colonize plant roots and assist in the decomposition of organic matter, nitrogen fixation, and the provision of other essential nutrients. The use of PGPR can reduce reliance on chemicals and support environmentally friendly and sustainable farming (Prasad et al., 2015)

This study aims to test the combination of organic fertilizers and PGPR as a solution to improve soil quality and avoid excessive use of inorganic fertilizers. During the first planting season, a substitution between organic and inorganic fertilizers was implemented, and it is expected that during the second planting season, the use of organic fertilizers together with PGPR can support sustainable rice production and improve soil fertility.

Thus, this research is expected to contribute to the development of more environmentally friendly and sustainable agricultural technologies, focusing on improving soil quality and reducing dependence on inorganic fertilizers.

II. METHODS

This study was conducted from March to July 2023 at the Jatimulyo Experimental Farm, Faculty of Agriculture, Brawijaya University, Malang, East Java, Indonesia. The tools used in this study included a leaf area meter (LAM), oven, analytical balance, camera, and SPAD. The materials used in this research consisted of Inpari 32 rice seeds, and fertilizers including urea, NPK fertilizer, organic fertilizer, and PGPR (Plant Growth-Promoting Rhizobacteria).

This study used a split-plot design, consisting of main plots and subplots. The main plots consisted of two PGPR treatments: without PGPR (R0) and with 15 ml per liter of PGPR (R15). The subplots consisted of six organic fertilizer dose treatments: (1) P0 = farmer's usual fertilization practice (500 kg ha^{-1} urea + 500 kg ha^{-1} NPK), (2) P1 = 100% inorganic (250 kg ha^{-1} urea + 275 kg ha^{-1} NPK), (3) P2 = 4.5 tons ha^{-1} organic fertilizer, (4) P3 = 7 tons ha^{-1} organic fertilizer, (5) P4 = 9.5 tons ha^{-1} organic fertilizer, and (6) P5 = 12 tons ha^{-1} organic fertilizer. A total of 12 treatment combinations were applied, repeated three times, resulting in 36 experimental plots. Each experimental plot consisted of 200 rice plant clumps, giving a total of 2,400 rice plant clumps used in this study.

III. FIGURES AND TABLES

Nutrient Residues

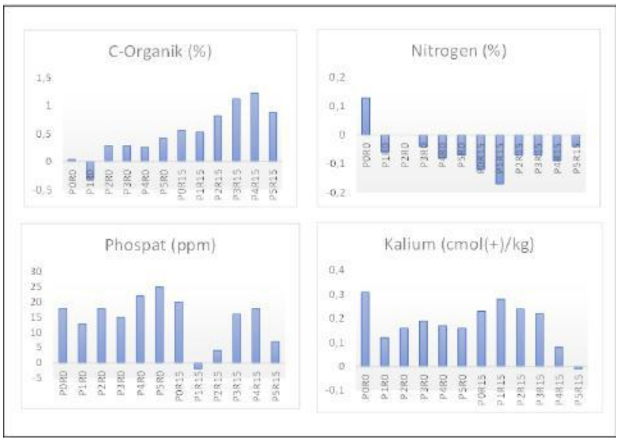

Fig.1. Nutrient Residue

C-Organic is an important parameter in determining soil quality, particularly in relation to fertility and the soil's ability to support crop productivity. The C-Organic graph shows a gradual increase in organic carbon content from treatment P0 to P5 and rotation up to R15.

At the start of the treatments (P0R0), the C-Organic content is very low, even approaching negative values. This indicates that the organic material content in the soil was relatively low initially, which may have been caused by previous soil management practices, such as excessive chemical use or the absence of organic matter inputs (Prakash, 2023).

However, from treatments P2 to P5, particularly at rotation R15, there is a significant increase in C-Organic content. This suggests that certain treatments, likely involving the addition of organic matter or changes in soil management techniques, play a major role in increasing organic carbon levels. The increase in C-Organic indicates enhanced accumulation of organic material in the soil (Zhao et al., 2023). Organic matter not only serves as a nutrient source for soil microorganisms but also improves soil structure, enhances water retention capacity, and increases nutrient availability for plants (Hussain et al., 2023).

The consistent increase in C-Organic demonstrates that these treatments not only improve soil fertility but also have the potential to mitigate climate change through soil carbon sequestration (Wenzel et al., 2023).

Nitrogen: Complex Dynamics and Decrease in Content Nitrogen is an essential nutrient for plants, yet its availability in soil is often highly dynamic due to its mobility in the soil ecosystem. The nitrogen graph shows significant fluctuations, with a declining trend in nitrogen content after several treatments and rotations. At the starting point (P0R0), a slight decrease is observed, followed by a brief increase at P1R0, but the subsequent trend tends to decline until P5R15.

The decrease in nitrogen content is likely caused by several factors. Nitrogen in the soil can be lost through various processes, including:

- Denitrification, the conversion of nitrate (NO_3^-) to nitrogen gas (N_2) by microorganisms under anaerobic conditions, which leads to nitrogen loss from the soil (Ding et al., 2021).
- Volatilization, the loss of nitrogen as ammonia (NH_3) gas, which occurs in soils with high pH or after the application of nitrogen fertilizers containing ammonium (Dominghetti et al., 2016).
- Leaching, the movement of nitrogen in the form of nitrate dissolved in water to deeper soil layers, especially under irrigation or heavy rainfall conditions (Pal et al., 2020).

Additionally, plants tend to absorb large amounts of nitrogen during the vegetative phase, which could explain the decline in nitrogen content in the soil after several rotations. A small increase in nitrogen is observed at the end of the cycle (P5R15), likely due to the return of plant residues or the addition of fertilizers that improve nitrogen content.

Phosphorus: Prominent Fluctuating Pattern Phosphorus is a nutrient required by plants in relatively small amounts compared to nitrogen but is crucial for plant growth and development. The phosphorus graph shows a notable fluctuating pattern, where some treatments lead to significant increases, but a drastic decrease is observed in the later stages.

At the beginning of treatments (P0 to P2), a significant increase in phosphorus content is observed, peaking at P2R15. This may be attributed to the mineralization of organic matter containing phosphorus. This increase suggests that early-stage treatments are highly effective in improving phosphorus availability in the soil (Cheng et al., 2020).

However, the drastic decrease in later stages, particularly after P4R15 to P5R15, suggests that phosphorus undergoes immobilization or is absorbed in large amounts by plants. Phosphorus immobilization in the soil can be caused by chemical reactions with metal ions like calcium (in alkaline soils), iron, or aluminum (in acidic soils), forming insoluble phosphate compounds that are difficult for plant roots to access (Ibrahim et al., 2022). This phenomenon indicates that although phosphorus is added to the soil, not all of it becomes available to plants due to various chemical interactions within the soil.

Potassium: Stability and Plant Absorption Potassium is an essential macronutrient for plant growth, particularly in regulating water balance, protein synthesis, and enzyme activity. The potassium graph shows a relatively stable trend compared to other nutrients. Initially, a decrease in potassium content (P0R0) is observed, but over time, its content tends to increase, reaching a peak at P3R15.

This stability in potassium may be due to its ability to remain in the soil for longer periods. Potassium is not easily lost through leaching, especially in clay soils or soils with a high cation exchange capacity (CEC) ((Thakur & Kumar, 2020). However, at the end of the rotation (P5R15), a decrease in potassium content is noted, possibly due to intensive potassium absorption by plants during the photosynthesis phase. Potassium plays a role in many physiological processes, including photosynthesis, enzyme activation within plants, translocation, and regulation of stomatal opening and closing. Inadequate potassium supply can lead to decreased photosynthetic carbon assimilation, ultimately hindering growth and reducing crop yield (Rawat et al., 2022).

This decrease also underscores the importance of reapplying potassium fertilizers after several growing seasons to ensure adequate potassium availability for plants in subsequent cycles.

Interaction of PGPR and Fertilizer Addition on Plant Nutrient Content

The addition of PGPR enhances the nitrogen content in plants derived from inorganic fertilizers. This suggests that PGPR can contribute to the increased effectiveness of fertilizer use, particularly under optimal conditions. PGPR reduces nitrogen leaching, meaning more nitrogen is available to plants because the loss of nitrogen to the environment is reduced. This indicates that although PGPR does not directly increase growth, it helps to improve the availability of nitrogen from inorganic fertilizers by decreasing nitrogen loss (Gallart et al., 2021). PGPR can assist in enhancing nitrogen absorption in plants (Adesemoye et al., 2010).

Table 1. Nitrogen Content

Treatment	Nitrogen Content (plant gram^{-1})					
	P0	**P1**	**P2**	**P3**	**P4**	**P5**
R0	**3,30 b**	**6,77 c**	**1,82 a**	**1,47 a**	**1,49 a**	**1,97 a**
R15	**6,77 c**	**6,34 c**	**1,48 a**	**1,70 a**	**1,78 a**	**1,50 a**
KK a (%)	**10,80**					
KK b (%)	**25,69**					

Table 2. Phosphorus Content

PGPR (ml L^{-1})	Phosphorus Content (plant gram^{-1})
R0	**0,79**
R15	**0,81**
KK (%)	**16,37**
Pupuk (ton ha^{-1})	
P0	**1,303 c**
P1	**1,142 b**
P2	**0,575 a**
P3	**0,587 a**
P4	**0,586 a**
P5	**0,590 a**
KK (%)	**16,20**

The use of inorganic fertilizers is highly effective in increasing the phosphorus content in plants. Although phosphorus from inorganic fertilizers is available, only a small percentage is absorbed by the plants, while the majority (67.2%) remains stored in the soil and a small portion (4.4%) is lost from the ecosystem. Therefore, although the addition of inorganic fertilizers can increase phosphorus content in plants, its efficiency is low, with the majority of phosphorus remaining in the soil and not directly taken up by the plants (Luo et al., 2024).

In the treatment with inorganic fertilizers, a significant increase in potassium content in plants is observed in the PGPR addition treatment compared to the control (no PGPR). This indicates that PGPR has the potential to increase potassium content in plants from inorganic fertilizers. PGPR has the ability to dissolve insoluble potassium in the soil into a form that is easily absorbed by plants through processes such as acidolysis, chelation, and exchange reactions. Thus, PGPR helps plants to more efficiently absorb potassium for optimal growth (Zhang et al., 2024).

Table 3. Potassium Content

Treatment	Potassium Content (plant gram^{-1})					
	P0	P1	P2	P3	P4	P5
R0	7,76 b	9,58 c	3,23 a	3,29 a	3,45 a	3,99 a
R15	12,37 d	8,26 b	2,81 a	3,52 a	3,94 a	3,32 a
KK a (%)	14,88					
KK b (%)	15,91					

The treatment with PGPR addition shows the highest values in the inorganic fertilizer treatment, which can be interpreted as evidence that the presence of PGPR supports the process of better nutrient absorption. This highlights the importance of considering biological factors (PGPR) in fertilization practices.

Principal Component Analysis (PCA) Results

Based on the results of Principal Component Analysis (PCA), growth parameters such as Plant Height, Number of Leaves, Number of Tillers, and Chlorophyll Content tend to be more influenced by treatments positioned on the left side of the PCA graph, namely P0R0, P0R15, P1R0, and P1R15. These treatments exhibit a stronger correlation with growth parameters, as indicated by their proximity to the growth-related variables on the left side of the graph. This suggests that the P0 (without fertilizer) and P1 (inorganic fertilizer) treatments have a more significant impact on plant growth based on the measured parameters.

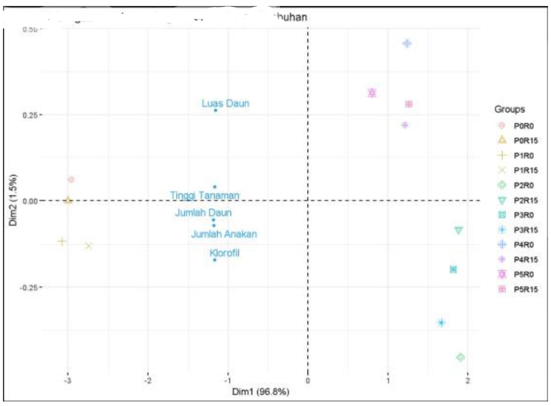

Fig.2. Principal Component Analysis (PCA)

In contrast, treatments located on the right side of the PCA graph, such as P2R0, P2R15, P3R0, P3R15, P4R0, P4R15, P5R0, and P5R15, show a weaker influence on the growth parameters. These treatments demonstrate a weaker correlation with growth variables, as indicated by their greater distance from the growth-related variables on the PCA graph.

The application of fertilizer significantly influences plants during the growth phase. The use of organic fertilizers has not yet been able to yield optimal results for plant growth, thus lagging behind inorganic fertilizers in performance. This is consistent with the findings of Santosa et al., (2017), which showed that the use of organic fertilizer derived from cow manure resulted in lower plant performance compared to treatments using inorganic fertilizers. This difference is attributed to the slower release of nutrients in organic fertilizers, while inorganic fertilizers release nutrients more quickly and precisely, making them easier and faster for plants to absorb.

According to Safitry & Kartika, (2013)), the application of inorganic fertilizers produces higher yields compared to organic fertilizers due to the faster availability of nutrients in inorganic fertilizers.

In terms of plant dry weight, observations across all growth stages show that inorganic fertilizers produce the highest results. This indicates that organic fertilizers still fall short of matching the performance of inorganic fertilizers in terms of plant dry weight at all growth stages. This finding aligns with the study by Bilalis et al., (2018), which demonstrated that inorganic fertilizers resulted in the highest plant dry weight. Furthermore, Sution et al., (2018) explained that applying inorganic fertilizers at doses of 100% to 150% can increase the dry weight of rice plants compared to treatments without fertilizer.

Based on PCA analysis results shown in Figure 2, parameters such as leaf area (*luas daun*), plant height (*tinggi tanaman*), number of tillers (*jumlah anakan*), number of leaves (*jumlah daun*), and chlorophyll content (*kandungan klorofil*) are strongly influenced by inorganic fertilizers. This highlights the significant role of inorganic fertilizers in supporting optimal plant growth.

IV. CONCLUSION

The Principal Component Analysis (PCA) revealed that plant growth parameters, such as height, leaf count, tiller number, and chlorophyll content, were most influenced by treatments on the left side of the PCA graph, namely P0R0, P0R15, P1R0, and P1R15, indicating a significant impact from inorganic fertilizers and the absence of fertilizers. Conversely, treatments on the right side (P2R0, P2R15, P3R0, P3R15, P4R0, P4R15, P5R0, and P5R15) showed weaker effects on growth parameters. Regarding nutrient residues, inorganic fertilizers had low phosphorus efficiency, with much of it remaining in the soil. PGPR application helped improve nitrogen availability by reducing nitrogen leaching, while organic fertilizers and PGPR increased potassium uptake. Overall, organic fertilizers and PGPR affected nutrient residues and plant nutrient uptake, improving soil fertility and plant health, but did not directly promote growth.

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Agro-Morphological Characteristics and Genetic Diversity of Traditional Glutinous Rice Varieties in Quang Ngai Province, Vietnam

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Abstract— *The analysis of genetic relationship among traditional glutinous rice varieties is crucial for genetic management, conservation, and the development of new varieties. The experiment was conducted from 2023 to 2024 in Duc Pho district, Quang Ngai province, Vietnam to assess the agro-morphological characteristics and genetic diversity of 106 traditional glutinous rice varieties. The study used 48 polymorphic SSR markers to calculate the polymorphic information content (PIC). Cluster analysis of the rice collection was then conducted using a similarity matrix and the Unweighted Pair-Group Method with Arithmetic Mean (UPGMA). The results revealed a total of 193 alleles, with an average of 4.02 alleles per locus. PIC values ranged from 0.33 to 0.87, with an average of 0.61. The genetic similarity coefficients of the 106 traditional glutinous rice varieties ranged from 0.41 to 0.98. Based on the UPGMA analysis of molecular data using NTSYS-pc 2.11a software, the 106 traditional glutinous rice varieties were grouped into two major clusters, indicating genetic differences. In addition, the varieties exhibited relatively wide range of growth time with most belonging to the short-day and medium-day groups. They displayed medium-to-high plant heights, medium-to-long panicle lengths, and 1000-grain weights ranging from high to extra-high. The correlation coefficient analysis showed that all the traits were correlated with each other, with the yield being strongly correlated with the 1000-grain weight. Therefore, the research findings not only provide an essential starting material for the development of high-quality, high-yield rice varieties but also contribute to the conservation and promotion of the Ngu glutinous rice genotype, which is closely associated with the Sa Huynh cultural heritage.*

Keywords— ***Quantitative morphological traits, alleles, genetic diversity, genetic resources, Sa Huỳnh's Ngự glutinous rice.***

I. INTRODUCTION

Glutinous rice is one of the specialty rice varieties widely grown in Vietnam and has a long-standing history. Currently, more than 250 glutinous rice varieties are cultivated across the country, grown in almost all localities, both in upland fields and lowland paddies, and are closely associated with traditional culture and national cuisine. Glutinous rice accounts for about 10% of the country's total rice production and commands a higher price compared to regular rice. Annually, it contributes approximately 20% of the total rice export volume. Indigenous rice varieties have evolved over generations, adapting to local cultivation conditions, and are known by various indigenous names (Rana *et al*., 2009). However, the number and cultivation area of traditional rice varieties, particularly specialty glutinous rice varieties, have significantly declined, replaced by hybrid and high-yielding improved rice varieties (Schiller *et al*., 2006). Laos is a major producer of glutinous rice, but in the 2000s, many indigenous glutinous rice varieties were no longer cultivated or were lost in the central and southern regions (Appa Rao *et al*., 2006). Therefore, it is crucial to collect, evaluate and conserve indigenous varieties before Vietnam's genetic diversity is further eroded. Genetic diversity forms the foundation for species survival. Processes such as genetic recombination and mutation provide a continuous source of new variations, while environmental adaptation and random genetic drift shape the distribution of genetic diversity over time and space (Brown *et al*., 1989; 1990). Thus, studying the genetic diversity of glutinous rice resources is not only crucial for conserving specialty rice varieties but also contributes significantly to the breeding of high-quality rice varieties, which supports sustainable agriculture and ensures food security (Begum *et al*., 2018; Acevedo-Siaca *et al*., 2020).

In the past, the assessment of genetic diversity was often based on phenotypes (agro-morphological traits), with farmers using certain morphological characteristics of crops for selection and identification. As a result, morphological traits are closely linked to genetic diversity, and the naming of these varieties reflects farmers' understanding of the genetic diversity present in their fields (Jarvis *et al*., 2000). Thus, agro-morphological characterization remains one of the simplest and most standardized methods for measuring crop genetic diversity (Watson & Eyzaguirre, 2002; Guru *et al*., 2017). Nowadays, with the advent of molecular marker techniques, powerful tools have been developed to accurately assess and describe genetic resources. Modern rice breeders are particularly interested in diversity at the molecular level (Becerra *et al*., 2015; Singh *et al*., 2016; Bhujel *et al*., 2018; Suvi *et al*., 2019; Park *et al*., 2019; Ab Razak *et al*., 2020). Various types of molecular markers are available for evaluating genetic variation in rice (Ni *et al*., 2002), including Restriction Fragment Length Polymorphism (RFLP) (Botstein *et al*., 1980), Random Amplified Polymorphic DNA (RAPD) (Williams *et al*., 1990), Amplified Fragment Length Polymorphism (AFLP) (Vos *et al*., 1995), and Simple Sequence Repeat (SSR) markers. SSRs are DNA regions (often part of non-coding regions) where one to five nucleotide sequences are repeated, evenly distributed across the genomes of most eukaryotic organisms. In plants, SSR sequences typically consist of AT and GA nucleotide repeats (Jae-Ryoung *et al*., 2019). The use of SSR molecular markers is a powerful tool for assessing genetic variation, elucidating genetic relationships within and between species, and offering advantages such as rapid, accurate, highly polymorphic, and stable analysis (Virk *et al*., 2000). Characterizing and evaluating diversity among traditional varieties provides breeders with essential information for identifying initial breeding materials to develop varieties with improved yield and quality. Many studies have utilized SSR markers to investigate genetic diversity and population structure in rice (Rana *et al*., 2009; Salgotra *et al*., 2015; Vilayheuang *et al*., 2016; Wunna *et al*., 2016; Prabha *et al*., 2017; Verma *et al*., 2017; Aljumaili *et al*., 2018; Muto *et al*., 2019; Nilthong *et al*., 2020). In Vietnam, genetic diversity among local indigenous rice varieties has been reported (Lang *et al*., 2009; Nguyen *et al*., 2012; Lang *et al*., 2014; Doan *et al*., 2016; Tran *et al*., 2021; Lang *et al*., 2024). However, the agronomic traits and genetic diversity of indigenous glutinous rice varieties remain largely unknown, particularly those of the Sa Huỳnh's Ngự glutinous rice.

In this study, we assessed the genetic diversity of traditional glutinous rice varieties known as Ngự Sa Huỳnh, also referred to as King's glutinous rice. This variety is closely associated with Sa Huỳnh region, a significant archaeological site of the ancient Sa Huỳnh culture—a nationally recognized cultural heritage site dating back approximately 3,000 years. The evaluation was conducted using agro-morphological traits and SSR markers. The findings of this study will contribute to conservation efforts, provide valuable genetic resource information, and support the exploitation and development of Sa Huỳnh's Ngự glutinous rice brand, renowned for its high quality. Additionally, the results will offer plant breeders essential information for identifying initial breeding materials to develop rice varieties with higher yield and improved quality.

II. MATERIALS AND METHODS

Plant Materials

A total of 106 Ngự glutinous rice samples were collected, including 100 samples from Quang Ngai, 4 samples from Binh Dinh, and 2 samples from the Plant Resources Center (PRC). The origins of these glutinous rice samples are presented in Table 1.

Table 1. Accession numbers and locations of the 106 traditional glutinous rice varieties used in the study

No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
1	NSH-1	Sa Huỳnh's Ngự glutinous rice -NSH1	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E	54	NSH-54	Sa Huỳnh's Ngự glutinous rice -NSH54	Pho Chau ward, Duc Pho District, has a latitude of 14°38'39.0"N and alongitude of 109°03'13.0" E
2	NSH-2	Sa Huỳnh's Ngự glutinous rice -NSH2	Pho Chau ward, Duc Pho District (14°38'39.0"N and 109°03'37.4" E)	55	NSH-55	Sa Huỳnh's Ngự glutinous rice -NSH55	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E
3	NSH-3	Sa Huỳnh's Ngự glutinous rice -NSH3	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E	56	NSH-56	Sa Huỳnh's Ngự glutinous rice -NSH56	Pho Chau ward, Duc Pho District, Quang Ngai province (14°38'34.8"N, E 109°03'19.9")
4	NSH-4	Sa Huỳnh's Ngự glutinous rice -NSH4	Pho Chau ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	57	NSH-57	Sa Huỳnh's Ngự glutinous rice -NSH57	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
5	NSH-5	Sa Huỳnh's Ngự glutinous rice -NSH5	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	58	NSH-58	Sa Huỳnh's Ngự glutinous rice -NSH58	Pho Chauward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
6	NSH-6	Sa Huỳnh's Ngự glutinous rice -NSH6	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E	59	NSH-59	Sa Huỳnh's Ngự glutinous rice -NSH59	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
7	NSH-7	Sa Huỳnh's Ngự glutinous rice -NSH7	Pho Chau Pho District, has a latitude of 14°38'38.8"N and alongitude of 109°03'41.1" E	60	NSH-60	Sa Huỳnh's Ngự glutinous rice -NSH60	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E
8	NSH-8	Sa Huỳnh's Ngự glutinous rice -NSH8	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'37.7"N and alongitude of 109°03'33.7" E	61	NSH-61	Sa Huỳnh's Ngự glutinous rice -NSH61	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
9	NSH-9	Sa Huỳnh's Ngự glutinous rice -NSH9	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	62	NSH-62	Sa Huỳnh's Ngự glutinous rice -NSH62	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'32.0"N and alongitude of 109°03'22.0" E
10	NSH-10	Sa Huỳnh's Ngự glutinous rice -NSH10	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E	63	NSH-63	Sa Huỳnh's Ngự glutinous rice -NSH63	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.9"N and alongitude of 109°03'19.9" E

No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
11	NSH-11	Sa Huỳnh's Ngự glutinous rice -NSH11	Pho Thanh ward, Duc Pho District, Vietnam (14°38'26.9"N, E 109°03'19.9")	64	NSH-64	Sa Huỳnh's Ngự glutinous rice -NSH64	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
12	NSH-12	Sa Huỳnh's Ngự glutinous rice -NSH12	Sa Huynh, Duc Pho District, Quang Ngai province, Vietnam (14°38'31.9"N and 109°03'46.2" E)	65	NSH-65	Sa Huỳnh's Ngự glutinous rice -NSH65	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E
13	NSH-13	Sa Huỳnh's Ngự glutinous rice -NSH13	Pho Thanh ward, Duc Pho District, has a latitude of 14°39'29.2"N and alongitude of 109°03'41.1" E	66	NSH-66	Sa Huỳnh's Ngự glutinous rice -NSH66	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E
14	NSH-14	Sa Huỳnh's Ngự glutinous rice -NSH14	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	67	NSH-67	Sa Huỳnh's Ngự glutinous rice -NSH67	Pho Chauward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
15	NSH-15	Sa Huỳnh's Ngự glutinous rice -NSH15	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E	68	NSH-68	Sa Huỳnh's Ngự glutinous rice -NSH68	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
16	NSH-16	Sa Huỳnh's Ngự glutinous rice -NSH16	Pho Chau Pho District, has a latitude of 14°38'38.8"N and alongitude of 109°03'41.1" E	69	NSH-69	Sa Huỳnh's Ngự glutinous rice -NSH69	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E
17	NSH-17	Sa Huỳnh's Ngự glutinous rice -NSH17	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'37.7"N and alongitude of 109°03'33.7" E	70	NSH-70	Sa Huỳnh's Ngự glutinous rice -NSH70	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
18	NSH-18	Sa Huỳnh's Ngự glutinous rice -NSH18	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	71	NSH-71	Sa Huỳnh's Ngự glutinous rice -NSH71	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'32.0"N and alongitude of 109°03'22.0" E
19	NSH-19	Sa Huỳnh's Ngự glutinous rice -NSH19	Sa Huynh, Duc Pho District, has a latitude of 14°39'33.3"N and alongitude of 109°03'48.8"E	72	NSH-72	Sa Huỳnh's Ngự glutinous rice -NSH72	Pho Chauward, Duc Pho District, has a latitude of 14°38'26.9"N and alongitude of 109°03'56.2"E
20	NSH-20	Sa Huỳnh's Ngự glutinous rice -NSH20	Pho Chauward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E	73	NSH-73	Sa Huỳnh's Ngự glutinous rice -NSH73	Pho Thanh ward, Duc Pho District, has a latitude of 14°40'37.8"N and alongitude of 109°03'30.0"E
21	NSH-21	Sa Huỳnh's Ngự glutinous rice -NSH21	Pho Thanh ward, Duc Pho District, Vietnam (14°38'34.8"N, E	74	NSH-74	Sa Huỳnh's Ngự glutinous rice -NSH74	Pho Thanh ward, Duc Pho District, Vietnam (14°38'26.9"N, E

No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
			109°03'19.9")				109°03'19.9")
22	NSH-22	Sa Huỳnh's Ngự glutinous rice -NSH22	Pho Thanh ward, Duc Pho District, Vietnam (14°38'31.9"N, 109°03'41.1" E)	75	NSH-75	Sa Huỳnh's Ngự glutinous rice -NSH75	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
23	NSH-23	Sa Huỳnh's Ngự glutinous rice -NSH23	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E	76	NSH-76	Sa Huỳnh's Ngự glutinous rice -NSH76	Pho Chau ward, Duc Pho District (14°38'34.1"N, 109°03'48.0"E)
24	NSH-24	Sa Huỳnh's Ngự glutinous rice -NSH24	Pho Thanh ward, Duc Pho District (14°39'29.2"N, 109°03'41.1" E)	77	NSH-77	Sa Huỳnh's Ngự glutinous rice -NSH77	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E
25	NSH-25	Sa Huỳnh's Ngự glutinous rice -NSH25	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	78	NSH-78	Sa Huỳnh's Ngự glutinous rice -NSH78	Pho Chauward, Duc Pho District (14°38'34.8"N, 109°03'19.9" E)
26	NSH-26	Sa Huỳnh's Ngự glutinous rice -NSH26	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	79	NSH-79	Sa Huỳnh's Ngự glutinous rice -NSH79	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'32.0"N and alongitude of 109°03'22.0" E
27	NSH-27	Sa Huỳnh's Ngự glutinous rice -NSH27	Pho Thanh ward, Duc Pho District, Vietnam (14°38'31.9"N, 109°03'41.1" E)	80	NSH-80	Sa Huỳnh's Ngự glutinous rice -NSH80	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
28	NSH-28	Sa Huỳnh's Ngự glutinous rice -NSH28	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E	81	NSH-81	Sa Huỳnh's Ngự glutinous rice -NSH81	Pho Chau ward, Duc Pho District (14°38'34.1"N, 109°03'48.0"E)
29	NSH-29	Sa Huỳnh's Ngự glutinous rice -NSH29	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	82	NSH-82	Sa Huỳnh's Ngự glutinous rice -NSH82	Pho Chauward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
30	NSH-30	Sa Huỳnh's Ngự glutinous rice -NSH30	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E	83	NSH-83	Sa Huỳnh's Ngự glutinous rice -NSH83	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
31	NSH-31	Sa Huỳnh's Ngự glutinous rice -NSH31	Pho Chau ward, Duc Pho District, Quang Ngai province (14°38'34.8"N, E 109°03'19.9")	84	NSH-84	Sa Huỳnh's Ngự glutinous rice -NSH84	Sa Huynh, Duc Pho District, Quang Ngai province, Vietnam (14°38'31.9"N and 109°03'46.2" E)

No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
32	NSH-32	Sa Huỳnh's Ngư glutinous rice -NSH32	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E	85	NSH-85	Sa Huỳnh's Ngư glutinous rice -NSH85	Pho Thanh ward, Duc Pho District (14°39'29.2"N, 109°03'41.1" E)
33	NSH-33	Sa Huỳnh's Ngư glutinous rice -NSH33	Pho Thanh ward, Duc Pho District, Vietnam (14°40'33.1"N - 109°03'25.1"E)	86	NSH-86	Sa Huỳnh's Ngư glutinous rice -NSH86	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
34	NSH-34	Sa Huỳnh's Ngư glutinous rice -NSH34	Sa Huynh, Duc Pho District, Quang Ngai province, Vietnam (14°39'34.6"N - 109°03'48.0"E)	87	NSH-87	Sa Huỳnh's Ngư glutinous rice -NSH87	Pho Chau ward, Duc Pho District (14°38'26.9"N and 109°03'56.2"E)
35	NSH-35	Sa Huỳnh's Ngư glutinous rice -NSH35	Pho Thanh ward, Duc Pho District, Duc Pho province (14°39'29.2"N and 109°03'41.1" E)	88	NSH-88	Sa Huỳnh's Ngư glutinous rice -NSH88	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E
36	NSH-36	Sa Huỳnh's Ngư glutinous rice -NSH36	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	89	NSH-89	Sa Huỳnh's Ngư glutinous rice -NSH89	Pho Chauward, Duc Pho District (14°38'24.7"N-109°03'36.6"E)
37	NSH-37	Sa Huỳnh's Ngư glutinous rice -NSH37	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E	90	NSH-90	Sa Huỳnh's Ngư glutinous rice -NSH90	Pho Chau ward, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'41.1" E
38	NSH-38	Sa Huỳnh's Ngư glutinous rice -NSH38	Pho Chau Pho District (14°38'38.8"N and 109°03'41.1" E)	91	NSH-91	Sa Huỳnh's Ngư glutinous rice -NSH91	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E
39	NSH-39	Sa Huỳnh's Ngư glutinous rice -NSH39	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'37.7"N and alongitude of 109°03'33.7" E	92	NSH-92	Sa Huỳnh's Ngư glutinous rice -NSH92	Pho Thanh ward, Duc Pho District (14°38'31.9"N and 109°03'41.1" E)
40	NSH-40	Sa Huỳnh's Ngư glutinous rice -NSH40	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	93	NSH-93	Sa Huỳnh's Ngư glutinous rice -NSH93	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'32.0"N and alongitude of 109°03'22.0" E
41	NSH-41	Sa Huỳnh's Ngư glutinous rice -NSH41	Sa Huynh, Duc Pho District, Quang Ngai province, Vietnam (14°39'33.3"N and 109°03'48.8"E)	94	NSH-94	Sa Huỳnh's Ngư glutinous rice -NSH94	Pho Chauward, Duc Pho District, has a latitude of 14°38'26.9"N and alongitude of 109°03'56.2"E
42	NSH-42	Sa Huỳnh's Ngư glutinous rice -NSH42	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9"	95	NSH-95	Sa Huỳnh's Ngư glutinous rice -NSH95	Pho Thanh ward, Duc Pho District (14°40'37.8"N and 109°03'30.0"E)

No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
			E				
43	NSH-43	Sa Huỳnh's Ngự glutinous rice -NSH43	Pho Thanh ward, Duc Pho District, Vietnam (14°38'34.8"N, E 109°03'19.9")	96	NSH-96	Sa Huỳnh's Ngự glutinous rice -NSH96	Pho Thanh ward, Duc Pho District, Vietnam (14°38'26.9"N, E 109°03'19.9")
44	NSH-44	Sa Huỳnh's Ngự glutinous rice -NSH44	Pho Thanh ward, Duc Pho District, Vietnam (14°38'31.9"N, 109°03'41.1" E)	97	NSH-97	Sa Huỳnh's Ngự glutinous rice -NSH97	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'34.8"N and alongitude of 109°03'19.9" E
45	NSH-45	Sa Huỳnh's Ngự glutinous rice -NSH45	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E	98	NSH-98	Sa Huỳnh's Ngự glutinous rice -NSH98	Pho Chau ward, Duc Pho District (14°38'34.1"N, 109°03'48.0"E)
46	NSH-46	Sa Huỳnh's Ngự glutinous rice -NSH46	Pho Thanh ward, Duc Pho District (14°39'29.2"N, 109°03'41.1" E)	99	NSH-99	Sa Huỳnh's Ngự glutinous rice -NSH99	Pho Chau ward, Duc Pho District, has a latitude of 14°38'34.1"N and alongitude of 109°03'48.0"E
47	NSH-47	Sa Huỳnh's Ngự glutinous rice -NSH47	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	100	NSH-100	Sa Huỳnh's Ngự glutinous rice -NSH100	Pho Chauward, Duc Pho District (14°38'34.8"N, 109°03'19.9" E)
48	NSH-48	Sa Huỳnh's Ngự glutinous rice -NSH48	Pho Thanh ward, Duc Pho District, has a latitude of 14°38'26.8"N and alongitude of 109°03'25.4" E	101	NBD-101	Hoai Nhon, Binh Dinh glutinous rice -NBD101	Hoai Nhon District, Binh Dinh province has a latitude of 14°26'35.62"N and a longitude of 108°59'30.57"E or 14.443229
49	NSH-49	Sa Huỳnh's Ngự glutinous rice -NSH49	Pho Thanh ward, Duc Pho District, Vietnam (14°38'31.9"N, 109°03'41.1" E)	102	NBD-102	Hoai Nhon, Binh Dinh glutinous rice - NBD102	Hoai Nhon District, Binh Dinh province has a latitude of 14°26'35.62" and a longitude of 108°59'30.57"E
50	NSH-50	Sa Huỳnh's Ngự glutinous rice -NSH50	Sa Huynh, Duc Pho District, has a latitude of 14°38'31.9"N and alongitude of 109°03'46.2" E	103	NBD-103	Hoai Nhon, Binh Dinh glutinous rice - NBD103	Hoai Nhon District, Binh Dinh province (N14° 26' 24", E 109° 5' 60")
51	NSH-51	Sa Huỳnh's Ngự glutinous rice -NSH51	Pho Chau ward, Duc Pho District, has a latitude of 14°38'23.5"N and alongitude of 109°03'33.7" E	104	NBD-104	Hoai Nhon, Binh Dinh glutinous rice - NBD104	Hoai Nhon District, Binh Dinh province (N14° 26' 24", E 109° 5' 60")
52	NSH-52	Sa Huỳnh's Ngự glutinous rice -NSH52	Pho Chau ward, Duc Pho District (14°38'21.5"N - 109°03'41.8"E)	105	NPCR-105	Quang Ngai glutinous rice -NSH105	The Plant Resources Center (PRC)

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No.	Accession number	Name of variety	Locations	No.	Accession number	Name of variety	Locations
53	NSH-53	Sa Huỳnh's Ngự glutinous rice -NSH53	Pho Chau ward, Duc Pho District, Quang Ngai province (14°38'34.8"N, E 109°03'19.9")	106	NPCR-106	Quang Ngai glutinous rice -NSH106	The Plant Resources Center (PRC)

Plant cultivation and care

A total of 106 traditional rice varieties were cultivated in the specialized Sa Huỳnh's Ngự glutinous rice fields in Pho Chau commune, Duc Pho district, Quang Ngaiprovince, Vietnam, during the 2023–2024 winter-spring crop. The seeds were sown on raised seedbeds, and 12–15-day-old seedlings were transplanted, with one seedling per hill. The experiment was conducted following the genetic resource evaluation method of the International Plant Genetic Resources Institute (IPGRI, 2001). Experimental farming methods and care techniques were implemented in accordance with the prevailing rice cultivation practices in the region. The process was overseen by the Departments of Agriculture and Rural Development of Quang Ngai Province and Duc Pho District to ensure compliance with local standards and best practices.

Indicators and measures of quantitative traits

The monitoring criteria in the field were assessed according to the rice genetic resource evaluation criteria of the International Rice Research Institute (IRRI, 2014).

Growth time (days): The number of days from sowing to seed maturity, defined as the stage when 85% of the seeds on the mature panicle are fully matured.

Plant height (cm): Measured from the soil surface to the tip of the tallest panicle (excluding awns). This measurement was taken from 10 randomly selected plants per accession per replication.

Panicle length (cm): Measured from the panicle neck to the tip of the main panicle. Thismeasurement was taken from 10 randomly selected primary panicles per accession per replication.

Number of panicles/m²: Determined by randomly sampling three representative one-square-meter regions from each plot.

Number of filled spikelets/panicle: The total number of filled spikelets per panicle was counted from 10 randomly selected clusters for each experimental plot.

Empty spikelet ratio (%): The percentage of unfilled spikelets per panicle.

1000-grain weight (g): The weight (in grams) of 1000 well-developed whole grains at 14% moisture content, taken from five randomly selected primary panicles per accession per replication. Yield (g/hill): Determined using the following formula:

$$Yield\ (g/hill) = \frac{Weight\ of\ harvest\ grain\ (g)}{No.\ of\ hills\ x\ No.\ of\ possible\ hills\ x\ MF}$$

Where:

$$MF = \frac{100 - MC}{86}$$

The moisture content (MC) of the harvested grains per plot was measured immediately after weighing, using a moisture meter.

Biomass-weight of 10 plants harvested from each accession per replication. Harvested plants were dried before weighing.

Harvest index (%): The harvest index was determined by the following formula:

$$\text{Harvest index (\%)} = \frac{Economic\ yield}{Biological\ yield}\ x\ 100$$

Where: Economic yield was defined as the total grain weight harvested from 10 plants per accession per replication. Biological yield encompassed the total grain weight and biomass from the same 10 plants per accession per replication.

DNA Extraction and PCR Analysis

DNA was extracted from freshly frozen leaves of individuals using an improved CTAB method (Oliveira *et al.*, 2015). A 2-3 cm section of traditional glutinous rice leaf was collected and placed in a labeled 1.5 mL centrifuge tube on ice after being ground into a fine powder. The tissue powder was mixed into an emulsion with a glass rod after adding 10 mL of extraction buffer (containing 2% CTAB, 0.7 M NaCl, 50 mM Tris-HCl pH 8.0, and 10 mM EDTA pH 8.0). The mixture was then incubated at 65°C for 1 hour. Then, a 10 mL mixture of chloroform and isoamyl alcohol (v:v/24:1) was added, and the solution was vigorously shaken to form an emulsion. The mixture was centrifuged at 14,000 rpm for 15 minutes at 20°C. The resulting supernatant was transferred to a fresh tube, and 10 µL of RNase (10 mg/mL) was added. The mixture was incubated at room temperature for 10 minutes. DNA was precipitated by gently shaking the mixture after adding 0.6 volume of isopropanol. The precipitated DNA was carefully collected and transferred into 70% ethanol for washing. The DNA was air-dried and subsequently resuspended in 50 µL of TE buffer. The extracted DNA was stored in ultra-pure water at −20°C in a refrigeratorfor future use.

DNA quality was assessed using 1% agarose gel electrophoresis. To prepare the gel, 3 g of agarose was dissolved in 300 ml of TAE buffer. The mixture was heated in a microwave for 5–6 minutes until fully melted and then allowed to cool to approximately 55–60°C. The cooled agarose solution was poured into a previously prepared electrophoresis box fitted with combs to create wells. The gel was allowed to set for approximately 45 minutes before the combs were carefully removed. A10 µl mixture containing 10 mM Tris-HCl (pH 8.0), 50 mM KCl, 1.5 mM $MgCl_2$, 50 mM each of dNTPs, 0.2 mM primer pairs, 0.5 U Taq polymerase (Merck KGaA, Darmstadt, Germany), and 20 ng DNA template was loaded into the wells. Electrophoresis was performed at 70–80 V and 60 mA for 45-48 minutes.

A total of 108 simple-sequence-repeat (SSR) markers used in the experiment were located on the12 chromosomes (Chr) of the rice genome (Table 2). The genomic sequences and SSR markers were obtained from the public database GRAMENE (http://archive.gramene.org/markers/index.html).

The polymerase chain reaction (PCR) for SSR markers was carried out in 10 µl mixture. The PCR cycle began with an initial denaturation at 94°C for 5 minutes, followed by 35 cycles of denaturation at 94°C for 30 seconds, annealing at 55°C for 30 seconds, followed by extension at 72°C for 30 seconds, and 72°C for 10 minutes using a Mastercycler Gradient PCR system (Eppendorf). 5 µl of each reaction mixture were loaded onto a polyacrylamide gel for electrophoresis. After the run, the plates were separated using a plastic wedge and removed from the electrophoresis tank. The acrylamide gel was then soaked in an ethidium bromide staining solution for 15-20 minutes. Stained bands were visualized and photographed under UV light.

Data analysis

Analysis of variance: The agro-morphological data collected were initially analyzed using analysis of variance (ANOVA) to verify genetic variation in the traits measured. Traits with insignificant genetic variation, based on the F-test, were not considered for further analyses.

Correlation analysis: The correlation coefficient (r) measured the degree of association between two or more variables. It provided a symmetrical measure of association and did not indicate dependency between variables. Correlation among agro-morphological traits was calculated using Statistix 10.0 software.

Distance matrix: The distance matrix was calculated using the Euclidean distance coefficient, as described by Sneath and Sokal (1973).

$$Eij = [\sum_k (X_{ki} - X_{kj})^2]^{1/2}$$

Where: *Eij* = 0 to ∞, the larger the value, the more distant the degree of relationship ; *Xi* and *Xj* are the standardized values for the i^{th} and j^{th} characters in k^{th} varieties.

Genetic diversity of Sa Huỳnh's Ngự glutinous rice varieties studied based on genotype: Molecular data were collected by scoring 1 for presence of band and 0 for absence of band. The data were entered directly into an Excel spreadsheet.

Data analysis :Pairwise comparisons of lines, based on the presence of unique and shared polymorphic products, were used to calculate the genetic similarity coefficients. Polymorphic Information Content (PIC) was calculated using the method of Weir (1996) with the following equation:

$$PIC(i) = 1 - \sum Pij^2$$

Where: Pij is the frequency of j^{th} allele with at the i^{th} locus. The collected data were analyzed using NTSYS-pc 2.11a software. A cluster analysis was performed based onthe similarity matrix, using the unweighted pair-group method with arithmetic average (UPGMA) clustering algorithm.

Cluster analysis: Cluster analysis was carried out for agro-morphology–based genetic distance matrix using UPGMA clustering method in the NTSYS-pc 2.11a software. The results of the UPGMA were used to draw the dendrogram of the 106 traditional glutinous rice varieties.

Statistical analysis: Mean, range and standard error were calculated using Statistix 10.0 software. Based on the LSD test (P< 0.01 and P< 0.05), statistical analyses were performed using one-way ANOVA to determine the significant difference between experiment means.

III. RESULTS AND DISCUSSION

Polymorphism of simple-sequence-repeat markers

PCR amplification was conducted using DNA samples extracted from 106 traditional glutinous rice varieties. The amplified PCR products were electrophoresed on a 3% agarose gel prepared with 1X TBE buffer, stained with ethidium bromide, and visualized under a UV transilluminator. A total of 108 SSR markers distributed throughout the 12 rice chromosomes were applied to analyze polymorphisms, among which only 48 (44. 44 %) SSR markers were found to be polymorphic. In total, 193 alleles were detected, with the number of amplified fragments ranging from 2 to 8 alleles per locus, and an average of 4.02 alleles per locus. Two primers, RM6314 (chromosome 4) and RM316 (chromosome 9), produced the highest number of alleles (8). The PIC values of the 48 SSR markers used in this study ranged from 0.33 (RM333) to 0.87 (RM6314), with an average PIC value of 0.61. This result is slightly lower than that of some previous studies on quality rice varieties. For example, Victoria (2007) reported an average PIC value of 0.68 when assessing the genetic diversity of quality rice varieties in the Philippines. Other studies, such as those by Shaptadvipa *et al*. (2009), Borba *et al*. (2009), and Upadhyay *et al*. (2011), reported higher PIC values of 0.923, 0.75, and 0.78, respectively. Khanin Pathak *et al*. (2016) used 65 polymorphic SSR markers to evaluate the genetic diversity of 100 glutinous rice samples, obtaining PIC values ranging from 0.613 to 0.995. More recently, Hoque M.I. *et al*. (2021) assessed the genetic diversity of 83 native rice varieties (both glutinous and non-glutinous) in Bangladesh using 9 SSR markers, reporting PIC values ranging from 0.766 to 0.951. In contrast, the PIC values observed in this experiment were higher than those reported in studies on specialty rice varieties. For example, Ravi *et al*. (2003) and Jain *et al*. (2004) reported average PIC values of 0.48 and 0.51, respectively. Similarly, studies on purple rice varieties by Ngo Thi Hong Tuoi *et al*. (2014) and local glutinous rice by Doan Thanh Quynh *et al*. (2016) showed average PIC values of 0.46 and 0.5, respectively. Lei *et al*. (2021), in their study on Kam glutinous rice varieties, reported an average PIC value of 0.5576 (Table 2).

Table 2. Results of polymorphic analysis of 106 traditional glutinous rice varieties based on SSR markers

No.	Primer SSR	Chr	No.of alleles	Size (bp)	PIC value
1	RM140	1	3	190-200	0.63
2	RM10843	1	5	180-200	0.73
3	RM10890	1	3	205-210	0.66
4	RM10115	1	4	240-250	0.72
5	RM284	1	3	147-155	0.57
6	RM221	2	3	220-230	0.66
7	RM106	2	2	300-350	0.56
8	RM154	2	2	165-199	0.45
9	RM71	2	3	210-230	0.56
10	RM347	3	4	207-240	0.48
11	RM3867	3	4	210-230	0.74
12	RM148	3	6	190-210	0.43
13	RM231	3	6	200-210	0.67
14	RM 514	3	7	240-280	0.86
15	RM317	4	2	146-166	0.46
16	RM1155	4	3	200-245	0.40
17	RM551	4	3	168-214	0.75
18	RM6314	4	8	142-169	0.87

19	RM122	5	4	205-230	0.64
20	RM13	5	5	190-210	0.63
21	RM5948	5	4	138-145	0.49
22	RM334	5	4	146-197	0.58
23	RM454	6	3	267-290	0.40
24	RM190	6	3	104-124	0.65
25	RM510	6	4	220-230	0.67
26	RM21539	7	2	205-210	0.45
27	RM5436	7	3	200-210	0.73
28	RM 455	7	3	130-140	0.58
29	RM418	7	4	200-215	0.56
30	RM346	7	5	140-160	0.68
31	RM547	8	5	200-210	0.49
32	RM152	8	3	175-200	0.63
33	RM284	8	4	141-149	0.48
34	RM433	8	5	222-232	0.66
35	RM24013	9	6	215-220	0.42
36	RM23662	9	3	210-220	0.64
37	RM 316	9	8	195-220	0.84
38	RM 171	10	7	321-353	0.73
39	RM484	10	3	291-299	0.48
40	RM333	10	3	164-215	0.33
41	RM11049	11	4	200-210	0.74
42	RM 536	11	7	230-268	0.71
43	RM224	11	2	120-157	0.41
44	RM277	12	3	115-125	0.54
45	RM463	12	4	210-225	0.52
46	RM 270	12	5	110-140	0.77
47	RM5364	12	3	150-160	0.66
48	RM12	12	3	162-184	0.74
Minimum			**2**	**-**	**0.33**
Average			**4.02**	**-**	**0.61**
Maximum			**8**	**-**	**0.87**
Total			**193**	**-**	**-**

Note: Chr: Chromosome; PIC: Polymorphic Information Content

. In addition, a dendrogram was constructed using cluster analysis based on the UPGMA method with the SAHN module in NTSYS-pc 2.11a, and it was generated and showed significant genetic variation among the traditional glutinous rice varieties studied in Figure 1. At genetic distance of 0.41, the 106 traditional glutinous rice varieties were separated into 2 major clusters namely, A and B. At a genetic distance of 0.55, cluster A was divided into sub-clusters A1 (11.32%), A2 (12.26%) and A3 (21.7%). Cluster B was divided into sub-clusters B1 (16.04%) and B2 (38.68%).

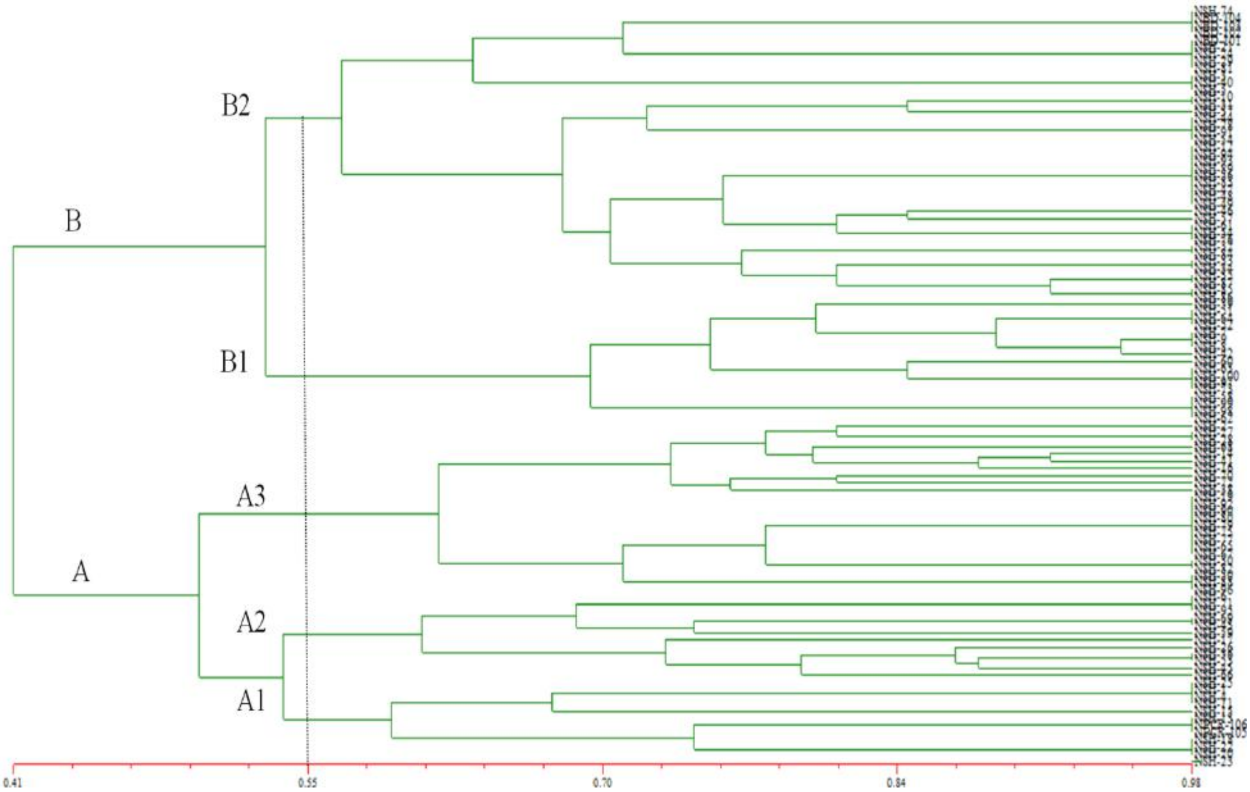

Fig.1. Classification of 106 traditional glutinous rice varieties based on genetic distance calculated from 48 SSR markers

Variance in agro-morphological characteristics

Morphological diversity analysis was conducted using the variance of agro-morphological features. For each of the 11 quantitative traits, key statistical parameters were calculated, including the mean, range (maximum and minimum), standard deviation, coefficient of variation (CV), mean standard error, and F-value. The results indicate that most of the quantitative traits exhibited high variability and all measurements followed a normal distribution (Table 3, Figures 2 to 4).

Table 3. Descriptive statistics of quantitative traits among 106 traditional glutinous rice varieties

Traits	Max	Min	Mean	CV (%)	P
Growing time (days)	132.00	106.00	115.28	0.42	<0.05
Plant height (cm)	154.90	115.00	140.31	0.55	<0.05
Effective tiller number/plant (no.)	4.00	1.00	1.82	4.80	<0.05
Panicle length (cm)	30.30	21.00	25.83	0.75	<0.05
Number of panicle/m^2 (no.)	387.00	146.00	260.45	1.94	<0.05
Number of filled spikelet/panicle (no.)	147.00	30.00	87.83	2.91	<0.05
Empty spikelet ratio (%)	40.30	1.12	9.65	6.55	<0.05
1000-grain weight (g)	41.02	31.08	34.61	0.52	<0.05
Yield (g/hill)	66.90	24.00	41.24	1.72	<0.05
Biomass (g)	83.98	33.75	62.29	1.31	<0.05
Harvest index (%)	0.72	0.12	0.50	2.72	<0.05

Note: *CV: Coefficient of Variation; Significantly different at $p < 0.05$*

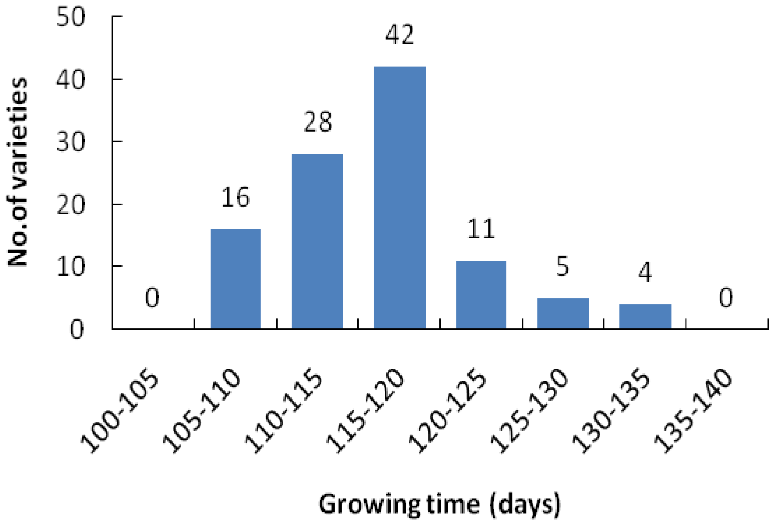

Fig.2. Frequency distribution of 106 traditional glutinous rice varieties based on GT

Table 4. The groups of 106 traditional glutinous rice varieties based on GT

Trait group	The number of varieties	Ratio (%)
Extra short-day (< 100 days)	0	0
Short-day (100-115 days)	44	41.51
Medium-day (116-130 days)	58	54.72
Long-day (> 130 days)	4	3.77

The growing time (GT)

The GT of rice varieties is a genetic trait that is affected by environmental factors, the earliest maturing genotype matured in 106 days, the latest maturing one took 132 days (Table 3). There are 44 short-day traditional glutinous rice varieties (41.51%), 58 medium-day varieties (54.72%) and 4 long-day varieties (3.77%), and no extra short-day varieties (Table 4 and Figure 2). Thus, the GT of the studied rice varieties was relatively diverse, with the majority of them falling into the short- and medium-day groups. The results of grouping according to GT are similar to the sub-group of commonly grown rice varieties in the northwest (short and medium-day varieties) in Doan Thi Thuy Linh'sprevious report (2013). Similarly, Van Quang Tran *et al*. (2021) also reported comparable findings regarding the agro-morphological characteristics and genetic diversity of glutinous rice landraces in northern Vietnam. GT is a valuable trait for selecting and developing new rice varieties; however, breeders still face the challenge of developing varieties with shorter GT without compromising yield.

Agronomic Characteristics

The plant height of traditional glutinous rice varieties ranged from 115 cm to 154.9 cm. Among them, 104 varieties (98.11%) had a plant height greater than 120 cm, while only 2 varieties (1.89%) fell into the medium-height category, with a plant height ranging between 100 and 120 cm.No semi-dwarf varieties were observed. The semi-dwarf stature contributed most to production gains during the green revolution due to associated improvements in harvest index and lodging under heavy fertilizer doses (Hargrove *et al*., 1980). Thus, breeders need to improve height of traditional glutinous rice to increase lodging resistance. Traditional glutinous rice varieties, in particular, and the traditional rice landraces, in general, produced alow number of tillers per plant (Rabara *et al*., 2014). In this study, traditional glutinous rice varieties exhibited low tiller numbers, with the effective tiller number per plant ranging from 1 to 4. Of these, 103 varieties (97.17%) had a low panicle level, and 3 varieties (2.83%) had a medium panicle level (Table 5 and Figure 3).

Table 5. Groups of 106 traditional glutinous rice varieties based on plant height and effective tiller number per plant

Trait group	The number of varieties	Ratio (%)
	Plant height (cm)	
< 100 cm (Semi-dwarf)	0	0
100-120 cm (Medium)	2	1.89
> 120 cm (Tall)	104	98.11
	Effective tillernumber/plant	
< 5 tiller (Low)	103	97.17
5-8 tiller (Medium)	3	2.83
> 8 tiller (High)	0	0

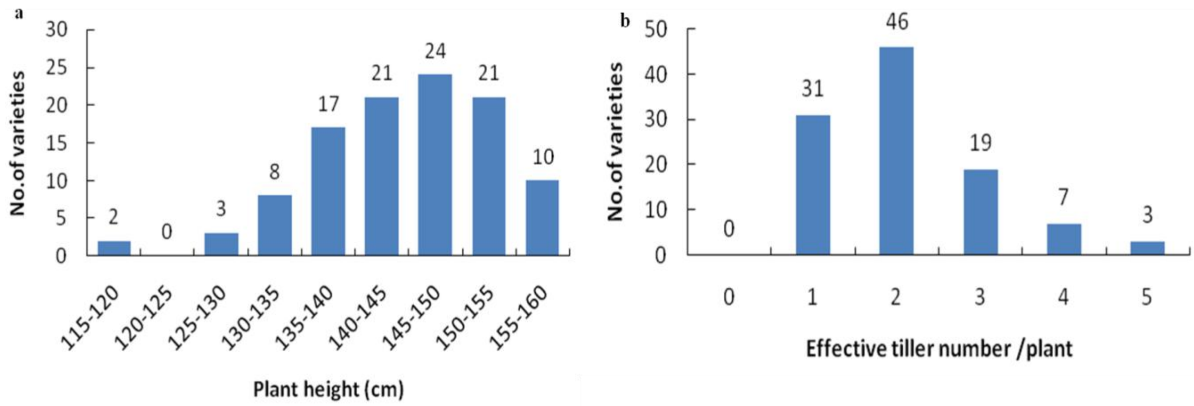

Fig.3. Frequency distribution of 106 traditional glutinous rice varieties based on plant height (a) and effective tiller number per plant (b).

The panicle length ranged from 21 cm to 30.3 cm. There were 22 varieties (20.75%) with medium panicles (20-25 cm), 77 varieties (72.64%) with long panicles (26-30 cm), and 7 varieties (6.61%) with extra-long panicles (>30 cm). The number of filled spikelets per panicle ranged from 30 to 147, and the number of panicles per square meter ranged from 146 to 387, showing high variation among varieties. The empty spikelet ratio ranged from 1.12% to 40.3%. The weight of 1000 grains varied among varieties, ranging from 31.08 g to 41.02 g. There are 42 varieties (39.62%) with high grain weight (30-35 g) and 64 varieties (60.38%) with extra-high grain weight (> 35 g). Since this trait is one of the most important yield components, the traditional glutinous rice varieties identified can serve as an important source of starting material for breeding rice varieties with higher yield. The individual yield ranged from 24 to 66.9 g per hill,with an average of 41.24 g per hill (Table 3, Figure 4a-f). This result is similar to the individual yield of rice landraces varieties in Vietnam (41.92 g/hill) reported in Nguyen Thi Lang's study (2014), but higher than the yield reported for Nep Ngu rice (36.33 g per hill) in Binh Dinh (2023). The biomass ranged from 33.75 to 83.98 g, with a mean of 62.29 g, and the harvest index ranged from 0.12% to 0.72%, with a mean of 0.5% (Table 3, Figure 4g-h). The average biomass values identified in this experiment were higher than the result reported for Nep Ngu rice (58.33 g) in Binh Dinh (2023).

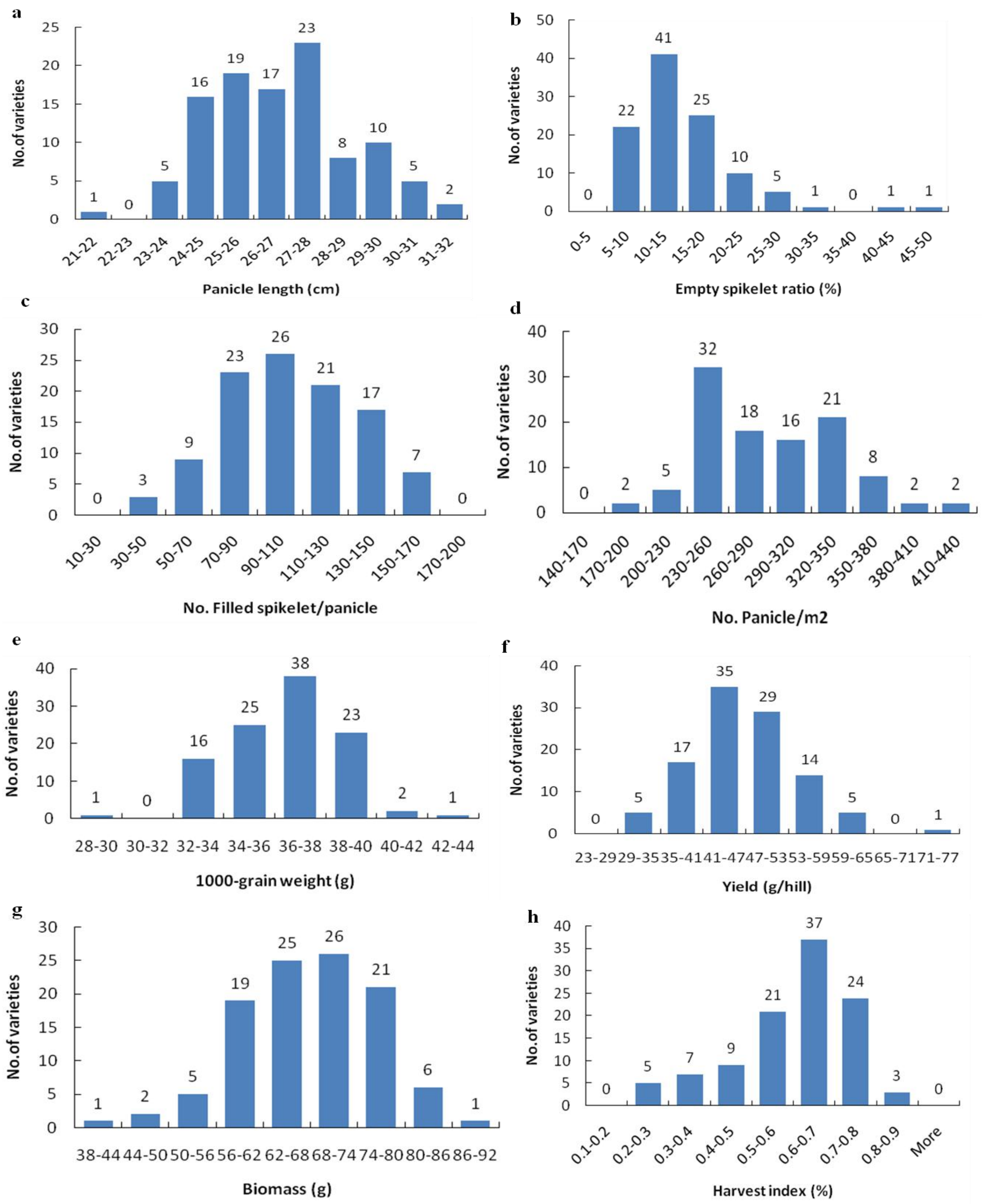

Fig.4. Frequency distribution of 106 traditional glutinous rice varieties based on panicle length (a), empty spikelet ratio (b), number of filled spikelet per panicle (c), number of panicle per m^2 (d), 1000-grain weight (e), yield (f), biomass (g) and harvest index (h).

Morphological characteristics show that most the traditional rice varieties, in general, and the traditional glutinous rice varieties, in particular, have late maturity, tall plant, and a higher number of filled seeds, a lower empty spikelet ratio, and a higher weight of 1000 grains. The variation in agro-morphological traits mentioned above can be attributed to genetic variability among the tested varieties. This diversity serves as a valuable resource for plant breeders to develop rice varieties with improved crop yields, superior grain quality, and greater photosynthetic efficiency.

Correlation among agro-morphological traits

The correlation coefficients among the agro-morphological traits measured are shown in Table 6. Panicle length was significantly correlated with plant height (r = 0.375*), which can be explained by the principle of morphological compatibility in plant architecture among 106 traditional glutinous rice varieties. This result is similar to Nguyen Thi Lang'sprevious report (2014). Other characteristics were strongly correlated with the panicle length. A significant correlation was also found between growing time and biomass (r = 0.301*). There was a strong negative correlation between the number of filled spikelet per panicle and the empty spikelet ratio (r =-0.485**), indicating that as the number of filled spikelet per panicle increases, the empty spikelet ratio decreases, and vice versa. The weight of 1000 grain was significantly correlated with the number of filled spikelets per panicle (r = 0.454**) and individual yield (r =0.41**). There was significantly correlated between individual yield and biomass (r =0.492**). Although the correlation coefficients did not show significant differences, individual yield and biomass were positively proportional to the panicle length and the number of panicles per square meter, while they were negatively proportional to plant height. The results differ from those of Lang *et al.* (2014), which can be explained by the unique characteristics of landrace varieties. The results indicate that higher yield is correlated with reproductive traits, growing time, panicle length, empty spikelet ratio, number of filled spikelet per panicle, number of panicle per square meter and especially the weight of 1000 grains. The information obtained from this study is critical for breeding and can guide further research on the relationship between 1000-grain weight and yield. Other traits were found to have weak correlations with agro-morphological traits.

Table 6. Correlation coefficients among 11 agro-morphological traits of 106 traditional glutinous rice varieties

Traits	GT (days)	PH (cm)	ET/P (no.)	PL (cm)	NP/m² (no.)	NFS/P (no.)	ESR (%)	1000W (g)	Y (g/hill)	B (g)	HI (%)
GT (days)	**1**										
PH (cm)	-0.009	**1**									
ET/P (no.)	0.058	0.091	**1**								
PL (cm)	-0.028	0.373*	0.133	**1**							
NP/m² (no.)	0.081	-0.080	-0.030	-0.080	**1**						
NFS/P (no.)	0.075	0.011	0.084	0.027	0.085	**1**					
ESR (%)	-0.112	0.071	-0.050	0.033	0.028	-0.485**	**1**				
1000W (g)	-0.107	0.156	-0.018	0.066	-0.231	0.454*	0.059	**1**			
Y (g/hill)	0.176	-0.100	0.055	0.136	0.127	0.049	0.116	0.410**	**1**		
B (g)	0.301*	-0.202	0.028	0.211	0.110	0.057	-0.050	-0.079	0.492**	**1**	
HI (%)	0.021	0.004	0.014	0.041	0.143	-0.135	0.028	0.079	0.017	-0.046	**1**

Note: *GT: Growing time;PH: Plant height; ET/P: Effective tiller number /plant (no.); PL: Panicle length; NP/m²: No. Panicle/m² (no.); NFS/P: No. Filled spikelet/panicle (no.); ESR: Empty spikelet ratio (%); 1000W:1000-grain weight (g); Y: yield (g/hill); B: Biomass (g); HI: Harvest index (%). Means with * and ** are significantly different at p< 0.05 and 0.01, respectively.*

IV. CONCLUSIONS

This study assessed the agro-morphological characteristics and genetic diversity of 106 traditional glutinous rice varieties. Agro-morphological traits and PCR-based markers provided valuable insights into the genetic diversity of Sa Huỳnh's Ngự glutinous rice varieties in Quang Ngai province, Vietnam. Molecular analysis revealed that SSR markers were highly effective in characterizing and assessing the extent and distribution of genetic variation among the 106 traditional glutinous rice varieties. Using UPGMA for molecular data analysis with NTSYS pc 2.11a software, the 106 traditional glutinous rice varieties were divided into two major clusters based on genetic differences. The data collected in this study provide valuable insights for breeding glutinous rice landraces using both traditional and molecular methods.

Using quantitative agro-morphological characters, ANOVA revealed highly significant differences among the traits of the106 traditional glutinous rice varieties. The traditional glutinous rice varieties exhibit relatively diverse growing times, with the majority falling into short-day and medium-day groups, they have medium-to-high plant heights, medium-to-long panicle lengths, and 1000-grain weights ranging from high to extra-high. Correlation coefficients showed that all the traits were correlated with each other, especially the yield, which was strongly correlated with 1000-grain weight but only slightly correlated with other traits.

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Optimization of Growth and Yield of Melon (*Cucumis melo* L.) on Rooftop through the Application of PGPR and Mycorrhizae

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Abstract— *Melon (Cucumis melo L.) holds significant economic value but faces declining production and export rates in Indonesia due to urbanization and limited agricultural land. Rooftop farming offers a solution, albeit with challenges such as extreme microclimatic conditions and nutrient deficiencies. This study aimed to evaluate the interaction between Plant Growth-Promoting Rhizobacteria (PGPR) and mycorrhizae in optimizing melon growth and yield under rooftop farming conditions. A split-plot design with four PGPR concentrations (0, 5, 10, 15 ml/L) and three mycorrhizal doses (0, 5, 10 g/plant) was employed. Growth and yield parameters were assessed alongside microclimatic data analysis. Significant interactions were observed between PGPR and mycorrhiza on fresh root weight, total dry weight, and fruit weight. The combination of 15 ml/L PGPR and 10 g/plant mycorrhiza produced the highest improvements, with fruit weight increasing by up to 67% compared to controls. Independent effects on root length, root dry weight, plant height, and leaf count were also observed. The synergistic effects of PGPR and mycorrhiza demonstrate the potential of microbial-based approaches for enhancing crop productivity in urban agricultural systems. These findings support the development of sustainable and adaptive solutions for urban farming challenges.*

Keywords— ***Cucumis melo, mycorrhiza, PGPR, rooftop farming, synergistic biofertilizers.***

I. INTRODUCTION

Melon (*Cucumis melo* L.) holds significant economic value in the global market [1], particularly in tropical countries such as Indonesia [2]. Indonesia's melon production index peaked at 162.26 in 2020 but declined to 139.38 in 2022. Similarly, melon export volumes decreased from 69,186 kg with an FOB value of US$ 52,214 in 2021 to 25,271 kg with an FOB value of US$ 18,047 in 2022 [2]. The increasing pressure on agricultural land due to urbanization necessitates the development of adaptive cultivation methods, such as rooftop farming, which utilizes unconventional spaces for agriculture [3]. However, rooftop environments present specific challenges, including extreme microclimatic conditions [4] and limited nutrient availability [5], potentially constraining plant growth and yield.

Microbial-based approaches, such as the use of Plant Growth-Promoting Rhizobacteria (PGPR) and mycorrhizae, have proven effective in enhancing nutrient uptake efficiency [6], [7], resilience to environmental stress [8], and crop productivity [6], [9]. PGPR promotes plant growth by producing phytohormones [10] and improving nutrient availability [10], [11], while mycorrhizae establish mutualistic symbiosis to facilitate the acquisition of essential nutrients [8]. The combination of these bioagents offers substantial potential to address agronomic challenges in rooftop environments. However, studies optimizing their application for melon cultivation on rooftop remain limited. This study aims to investigate the interaction between PGPR and mycorrhizae in rooftop cultivation systems, focusing on the growth and yield of melon. The findings are expected to provide a viable solution for urban agriculture development, particularly in melon production within urban settings.

II. MATERIALS AND METHODS

The study was conducted from January to April 2023 on the rooftop of the Faculty of Agriculture, Universitas Brawijaya, located at an altitude of 514 meters above sea level. The materials used included melon seeds of the Action 434 variety, PGPR containing *Bacillus subtilis*, mycorrhiza (*Glomus sp.*), and a growing medium composed of soil mixed with compost and rice husk charcoal. A split-plot experimental design with three replications was employed to ensure data validity. The main plot treatments (PGPR concentrations) comprised four levels: 0 ml/L (control, without PGPR), 5 ml/L, 10 ml/L, and 15 ml/L. The sub-plot treatments consisted of three levels of mycorrhizal doses: 0 g/plant (without mycorrhiza), 5 g/plant, and 10 g/plant.

Data collection in this study employed both non-destructive and destructive methods. Non-destructive observations included the measurement of plant height and leaf count, conducted twice at 24 and 44 days after planting (DAP). Destructive observations involved the analysis of fresh root weight and total dry weight of the plant, performed five times at 14, 24, 34, 44, and 54 DAP. Additional destructive measurements, such as root length and dry root weight, were taken three times at 14, 34, and 54 DAP. Additionally, fruit weight at harvest was measured. To support these measurements, environmental factors were monitored periodically to assess the range of microecosystem variables. These parameters included solar radiation intensity, air temperature, air humidity, soil temperature, and soil moisture. Solar radiation intensity was measured daily at 11:00 AM, while air temperature, air humidity, and soil temperature and moisture were recorded at 04:00 AM and 01:00 PM to capture the daily minimum and maximum values. Soil temperature was measured at a depth of 10 cm using an ITUIN soil thermometer, while soil moisture was assessed using a soil moisture meter at the same depth. Data obtained were analyzed using Analysis of Variance (ANOVA) at a 5% significance level to identify significant interactions or effects between treatments. In cases where significant results were found, further analysis was conducted using the Honestly Significant Difference (HSD) test at a 5% significance level to determine meaningful differences between treatments.

III. RESULT AND DISCUSSION

The microclimatic data collected on the rooftop during the study revealed significant variations in air temperature, soil temperature, air humidity, soil moisture, and sunlight intensity. Air temperature ranged from a minimum of 18.4–23.6°C to a maximum of 27.4–34°C. Air humidity exhibited a minimum variation of 39–80% and a maximum range of 83–99%. Sunlight intensity fluctuated widely, with the lowest recorded value at 1,316 foot-candles (FC) and the highest reaching 25,957 FC. Soil temperature showed fluctuations, with a minimum range of 20–26°C and a maximum of 28–34°C. Soil moisture varied between 21–89% at its minimum and 40–90% at its maximum. These variations provide a comprehensive overview of the rooftop's microclimatic conditions during the study, which may have influenced plant responses to microbial treatments.

Under these microclimatic conditions, the research findings revealed significant interactions between PGPR concentrations and mycorrhizal doses on fresh root weight at 34, 44, and 54 DAP, as well as on total dry weight at 34 DAP, indicating a substantial synergistic effect during specific growth phases (Table 1 and Tables 4-5). Additionally, interactions were observed in fruit weight per harvest (Fig. 1). Meanwhile, other parameters such as root length, root dry weight, plant height, and leaf count were independently influenced by either PGPR or mycorrhiza, without any interaction. PGPR promotes growth by secreting hormones such as auxin [11], [12] and enhancing nitrogen availability [13], [14]. In contrast, mycorrhiza supports phosphorus and water uptake [8], [15]. Although these mechanisms differ, they are complementary [16], contributing to improved plant growth and development. This synergy highlights the need to optimize PGPR and mycorrhizal applications during key growth stages for improved biomass and yield.

3.1 Root

Roots are essential for water and nutrient uptake as well as structural stability. Their efficiency can be enhanced through microbial associations with PGPR and mycorrhizal fungi, which improve nutrient acquisition and stimulate root growth. Mycorrhizae form hyphal networks for better phosphorus uptake, while PGPR secrete phytohormones that promote root development. The synergistic effects of these microbes on root biomass and architecture under varying application rates require further study to optimize their use for sustainable agriculture and improved productivity [17].

Table 1. Average root fresh weight at various PGPR concentrations and mycorrhizal doses

Plant age (DAP)	PGPR concentration (ml/L water)	Mycorrhiza dosage (g $plant^{-1}$)		
		0	5	10
34	0	0.30 a A	0.44 a A	0.54 a A
	5	0.31 a A	0.44 ab A	0.60 b AB
	10	0.37 a A	0.60 ab AB	0.87 b BC
	15	0.41 a A	0.82 b B	1.06 b C
HSD 5%		0.28		
44	0	0.66 a A	0.84 a A	1.01 a A
	5	0.73 a A	1.21 a A	1.80 a A
	10	0.93 a A	2.75 ab A	4.28 b B
	15	1.65 a A	5.18 b B	5.67 b B
HSD 5%		2.20		
54	0	0.67 a A	0.91 a A	1.17 a A
	5	0.76 a AB	1.39 a A	2.20 a A
	10	1.01 a AB	3.23 ab A	4.56 b B
	15	3.05 a B	6.48 b B	6.80 b B
HSD 5%		2.33		

Note: Numbers followed by the same lowercase letter in the same row or the same uppercase letter in the same column indicate no significant difference based on the 5% HSD test. DAP: days after planting.

The fresh root weight of plants was significantly influenced by the interaction between PGPR and mycorrhiza. At 34 DAP, the application of 10 g mycorrhiza/plant combined with 15 ml PGPR/L increased fresh root weight by 158.54%. In contrast, applying 5 ml PGPR/L showed no significant difference compared to the control without mycorrhiza. These results indicate that the effectiveness of PGPR improves with higher mycorrhizal doses, accelerating root development. At 44 DAP, the combination of 10 g mycorrhiza/plant and 10 ml PGPR/L resulted in a larger increase in fresh root weight, reaching 330.22%. A further increase was observed with 15 ml PGPR/L, which enhanced fresh root weight by up to 516.67%. At 54 DAP, 15 ml PGPR/L yielded the highest fresh root weight (612.09%) at 5 g mycorrhiza/plant. The increase in fresh root weight demonstrates that higher

PGPR concentrations can support mycorrhizal symbiosis, thereby promoting optimal root development. The combination of higher doses of mycorrhiza and PGPR has been proven to support overall plant growth. These findings are consistent with previous studies by El-Sawah et al. (2021) and Chen et al. (2023).

In addition to enhancing mycorrhizal efficiency, PGPR also strengthens plant resilience against environmental stress, as reported by Galindo et al. (2024). Their research showed that PGPR increases root and plant biomass through improved CO^2 assimilation, thereby supporting photosynthetic activity, water use efficiency, and transpiration regulation. Furthermore, PGPR helps plants mitigate environmental stress by reducing oxidative stress, as evidenced by decreased reactive oxygen species (ROS) levels and membrane lipid damage. This reduction in oxidative damage is crucial for maintaining cellular integrity under stressful conditions. PGPR also promotes the synthesis of stress-related proteins that protect plant cells from environmental damage. The enhanced root growth further supports nutrient uptake, ensuring that plants maintain optimal growth even under unfavorable conditions. Consequently, PGPR applications offer a promising strategy for improving plant health and productivity in diverse agricultural systems.

Table 2. Average root length and root dry weight at various PGPR concentrations and mycorrhizal doses

Treatment	Root length (cm) ages (DAP)			Root dry weight (g) ages (DAP)		
	14	34	54	14	34	54
PGPR concentration (ml/L water)						
0	7.90	20.03	25.9 a	0.10	0.34	0.80 a
5	8.08	24.03	30.94 ab	0.10	0.37	1.15 a
10	8.27	25.78	35.9 b	0.10	0.47	2.30 ab
15	8.37	28.26	39.64 b	0.10	0.49	3.79 b
HSD 5%	ns	ns	12.42	ns	Ns	1.69
Mycorrhiza dosage (g $plant^{-1}$)						
0	7.64	19.05 a	26.01 a	0.10	0.27 a	1.21 a
5	8.16	25.18 b	33.31 b	0.10	0.43 b	2.32 b
10	8.66	29.35 c	39.97 c	0.10	0.56 b	2.50 b
HSD 5%	ns	3.89	5.57	ns	0.13	0.99

Note: Numbers followed by the same letter within the same observation age and treatment indicate no significant difference based on the 5% HSD test. DAP: days after planting, ns: not significant.

Root length and dry weight at 54 DAP (Table 2) demonstrated a positive response to the application of PGPR and mycorrhiza. Root length increased by 53.05% with 15 ml PGPR/L, while a concentration of 10 ml PGPR/L resulted in a 38.61% increase compared to the control. Mycorrhiza also had a significant effect, with a dose of 10 g/plant increasing root length by 53.84%, and 5 g/plant leading to a 29.83% increase. Regarding root dry weight, the highest value (3.79 g) was observed at 15 ml PGPR/L, which was substantially greater than the values recorded at 5 ml PGPR/L (1.15 g) and without PGPR (0.80 g). However, reducing the concentration from 15 ml/L to 5 ml/L resulted in a marked decrease in root dry weight, with reductions of 2.99 g (78.89%) and 2.64 g (69.66%) compared to the 10 ml PGPR/L treatment (2.30 g). Mycorrhiza also showed a consistent pattern of improvement, where 5 g and 10 g/plant significantly increased root dry weight compared to the control. The observed improvements in root length and dry weight suggest that PGPR and mycorrhiza play a crucial role in supporting root development. According to Chen et al. (2023), both PGPR and mycorrhiza enhance nutrient uptake and expand root networks, which are essential for promoting plant growth. Mycorrhiza contributes to root development by improving the absorption of phosphorus, water, and other nutrients, while PGPR enhances soil microflora to support root growth [6], [11].

3.2 Shoot

Vegetative growth, marked by rapid shoot and leaf development, is significantly influenced by nutrient uptake and hormonal regulation. PGPR enhances this phase by fixing nitrogen and secreting growth-promoting hormones such as auxins and gibberellins [11], [12], while mycorrhizal fungi improve phosphorus and water uptake through extensive hyphal networks [8], [16]. Although PGPR and mycorrhiza independently promote shoot elongation and leaf proliferation, their effects on these parameters are not synergistic. Instead, their individual contributions create favorable conditions for vegetative growth, supporting biomass accumulation during critical stages.

Table 3. The average plant length and number of leaves at various PGPR concentrations and mycorrhiza doses

Treatment	Plant length (cm) ages (DAP)		Number of leaves (unit) Ages (DAP)	
	24	44	24	44
PGPR concentration (ml/L water)				
0	35.38 a	83.27 a	7.11 a	15.81 a
5	49.61 ab	122.40 ab	9.04 ab	22.19 ab
10	66.96 bc	163.80 b	10.07 b	23.85 ab
15	79.11 c	180.90 b	10.52 b	27.70 b
HSD 5%	21.19	80.53	2.82	11.05
Mycorrhiza dosage (g plant^{-1})				
0	54.29	102.30 a	8.44 a	19.06 a
5	59.25	155.00 b	9.25 ab	23.44 ab
10	59.76	155.50 b	9.86 b	24.67 b
HSD 5%	ns	33.98	1.32	4.53

Note: Numbers followed by the same letter within the same observation age and treatment indicate no significant difference based on the 5% HSD test. DAP: days after planting, ns: not significant.

The shoot growth, comprising plant height and leaf number, significantly increased with the application of PGPR and mycorrhiza. At 24 DAP, the application of 15 ml PGPR/L increased plant height by 123.60% compared to no PGPR, though no significant difference was observed between 5 ml and 10 ml PGPR/L. At 44 DAP, treatments with 10 ml and 15 ml PGPR/L resulted in height increases of 96.71% and 117.25%, respectively, while 5 ml PGPR/L showed no significant difference from the control. Similarly, mycorrhiza at doses of 5 g and 10 g/plant improved plant height by 51.76% at 44 DAP. In terms of leaf number, the application of 10 ml and 15 ml PGPR/L increased leaf number by 41.63% and 47.96% at 24 DAP, while at 44 DAP, 15 ml PGPR/L led to a 72.04% increase compared to the control. Mycorrhiza at 10 g/plant increased leaf number by 16.82% at 24 DAP and 29.47% at 44 DAP, whereas the 5 g dose did not show a significant effect. These findings underscore the role of PGPR in enhancing nutrient availability and root activity [19] and the contribution of mycorrhiza to improved water and nutrient uptake [8], [16]. Moreover, the increase in leaf number can be attributed to the ability of PGPR to stimulate root and leaf growth [20], [21], coupled with the role of mycorrhiza in nutrient uptake efficiency, particularly during the vegetative phase [22]–[24].

3.3 Total plant biomass

Total plant dry weight is a key indicator for evaluating growth and biomass accumulation in plants, influenced by treatments such as PGPR and mycorrhiza application. Increasing PGPR concentration to 15 ml/L significantly enhanced total dry weight by 2.65 g (63.86%) compared to no PGPR (Table 4). A similar trend was observed at 44 and 54 DAP, where 15 ml/L PGPR increased dry weight by 17.12 g (77.54%) and 12.57 g (47.2%), respectively (Table 5). The highest dry weight was achieved at 15 ml PGPR/L, indicating the effectiveness of this concentration for biomass accumulation. Similarly, mycorrhiza at 10 g/plant resulted in substantial dry weight increases, with a 72.94% rise at 24 DAP and an average of 87.24% at 44 and 54 DAP compared to no mycorrhiza. Treatments without mycorrhiza consistently showed lower dry weights at all observation points.

Table 4. Interaction of PGPR concentration and Mycorrhiza dosage on average of total plant dry weight at 34 DAP

PGPR concentration (ml/L water)	Total plant dry weight (g) at 34 DAP		
	Mycorrhiza dosage (g plant^{-1})		
	0	5	10
0	10.10 a	10.47 a	9.19 a
	A	A	A
5	9.84 a	8.58 a	10.27 a
	A	A	A
10	10.84 a	11.12 a	15.74 a
	A	A	AB
15	12.57 a	28.35 b	29.25 b
	A	B	B
HSD 5%	14.13		

Note: Numbers followed by the same lowercase letter in the same row or the same uppercase letter in the same column indicate no significant difference based on the 5% HSD test. DAP: days after planting.

Table 5. The average total plant dry weight at various PGPR concentrations and mycorrhiza doses

Treatment	Total plant dry weight (g) ages (DAP)			
	14	24	44	54
PGPR concentration (ml/L water)				
0	1.52 ab	4.15 a	17.15 a	27.01 a
5	1.30 a	4.52 ab	21.64 ab	31.62 ab
10	2.25 b	5.57 ab	43.90 bc	55.77 bc
15	2.29 b	6.80 b	48.80 c	71.60 c
HSD 5%	0.89	2.62	26.59	26.99
Mycorrhiza dosage (g plant^{-1})				
0	1.73	3.77 a	20.93 a	31.12 a
5	2.03	5.50 ab	37.45 b	51.16 b
10	1.76	6.52 b	40.23 b	57.23 b
HSD 5%	ns	1.904	16.49	15.54

Note: Numbers followed by the same letter within the same observation age and treatment indicate no significant difference based on the 5% HSD test. DAP: days after planting, ns: not significant.

The synergistic effects of PGPR and mycorrhiza are underpinned by complementary physiological mechanisms. PGPR promotes nutrient uptake and enhances metabolic efficiency through the production of growth hormones like auxins [11], [12], while the observed increase in dry weight suggests the need to optimize PGPR concentrations to avoid saturation [6]. Mycorrhiza facilitates nutrient absorption by expanding root networks via mutualistic symbiosis, particularly in phosphorus-limited environments [6], [8]. These findings align with prior research indicating that the combination of PGPR and mycorrhiza enhances root and shoot biomass, especially during the vegetative phase [6].

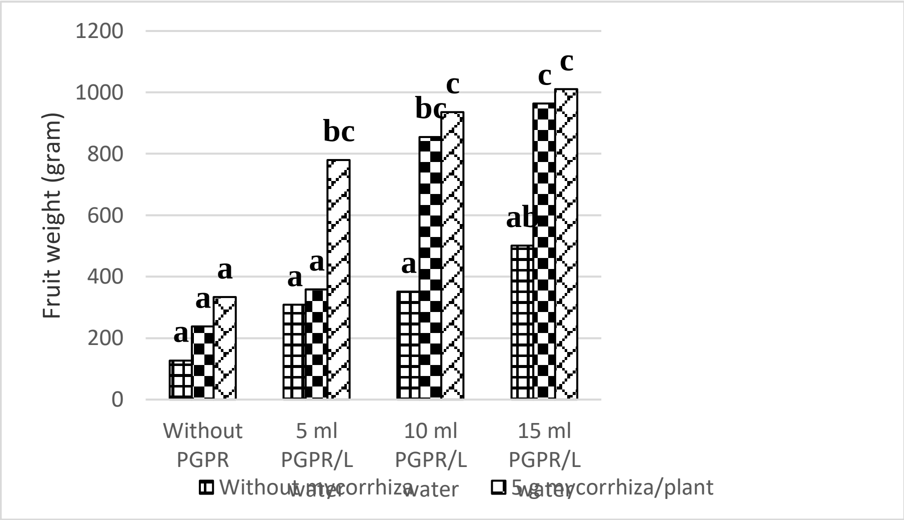

Fig. 1: Average fruit weight at various PGPR concentrations and mycorrhizal doses

Fig. 1 demonstrates that the combination of mycorrhizae and PGPR significantly influences fruit weight, which correlates with improved root and shoot growth variables. In treatments without mycorrhizae, fruit weight remained low even as PGPR concentrations increased, indicating that the effect of PGPR was not optimal in the absence of mycorrhizae. Conversely, the application of 10 g of mycorrhizae per plant produced higher fruit weights at PGPR concentrations of 5, 10, and 15 ml/L water, with respective increases of 57.18%, 64.28%, and 67.01% compared to treatments without PGPR. A significant reduction in fruit weight occurred when PGPR concentrations decreased or were not applied, underscoring the importance of synergy between these two biological agents.

These findings align with previous studies indicating that mycorrhizae enhance phosphorus uptake and the absorption of other nutrients [7], [16], while PGPR produces plant hormones such as auxins that promote growth and productivity [11], [12]. Moreover, the synergistic interaction between mycorrhizae and PGPR also impacts plant growth variables, including root elongation and shoot development, which directly affect fruit productivity. Mycorrhizae contribute by expanding the root absorption area and increasing water and phosphorus uptake efficiency, thereby supporting enhanced photosynthesis and shoot biomass [16]. PGPR complements this role by producing hormones such as auxins and gibberellins that accelerate root growth and establish a stronger and more efficient root system [12]. This combination optimizes the plant system, substantially increasing fruit weight by up to 67% compared to treatments without PGPR or mycorrhizae.

IV. CONCLUSION

This study demonstrated the synergistic interaction between PGPR concentrations and mycorrhizal doses in enhancing the growth and yield of melon in a rooftop farming system. The combination of 15 ml/L PGPR and 10 g/plant mycorrhiza significantly improved root and shoot development, especially fruit weight achieving up to a 67% increase compared to control treatments. These findings highlight the potential of integrating microbial-based approaches to address the challenges of urban farming, including nutrient limitations and extreme microclimatic conditions. Furthermore, the results provide a basis for optimizing microbial applications to enhance crop productivity in non-conventional agricultural environments. Future research should focus on evaluating the long-term effects and scalability of these practices in diverse urban contexts.

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Effect of stinging nettle extract and potassium bromate on histological and physiological changes of male rabbit reproductive organs

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Abstract— *This study was conducted to evaluate the various effects of nettle extract and potassium bromate on the histological and physiological changes of male rabbit reproductive organs and semen quality. Rabbit breeding experiments were conducted on a private farm in Lamluda region, Al-Qubbah city, eastern Libya, during the year 2024. Rabbits were divided into three groups: the first was dosed with potassium bromate, the second was dosed with nettle extract, and the third was dosed with potassium bromate for three days followed by nettle extract for three days, compared to the fourth group, as a control group. At the experiment's end, all animals were sacrificed, their epididymides were removed, and sperm assays were performed. The results showed that the weights of rabbits treated with potassium bromate and a mixture of potassium bromate + nettle extract decreased by 26.59% and 19.48% compared to the control, and the testis weight decreased by 190.39%, 25.83%, and 71.59% for each of the samples treated with potassium bromate, nettle extract, and the mixture of both compared to the control, respectively. The findings revealed that animals exposed to potassium bromate had a significantly decreased sperm count, higher semen viscosity, distracted and erratic sperm motility, and abnormalities in the sperm, with the head becoming spherical and the tail short, broken, and divided. The use of nettle extract, however, reduced these disturbances.*

Keywords— ***Urtica dioica, stinging nettle, potassium bromate, reproductive organs, semen quality***

I. INTRODUCTION

According to **Thomford *et al.*** (2015), the use of medicinal plants for therapeutic purposes has traditionally earned widespread acceptability for health care in local communities around the world, owing to cheap or no cost, poverty, scarcity, or a lack of access to modern pharmaceuticals. Extracts from medicinal plants and their bioactive metabolites have proven to be effective in the treatment and prevention of many diseases. Stinging nettle, or *Urtica dioica*, is an important medicinal herb from the *Urticaceae* family. Nettle is an herbaceous perennial-blooming herb that has long been renowned for its therapeutic value in folk medicine (**Awoyemi *et al.*, 2022**). Where **Edirne *et al.*** (2010) reported that the various phytochemicals found in the leaves and roots of *Urtica dioica* (Nettle) extract could be used for many therapeutic purposes, such as treating infertility.

Urtica dioica L. (stinging nettle) is a perennial herb that grows in temperate and tropical areas including northern Africa, Europe, Asia, and North America. It has long been used as a traditional herbal medicine for several illnesses, and as a nutritional supplement. The plant's aerial parts are also used in traditional medicine (**Albadawi *et al.*, 2024**). With the leaf appearing in numerous cultures for a varied variety of ailments, including diabetes, asthma, and hypertension (**Mohamed *et al.*, 2024**)

Chemically, stinging nettle is a complex mixture of water and alcohol-soluble compounds, including phenolic, sterols acids, proanthocyanidins, coumarins, lectins, flavonoids and their glycosides, fatty acids, vitamins, polysaccharides, carotenoids, and minerals. The leaves contain amino acids, flavonoids, carotenoids, phenolic acids, and fatty acids. Nettle-derived compounds such as rutin, kaempferol, and vitamin A have been demonstrated to have anti-inflammatory, antioxidant, immunomodulatory, and anticancer properties (**Albadawi *et al.*, 2024; Devkota *et al.*, 2022**). *Urtica dioica* leaf extract with high quantities of quercetin, esculetin, scopoletin, and rutin showed anti-inflammatory and antioxidant activity in diabetic mouse hippocampal neurons (**Albadawi *et al.*, 2024; Patel *et al.*, 2018**). It includes several beneficial compounds for human health, such as polyphenols, triterpenoids, sterols, flavonoids, lectins, and fatty acids. Clinically important mechanisms include antioxidant and anti-inflammatory effects, suppression of 5α-reductase and aromatase, and antiproliferative and cell cycle arrest in malignancies. Preclinical studies have demonstrated benefits in both benign prostate hyperplasia or hypertrophy (BPH) and prostate cancer cell lines, as well as the prevention of diabetes-induced reproductive dysfunction (**Leisegang, 2021**). This plant has also been reported to have anticancer (**Durak *et al.*, 2004**), anti-inflammatory (**Hajhashemi, and Klooshani, 2013**), anti-osteoporotic (**Gupta *et al.*, 2014**), antihypertensive, hypoglycemic, hepatoprotective (**Roschek *et al.*, 2009**), testicular protective effects, and the ability to improve the quality of spermatozoa and sperm parameters (**Jalili *et al.*, 2014**).

Potassium bromate is a colorless, odorless white crystal or powder, highly soluble in water and less soluble in acetone, dimethyl sulfoxide, ethanol, methanol, and toluene (National Toxicology Program, 1992) (**Thompson 1992**). In distilled water, potassium bromate degrades to form potassium bromide (KBr) and oxygen (O2). However, under the optimum conditions, it is converted to potassium bromide, which is not harmful for consumption. Potassium bromate is an oxidizing agent that is used throughout the baking process for fermentation and proofing. As a result, potassium bromate is a popular food additive in bread to improve its baking effect, as well as in textile dyeing and as a neutralizer in the cosmetic industry. However, numerous reports have documented its harmful impact on human health. The IARC considers it a probable human carcinogen and classifies it as 2B (**Shanmugavel *et al.*, 2020**; **Sahu *et al.*, 2016**). It has also been reported to cause some acute health consequences, such as abdominal pain, diarrhea, and irritation to the mucous membrane of the upper aero digestive tract, and vomiting (**Nkwatoh *et al.*, 2023; Adebiyi *et al.*, 2022**). As a result, many governments around the world have partially or entirely outlawed it.

The purpose of this study is to assess the varied impacts of stinging nettle extract on the histological and physiological changes of male rabbit reproductive organs treated with potassium bromate.

II. METHODOLOGY

2.1. Preparation of leaves extract of Nettle

Nettle leaves were collected and washed with distilled water, after that were dried in the oven. The dried leaves were blended to powder using a kitchen blender. 10 g of the powdered leaves was soaked in 100 ml distilled water with intermittent shaking as a cold maceration extraction. The root extract was concentrated using a rotary evaporator and further using a water-bath. The resulting solution was filtered to obtain the pure extract, which was then distributed into 10 ml test tubes and centrifuged at 3500 rpm for 20 minutes. The filtered extract was collected and condensed with a rotary evaporator to get the dry extract. Next, refrigerate the extract until needed, then dilute it with 1 mL of distilled water for each dosage.

2.2. Preparation of potassium bromate

Potassium bromate ($KBrO_3$) was prepared with a concentration of 1% by dissolving 1 g of potassium bromate powder in 100 ml of distilled water in a glass flask.

2.3. Animal experimental model

16 male rabbits with an average of 845 g (829-890g) were picked from the animal home. The rabbits were grouped into 4 treatment groups; each group consisted of 4 rabbits (4 rabbits per cage). Cages were kept in a well-ventilated room with typical circumstances (25±2°C, 55-60% RH, 12:12 h light/dark cycle).

- Group I: (Control): Without any treatments (as control).
- Group II: This group's rabbits were given 2 ml potassium bromate each for 3 days.
- Group III: This group's rabbits were given 2 ml *Urtica dioica* extract each for a week.
- Group IV: This group's rabbits were given 2 ml of potassium bromate each for three days, and on the fourth day, they were followed by 2 ml of nettle extract each for a week.

2.4. Characteristics studied

At the end of the experimental period after 10 days, the following characteristics were studied on all rabbits in the experiment:

- Rabbits weight (g).
- Testis weight (mg).

- Semen quality: Sperm analysis which contain (sperm motility, sperm concentration, sperm counts, sperm morphology, and semen viscosity), were determined according to WHO protocol 2010.
- Testosterone concentration in blood (ng/ml).

2.5. Statistical analysis

One-way analysis of variance (ANOVA) was used with SPSS to evaluate differences between groups. The least significant difference (LSD) test was used as a post hoc test for intergroup comparisons, and p value <0.05 was considered statistically significant.

III. RESULTS AND DISCUSSION

The data in the following graphs (1, 2) illustrate the effect of dosing male rabbits with potassium bromate and nettle extract on the weight of rabbits and testicle weight. The results show that using potassium bromate alone or with nettle extract reduced the weight of male rabbits by 26.95% and 19.18%, respectively. On the contrary, treating male rabbits with nettle extract increased the weight of rabbits at the end of the experiment by 23.61% (fig.1). On the other hand the testicle weight decreased by 190.39%, 25.83%, and 71.59% for each of the samples treated with potassium bromate, nettle extract, and the mixture of both compared to the control, respectively (fig.2). This results agree with **Elsheikh *et al.*** (2016), where reported the usage of potassium bromate in water led to reduce weight of testicle in rates. Similarly, many researchers found that endocrine disrupting chemicals reduce pubertal body weight. Factors known to alter thyroid function are also accused of limiting physiologically active iodine (**Klinefelter *et al.*, 2004; Elsheikh *et al.*, 2016**).

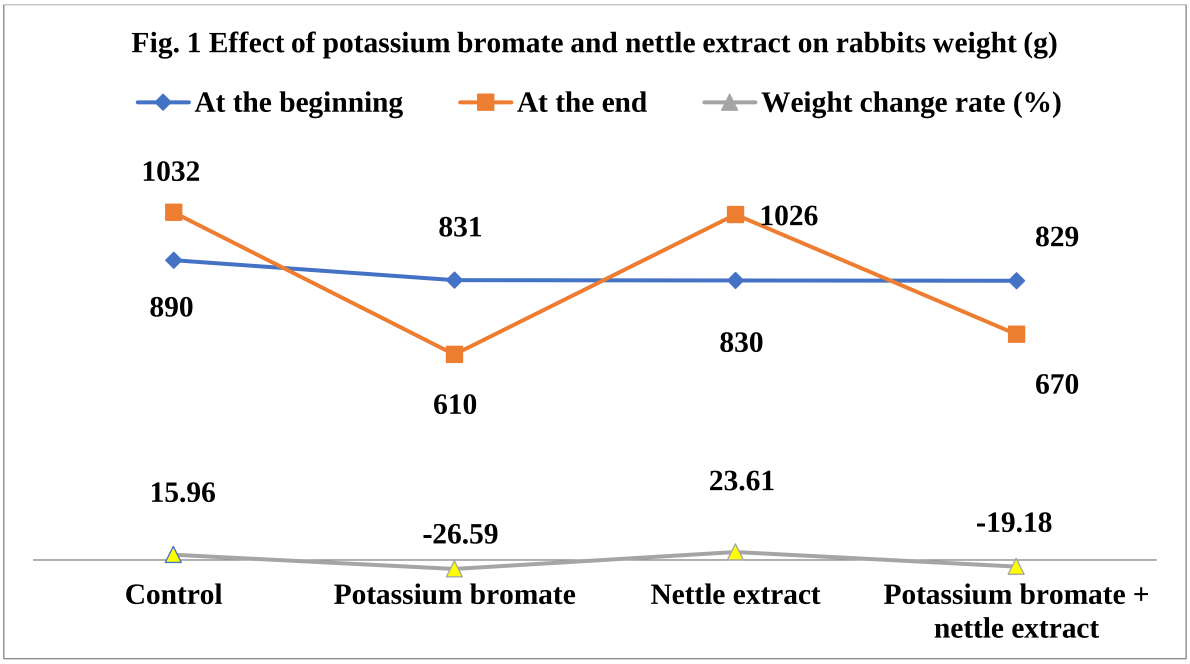

Fig. 1 Effect of potassium bromate and nettle extract on rabbits weight (g)

The findings in figure 3 revealed that the hormone testosterone levels in the blood increased when using nettle extract, reaching 30.45 ng /ml with an increase of 7.56% compared with the control. On the contrary, the use of potassium bromate has negative effects on the level testosterone, where its concentration, was reduced by 84.79% and 98.76% compared with control and exposure rabbits, respectively. On the other hand, the results showed that using nettle extract on rabbits that were previously dosed with potassium bromate led to an increase in the testosterone level in the blood compared to those that were dosed with potassium bromate and were not treated with nettle extract, where increased from 15.32 to 28.01 ng/ml. These results were consistent with those explained by **Gheth *et al*.** in 2021, where they explained the negative effect of using potassium bromate on testosterone levels in the blood of mice. They concluded that reduced testosterone secretion was most likely caused by increased oxidative stress and the degradation of Leydig cells (**Jasim, 2024**).

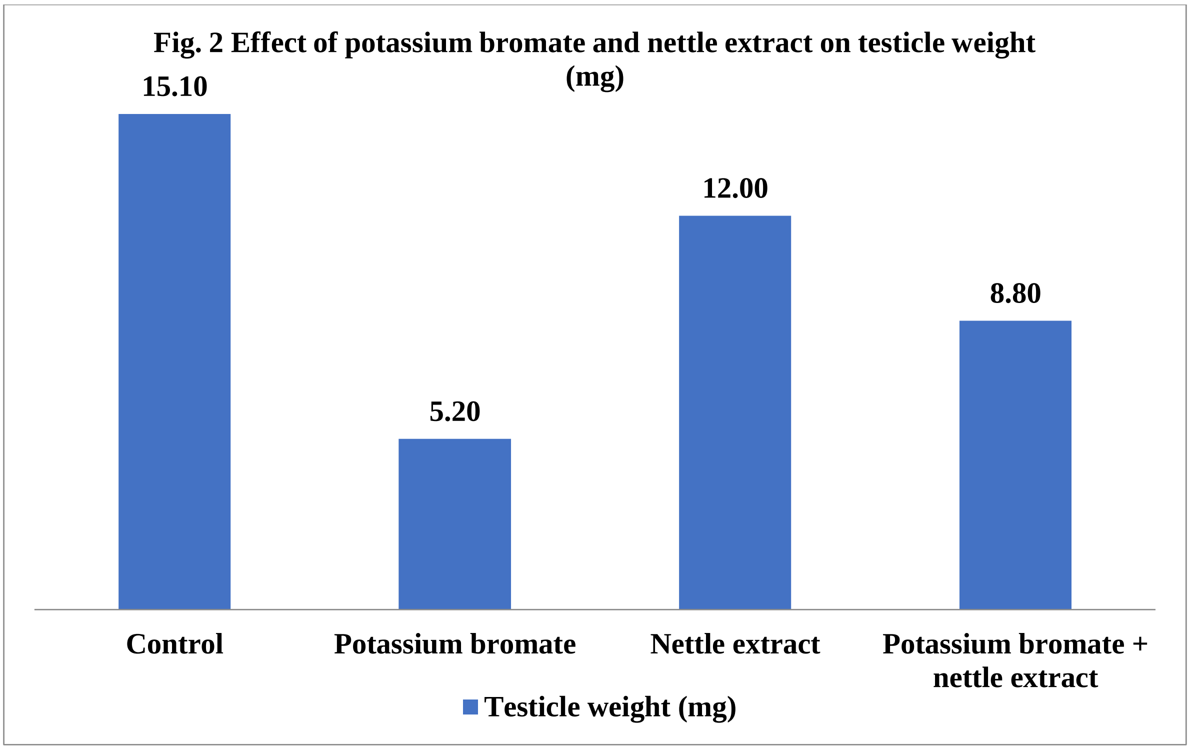

Fig. 2 Effect of potassium bromate and nettle extract on testicle weight (mg)

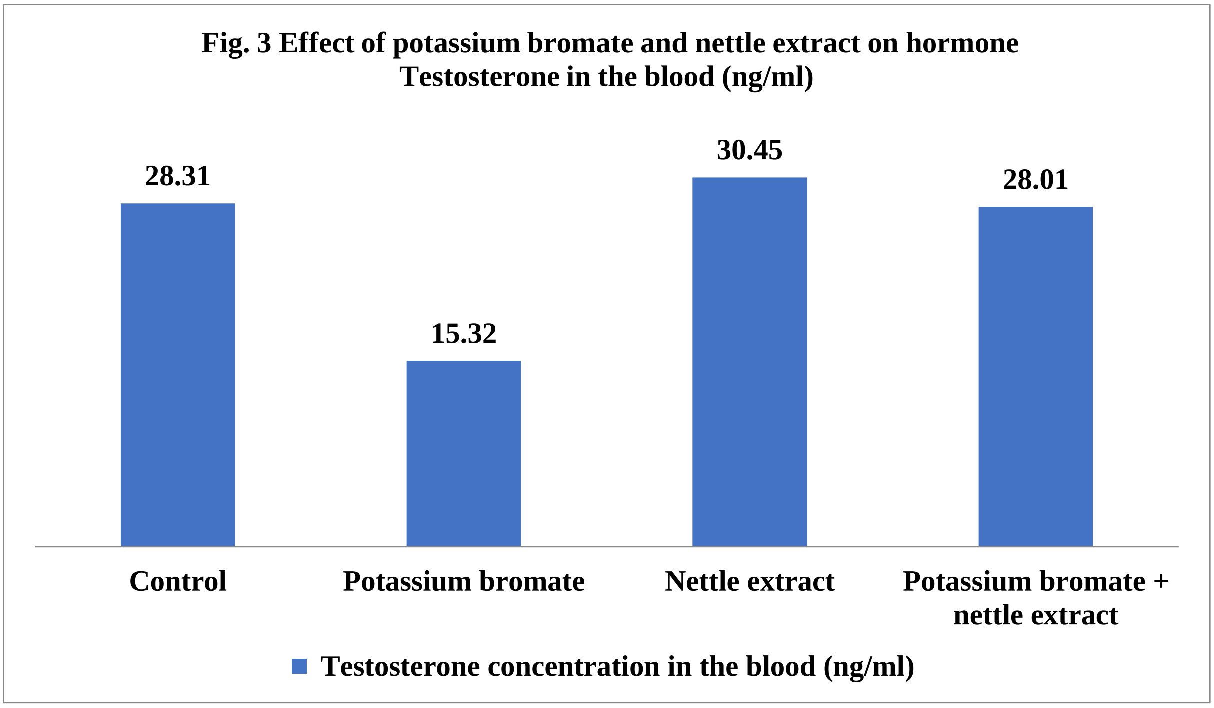

Fig. 3 Effect of potassium bromate and nettle extract on hormone Testosterone level in the blood (ng/ml)

Epididymal Sperm quality:

As rabbits were given potassium bromate, *epididymal* sperm motility, progressive motility, sperm count, and viability all decreased dramatically, also sperm cells with aberrant morphology increased significantly as compared to control groups. In contrast, the use of nettle extract increased the concentration, quantity, and quality of sperm. On the other hand, the co-treatment with nettle extract reduces the harmful effect of potassium bromate while improving sperm quality.

Data in the following figure (4) showed that, the impact of potassium bromate and nettle extract on the count of sperm in rabbit semen. Where the rabbits were given potassium bromate, the sperm concentration in the semen reduced by 77.67% compared to the control group. While using nettle extract increased the quantity of sperm in rabbit semen by 25.06% and 122.18% compared to the control and potassium bromate groups, respectively. When using nettle extract with rabbits that were treated with potassium bromate beforehand, it led to a relative improvement in the number of sperm in the semen compared to the group of rabbits that were treated with potassium bromate, as it increased by 55.52%.

These results are consistent with what **Elsheikh *et al*.**(2016), explained in experiments conducted on mice when potassium bromate was used in drinking water, which led to major deformities in the seminiferous tubules, which led to them being devoid of sperm.

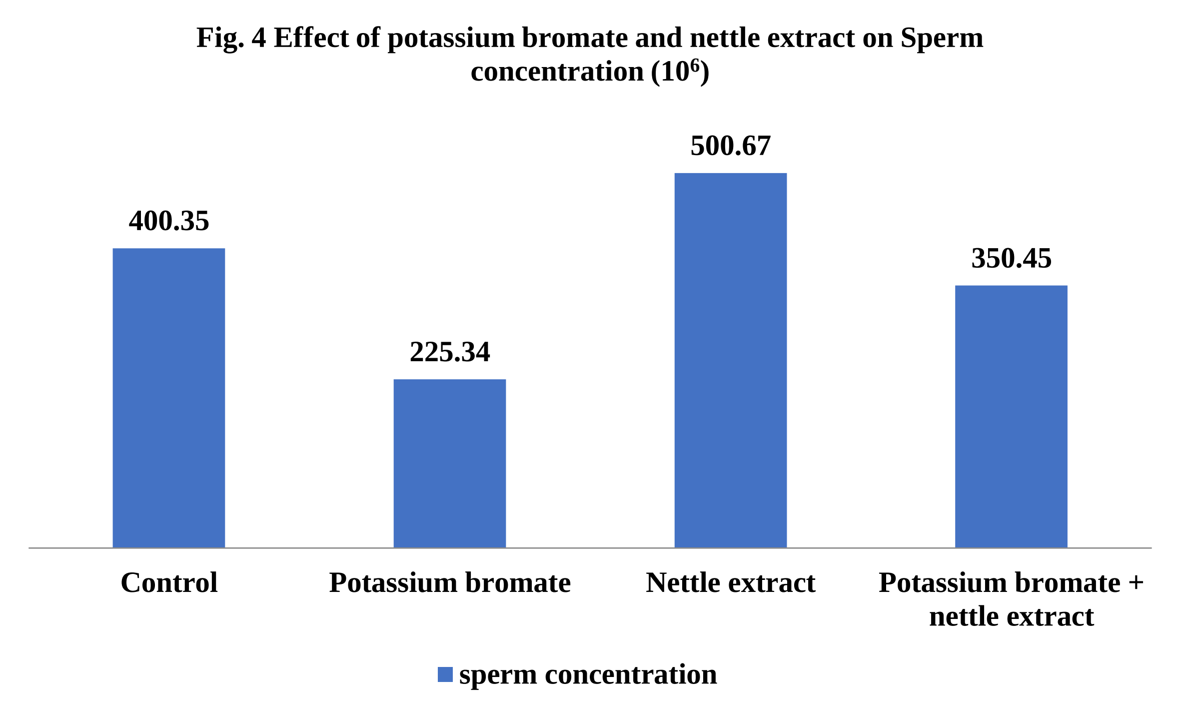

Fig. 4 Effect of potassium bromate and extract on sperm concentration in semen

The results in Table 1 showed that the exposure of animals to potassium bromate had a considerably lower sperm count, increased semen viscosity, led to motility distracted and random of sperm, and also led to abnormalities in the sperm, as the head became spherical and the tail short, fractured, and divided. But these perturbations were attenuated by using nettle extract. These results agreed with many studies; the effect of giving male rats dosages of potassium bromate was examined in terms of morphological changes in sperm cells. Where reported, potassium bromate significantly led to an increase in sperm morphological abnormalities. Also, potassium bromate affected the number and motility of epididymis sperm and increased the incidence of defective sperm. This demonstrates how artificial food additives may have an impact on reproductive health (**Airaodion *et al.*, 2022**).

Table 1 Effect of potassium bromate and nettle extract on epididymal sperm quality of rabbit samples

Treatment	Semen			
	Viscosity	Motility	Abnormalities	Count
Control	Natural	Natural and one-way	Natural, oval head, straight, movable tail	More 50
Potassium bromate	More viscous	Distracted and random	Head spherical, tail short, broken and divided	10
Nettle extract	Natural	Natural and one-way	Natural, oval head, straight, movable tail	More 50
Potassium bromate + Nettle extract	Less viscous	Natural and one-way	There are some deformities in the head.	Not less than 40

IV. DISCUSSION

Low epididymal weights are caused by growth retardation and azoospermia as a result of testicular hypoplasia. The histological sections of the testes indicated significant hypoplasia of the testicular structure as well as impaired spermatogenesis. These changes are likely owing to an iodine shortage caused by KBro3 supplementation in water. Iodine helps to decrease oxidative stress, a known factor that triggers germ cell death, because it neutralizes hydroxyl ions (**Sahoo *et al.*, 2008**). Furthermore, it is possible that potassium bromate altered the antioxidant activity of iodine and its carbon-bonded metabolites, as well as iodolactones, disrupting thyroid gland functions and reducing growth rate, epididymal, and testicular weights (**Smyth *et al.*, 2009**). The iodine deficit caused by potassium bromate may have impeded the manufacture of thyroid hormones, which are crucial for coordinating physiology within and between cells and tissues, and so impaired the growth and function of the gonads (**Crockford, 2009**). Potassium bromate causes iodine deficiency in the testes, making them sensitive to oxidative stress due to their high polyunsaturated fatty acid content and weak antioxidant defenses (**Elsheikh *et al.*, 2016**).

V. CONCLUSION

After assessing the effect of potassium bromate and nettle extract on the histological, physiological changes, and *Epididymal* sperm quality of the male reproductive organs of rabbits. The assessment showed that potassium bromate had a negative effect on testicular weight and semen quality and caused sperm abnormalities and reduced sperm count, while the use of nettles overcame these negative and toxic effects of potassium bromate administration for male rabbits.

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Invitro analysis of seed germination parameter in blackgram(*Vigna mungo* L. Hepper) by using Polyethylene glycol (PEG)

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Abstract—*The present invitro study carried out with eleven blackgram genotypes including T-9 used as check were collected from NBPGR regional centre Hyderabd and ICAR-CRIDA Hyderabad respectively. Seeds that were healthy and uniformly sized were surface sterilized for two to three minutes using 0.1% mercuric chloride (HgCl2) before being thoroughly washed with distilled water. The sterilized (10) seeds were sown in petri plates with moistened germination paper and various water potentials, namely, 0.0 (control), 5%, 10%, 15%, 20%, 25% and 30% of PEG 6000 in 100 ml of distilled water. The ANOVA results revealed sgnificant variability due to treatment, genotype and treatment verses genotype for the trait seed grmination at all the percentage of PEG 6000 studied. The results showed that among eleven genotypes IC426766 and IC382811 recorded higher germination percentage at higher PEG concentration and upto 20% PEG very lower percentage of germination was observed. It indicates that the variety IC426766 with hold the water even at higher concentration and showing water stress condition.*

Keywords— Blackgram, Germination%, Polyethylene glycol

I. INTRODUCTION

The expected reduction in food crop yield over the next 50 years is due to global climate change, which expresses as higher temperatures and decreasing soil moisture. Lack of soil moisture has a direct impact on a plant's ability to germinate seeds and produce seedlings. A practical technique for evaluating how seeds respond to low water potential during germination is to germinate them in solutions with varying water potentials. Polyethylene glycol (PEG) molecules have been utilized to maintain consistent water potentials by simulating the effects of osmotic stress in vitro studies has shown that PEG 6000 is an effective solution to induce osmotic stress without harming plant cells (Datta *et al.*, 2011). PEG 6000 molecules are sufficiently large to prevent plant absorption but sufficiently small to affect the osmotic potential. Also, PEG simulates dry soil by drawing water out of the cell without entering the apoplast (Hatem Zgallai *et al.*, 2005 and Radhouane 2007). The results mentioned previously suggest that PEG solution may be utilized in laboratory conditions to screen for drought-tolerant cultivars. In order to protect the germplasm of ten blackgram genotypes from moisture stress during the germination and seedling phases in vitro, the current experiment was designed. One of the most valuable pulse crops, blackgram is grown practically everywhere in India. Because of its delicious flavor and many other health benefits, it has unavoidably established itself as the most popular pulse and is most appropriately referred to as the "king of pulses."Blackgram has an abundance of nutrients, including proteins (25-26%), carbohydrates (60%), fat (1.5%), minerals, amino acids, and vitamins. It is either cooked and consumed immediately or broken into dhal. It is advised for diabetics and widely utilized in a variety of culinary recipes. The green pods are used as a nutrient-dense vegetable. Cattle are fed the hulls or the outermost coating of straw and green (Baroowa and Gogoi 2015). The primary barrier to improved production for blackgram, which is mostly cultivated in marginal and rain fed areas, is inadequate moisture. Therefore, developing genotypes that can withstand drought is essential for agriculture in these regions. The purpose of this study was to determine which blackgram genotypes were more suited for drought tolerance and to evaluate the impact of polyethylene glycol on the germination ability of certain genotypes.

II. MATERIALS AND METHODS

The research work was carried out at experimental farm, Department of Genetics, Osmania University, Hyderabad during 2022. The ten blackgram accessions (IC261182, IC382811, IC426766, IC436524, IC436628, IC476753, IC476784, IC519620, IC546452, IC546472) along with T-9(check) were collected from NBPGR regional center, Hyderabad and ICAR-CRIDA, Hyderabad respectively were used in the present study. Seeds that were healthy and uniformly sized were surface sterilized for two to three minutes using 0.1% mercuric chloride ($HgCl_2$) before being thoroughly washed with distilled water. According the Hadas (1976) technique, sterilized (10) seeds were sown in petri plates with moistened germination paper and various water potentials, namely, 0.0 (control), 5%, 10%, 15%, 20%, 25% and 30% of PEG 6000 in 100 ml of distilled water. Three replications were kept for each treatment. The germination criterion was established as the appearance of a 2 mm radicle (Kaur *et al.*, 2017 and Yadav *et al.*, 2013). Numbers of seeds germinated were counted from day-3 to day-6 after sowing to determine the germination percentage.

The following formula.

$$\text{Germination percentage (\%)} = \frac{\text{Numberofseedsgerminated}}{\text{Totalnumberofseeds}} \text{x}100$$

III. RESULTS AND DISCUSSION

The ANOVA results The ANOVA results revealed sgnificant variability due to treatment, genotype and treatment verses genotype for the trait seed grmination at all the percentage of PEG 6000 studied (Table 1).

Table 1. Analysis of variance in blackgram for the trait seed germination at various concentration of PEG.

Source of Variation	DF	MSSQ					
		Characters					
		5%	10%	15%	20%	25%	30%
Replications	**2**	0.797	0.624	0.225	1.100	0.660	0.66
Treatments	**1**	136.627**	235.91**	1727.898**	6790.556**	18639.266**	27121.78**
Genotypes	**10**	219.303**	205.182**	224.335**	366.831**	497.46**	497.46**
Treatments vs Genotypes	**10**	14.323**	11.373**	31.294**	94.979**	210.946**	210.946**
Error		1.39	0.805	0.603	0.971	1.497	1.497
SD		0.290	0.221	0.191	0.243	0.301	0.301
CV%		1.37%	1.05%	0.94%	0.01	1.73%	1.95%

Highest germination percentage genotype IC382811 was recorded (94.16%), and lowest genotype IC476784recorded as (76.18%) fallowed by IC426766 (93.82%), IC261182 (93.03%), T-9 (88.38%), IC436524 (83.58%), IC476753 (82.34%), IC546472 (82.20%), IC436628 (81.00%), IC519620 80.85%), IC546452 (77.59%) and IC476784 (76.18%) respectively were observed at 5%PEG 6000concentration**.**The genotype IC426766 (93.20%) was shown higher whereas lower genotype IC546452was recorded (77.17%). Fallowed by IC382811 (91.93%), IC261182 (90.62%), T-9 (89.27%), IC436524 (81.52%), IC546472 (80.96%), IC519620 (80.57%), IC476753(80.50%), IC436628 (79.83%), IC476784 (77.63%), IC546452 (77.17%) respectively were observed at 10% PEG 6000 concertation.

Table 2: Mean values of seed germination% in blackgram at different PEG concentrations

Genotypes	5%	10%	15%	20%	25%	30%	Control
IC261182	93.03	90.62	79.45	71.63	58.9	42.9	95.34
IC382811	94.16	91.93	87.82	81.56	77.77	61.77	94.6
IC426766	93.82	93.2	91.69	90.37	77.28	61.28	93.82
IC436524	83.58	81.52	74.3	63.72	54.5	38.5	85.13
IC436628	81.00	79.83	73.01	64.99	54.52	38.52	81.36
IC476753	82.34	80.5	74.27	55.69	44.37	28.37	87.06
IC476784	76.18	77.63	71.44	54.4	46.86	30.86	80.4
IC519620	80.85	80.57	70.78	60.86	30.74	14.74	89.84
IC546452	77.59	77.17	74.25	67.87	50.6	34.6	82.73
IC546472	82.2	80.96	72.7	59.92	41.41	25.41	80.73
T-9	88.38	89.27	82.52	70.61	58.12	42.12	93.78
SD	***6.482***	***6.026***	***7.023***	***10.866***	***14.153***	***14.153***	***5.990***
SE	***1.954***	***1.817***	***2.117***	***3.276***	***4.267***	***4.267***	***1.806***

Higher genotype IC426766 was recorded 91.69% whereas lower germination genotype IC519620 recorded as 70.78% fallowed by genotypes IC382811 (87.82%), T-9 (82.52%), IC261182 (79.45%), IC436524 (74.30%), IC476753 (74.27%), IC546452 (74.25%), IC436628 (73.01%), IC546472 (72.70%), IC476784 (71.44%) respectively were observed at 15% PEG6000 concentration. Germination at 20% PEG 6000 concentration was observed the highest genotype IC426766 was 90.37% and lowest germination percentage genotypes IC476784 was observed 54.40% whereas germination percentage range fallowed by IC382811 (81.56%), IC261182 (71.63%), T-9 (70.61%), IC546452 (67.87%), IC436628 (64.99%), IC436524 (63.72%), IC519620 (60.86%), IC546472 (59.92%), IC476753 (55.69%), IC476784 (54.40%) respectively were observed at 20% PEG 6000 concentration. Seed germination percentage was recorded the genotype IC382811 (77.77%) and lower genotype IC519620 was observed 30.74% fallowed by genotypes were IC426766 (77.28%), IC261182 (58.90%), T-9 (58.12%), IC436628 (54.52%), IC436524 (54.50%), IC546452 (50.60%), IC476784 (46.86%), IC476753 (44.37%), IC546472 (41.41%) and IC519620 (30.74%) respectively were observed at 25% PEG6000 concertation. The germination percentage was highest genotype IC382811was recorded as 61.77% fallowed by IC426766(61.28%), IC261182(42.90%), T-9(42.12%), IC436628(38.52%), IC436524(38.50%), IC546452(34.60%), IC476784(30.86%), IC476753(28.37%), IC546472 (25.41%) and IC519620(14.74%) respectively were observed at 30% PEG 6000 concentration (Table 2).

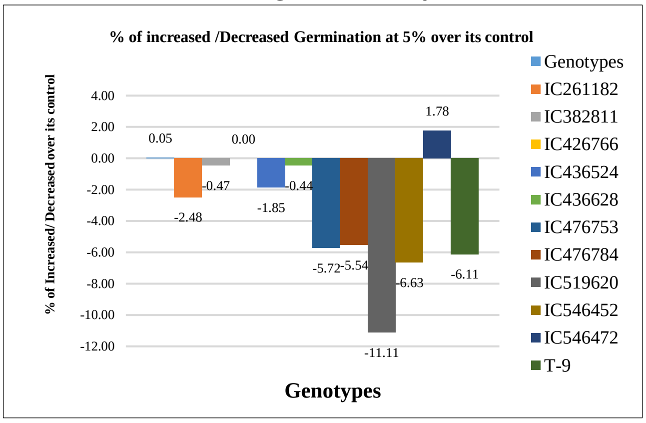
In the present study it was observed that with an increase in water stress (5%– 30%), there was a gradual depletion in rate of water uptake by blackgram seeds of all genotypes. This reduction might be due to the fact that water moves from high potential to low potential due to differences in the free energy content. The gradient of water potential between dry seeds and pure water (0.0 Mpa) decrease rapidly with the addition of any soluble substances such as polyethylene glycol in water. All the genotypes were observed seed germination at 5% over respective controls under PEG 6000 concentration the genotype IC546472 was presented 1.78% increased percentage and the genotype IC426766 showed 0.00 no significant over its control at 5% PEG 6000 concentration. In our study the highest reduction was observed genotype IC519620 result revealed -11.11%, followed by genotypes results were revealed IC546452 (-6.63%), T-9 (-6.11%), IC476753 (-5.72%), IC476784 (-5.54%), IC261182 (-2.48%), IC436524 (-1.85%), IC382811 (-0.47%), IC436628 (-0.44%) respectively decreasing over its control at 5% PEG concentration. Similar results were found in blackgram by Mohanlal *et al*., 2020; Ghanbari MohebSeraj *et al.*, 2021; Shobanadevi *et al.*, 2022; Bordoloi *et al*.,2023.

Table 3: Increased/ decreased seed germination percentage of blackgram at various concentration of PEG over its control

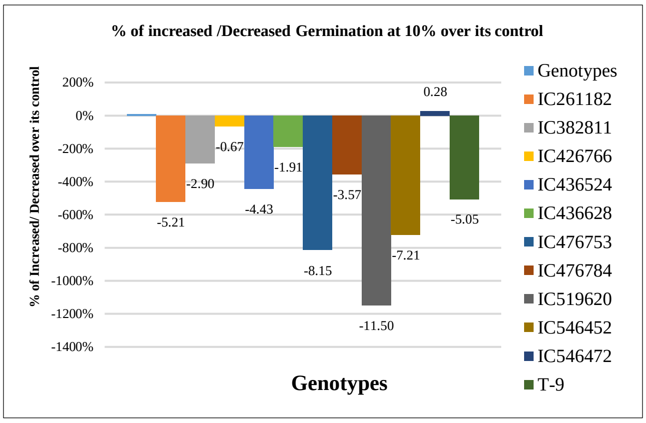
Genotypes	5%	10%	15%	20%	25%	30%
IC261182	-2.48	-5.21	-20.00	-33.09	-61.86	-122.22
IC382811	-0.47	-2.90	-7.72	-15.98	-21.65	-53.16
IC426766	0.00	-0.67	-2.32	-3.82	-21.41	-53.11
IC436524	-1.85	-4.43	-14.59	-33.60	-56.21	-121.13
IC436628	-0.44	-1.91	-11.43	-25.18	-49.22	-111.21
IC476753	-5.72	-8.15	-17.22	-56.33	-96.22	-206.90
IC476784	-5.54	-3.57	-12.55	-47.79	-71.56	-160.50
IC519620	-11.11	-11.50	-26.93	-47.60	-192.22	-509.34
IC546452	-6.63	-7.21	-11.43	-21.90	-63.49	-139.09
IC546472	1.78	0.28	-11.04	-34.73	-94.95	-217.68
T-9 (check)	-6.11	-5.05	-13.65	-32.81	-61.36	-122.65

The percentage of increased calculated at 10% PEG 6000 the genotype IC546472 was presented 0.28%. The genotype IC426766 was observed low value -0.67% seed germination percentage at 10% PEG 6000 concentration over its control(irrigated) was observed earlier in blackgram by Shobanadevi *et al.*, 2022; Mohanlal *et al.*, 2023. Also similar results showed in legumes by Swathi *et al.*, 2017; Priyadharshini *et al.*, 2021; Aadarsha and Shrestha. 2024.The decreased percentage calculated at 10% PEG 6000 concentration presented values lower in genotypes fallowed by IC436628(-1.91%), IC382811(-2.90%), IC476784(-3.57%), IC436524(-4.43%), T-9(-5.05%), IC261182(-5.21%), IC546452(-7.21%), IC476753(-8.15%) and IC519620(-11.50%) respectively condition over its control(irrigated) was observed earlier in blackgram by Priyadharshini *et al.*, 2021; Aadarsha and Shrestha. 2024.The decreased percentage of seed germination at 15% PEG 6000 concentration was observed low reduction genotype IC426766 was (-2.32%) and the genotype IC382811(-7.72%) over its control(irrigated). Lowest seed germination percentage was exhibited by 15% PEG 6000 concentration genotypes fallowed by IC546472(-11.04%), IC546452(-11.43%), IC436628(-11.43%), IC476784(-12.55%), T-9(-13.65%), IC436524(-14.59%), IC476753(-17.22%), IC261182(-20.00%) and IC519620(-26.93) respectively over its control was observed earliest in blackgram by Hellal *et al.*, 2018; Mohanlal *et al.*, 2023.The present results are in accordance with the reports of Sabesan and Saravanan 2016; Partheeban *et al.*,2017; Swathi *et al.*, 2017 in legume plants. The decreased percentage of seed germination at 20% calculated low in genotype IC426766 was -3.82% over its control(irrigated). The lowest decreased percentage of seed germination significant results followed genotypes byIC382811(-15.98%), IC546452(-21.90%), IC436628(-25.18%), T-9(-32.81%), IC261182(-33.09%), IC436524(-33.60%), IC546472(-34.73%), IC519620(-47.60%), IC476784(-47.79%) and IC476753(-56.33%) respectively over its control(irrigated) was observed earlier in blackgram by Hellal *et al.*, 2018; Jothimani and Arulbalachandran. 2020; Shobanadevi *et al.*, 2022; Khulal *et al.*, 2022; Samita *et al.*, 2022; Kumawat *et al*., 2023; Aadarsha and Shrestha, 2024.The percentage of decreased in seed germination at 25% PEG compared to control(irrigated) low values observed in genotype IC426766 was -21.41% and the genotype IC382811 was -21.65% *In vitro* condition, reduction in germination percentage respectively over its control (irrigated). *In vitro* screening of blackgram genotypes using PEG 6000 concentration found that the genotype IC426766(-21.41%) expressed tolerance to drought at seed germination level same results were found in blackgram by Dong and Beckles, 2019; Aman *et al*., 2022.At the 25% seed germination percentage of decreased was lowest values observed genotypes fallowed byIC436628(-49.22%), IC436524(-56.21%), T-9(-61.36%), IC261182(-61.86%), IC546452(-63.49%), IC476784(-71.56%), IC546472(-94.95%), IC476753(-96.22%), and IC519620 (-192.22%) respectively over its control(irrigated).Also have reported that increase in the osmotic concentration decreased energy of seed germination percentage in blackgram by Swathi *et al.*, 2017; Kaur *et al.*, 2017. Seed germination was observed PEG 6000 concentration earlier in blakgram by Jothimani and Arulbalachandran. 2020; Shobanadevi *et al.*, 2022; Aadarsha and Shrestha. 2024.The percentage of decreased in seed germination low result revealed in genotype IC426766 was -53.11% and IC382811 observed -53.16% over its control(irrigated) at

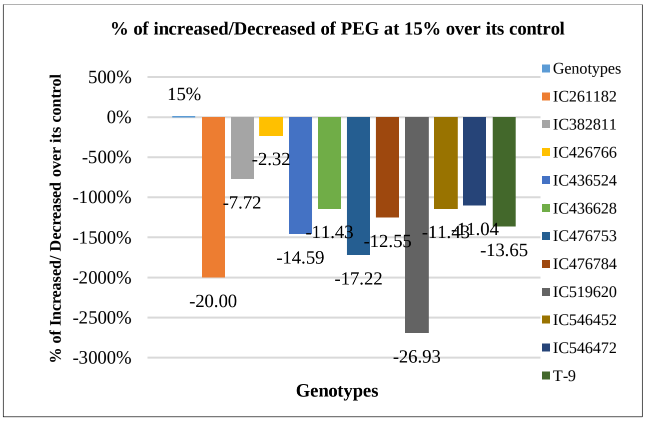
30% PEG concentration. The lower water potential during germination inhibits the seed germination or suppress the growth and development of seedlings in blackgram by Kaur *et al.*, 2017. Same results revealed significant in all genotypes fallowed by IC436628(-111.21%), IC436524(-121.13%), IC261182(-122.22%), T-9(-122.65%), IC546452(-139.09%), IC476784(-160.50%), IC476753(-206.90%), IC546472(-217.68%), and IC519620(-509.34%) respectively over its control(irrigated) was observed earlier in blackgram by Sridhar *et al*., 2020; Mohanlal *et al.*, 2023.A significant delay in the initiation and completion of germination was also observed in PEG 6000 treated varieties. The decreased germination in response to water stress is not uniform in all cultivars. A significant decrease in the germination percentage was observed at 30% concentration the germination percentage was higher decline in germination percentage due to lower water potential have been reported earlier in blackgram by Babu and Rosaiah. 2017; Rana *et al.*, 2017; Swathi*et al.*, 2017; Hellal*et al.*, 2018; Shobanadevi *et al.*, 2022; Aadarsha and Shrestha.2024 (Table 3).



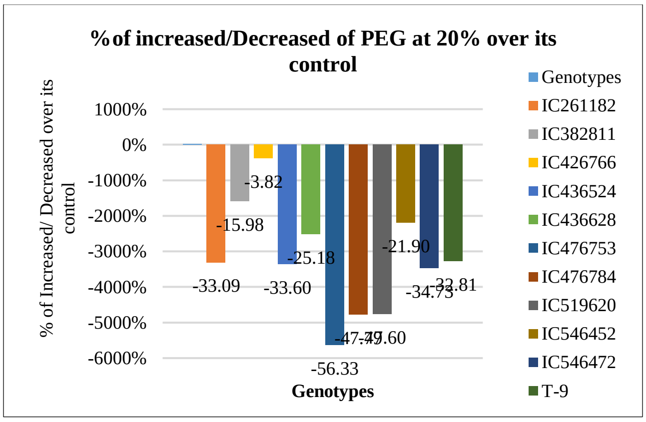
(a) % of increased /Decreased Germination% at 5% over its control



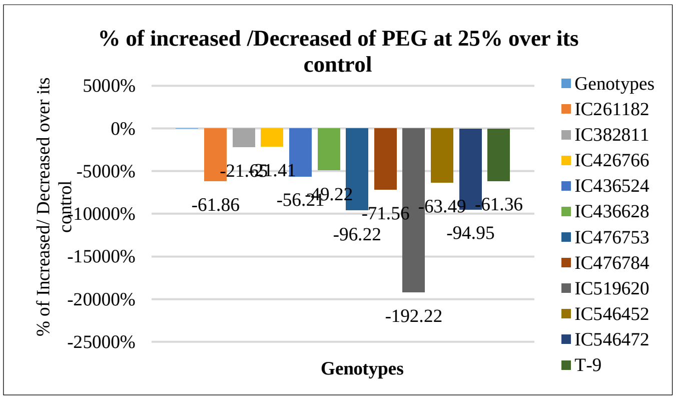
(b) % of increased /Decreased Germination% at 10% over its control



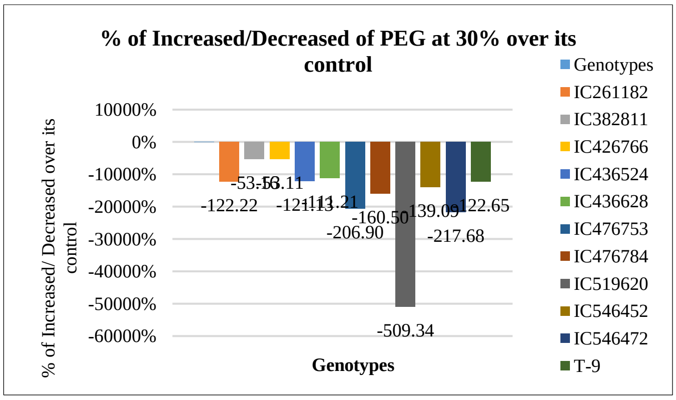
(c) % of increased /Decreased Germination% at 15% over its control



(d) % of increased /Decreased Germination% at 20% over its control



e) % of increased /Decreased Germination% at 25% over its control



(f) % of increased /Decreased Germination% at 30% over its control

Fig. 1. Increased/ decreased seed germination percentage of blackgram at various concentration of PEG over its control

IV. CONCLUSION

The present experiment results revealed that during the germination, the blackgram genotypes IC426766 and IC382811 shown higher germination percentage at higher concentration of PEG (>50% germination percentage). The chosen genotypes can be used for more field condition in research because they have been shown to have tolerance traits to withstand water stress.

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Increasing the growth and yield of eggplant (*Solanum melongena* L.) plants by applying chicken manure and PGPR (*Plant Growth Promoting Rhizobacteria*) on ultisols

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***Abstract*— *The land's low physical and chemical carrying capacity has impacted the low productivity of eggplant plants grown in ultisol soil. Therefore, using chicken manure and PGPR is highly recommended to increase plant productivity. This research aims to determine the appropriate chicken manure dosage and PGPR concentration for cultivating eggplant plants on this land. The experiment used a split-plot design by placing chicken manure doses in the main plot: (0%, 50%, and 100%) of the recommended dose. PGPR concentrations were placed in sub-plots: (without PGPR, 15 ml PGPR/L of water, and 30 ml PGPR/L of water). The experiment was repeated three times. F test at 5% is used to determine the existence of interactions or significant effect of treatment. Differences between treatments were considered Honestly Significant Difference (HSD) value at 5%. The study showed no significant interaction between chicken manure and PGPR on all observed growth and harvest parameters. However, each factor had a significant effect on growth observations: fresh root weight/plant, leaf area, and total dry weight of plants, and yield observations: fresh weight of fruit consumed/harvest plot and fresh weight of fruit consumed/ha. Application of 100% chicken manure can increase the fresh weight of eggplant fruit/ha by 7.27 t ha^{-1} (38.55%) and 18.47 t ha^{-1} (233.72%) from 50% and 0% chicken manure. In the PGPR treatment, to get a fresh weight of the maximum consumption fruit of 19.62 tons ha^{-1} requires the optimum PGPR concentration of 3.11 ml/ L water.*

***Keywords*— chicken manure, eggplant, PGPR, Ultisol**

I. INTRODUCTION

Various environmental conditions influence soil characteristics, such as climate, topography, and vegetation cover. Sukarman (2021) states that soil characteristics such as morphology, chemistry, physics, mineralogy, and soil biology are formed due to differences in soil types and environmental conditions in the region. Proper and wise handling is needed in connection with these problems.

Indonesia is known as an agricultural country with great opportunities to develop various types of food crops. However, 78% of its total land area is dry land. Dry land is sub-optimal, with low water availability as the main limiting factor [1]. As a result, plants will experience a lack of water, which can disrupt carbohydrate synthesis. Water plays a role in regulating the opening and closing of stomata. Therefore, when plants experience a lack of water, the plant's stomata will close, which is a form of plant adaptation to prevent more water loss from the soil and plants [28]. This reaction is detrimental to plants because it decreases the rate of plant photosynthesis [5]. This condition is exacerbated by the dominance of soil that is included in the ultisol order. Soil included in this order has a low ability to store and hold water [14]. Therefore, to achieve high soil productivity, it is necessary to improve the physical properties of the soil through the application of organic materials. Based on the results of the initial soil analysis, it was found that the content of soil organic matter (2.24%), and soil C-organic (1.30%) was low. Whereas organic matter is an important component of soil, it can affect the soil's physical, chemical, and biological quality. Organic matter derived from the decomposition of living things (plants and animals) has a major impact on improving soil structure, nutrient content, and microbial activity [31]. Physically, organic matter can improve soil structure and water-holding capacity, thus allowing better root penetration and development. Biologically, organic matter encourages the growth of soil organisms and is useful for helping the plant nutrient cycle [18]. On the other hand, high intensity of solar radiation will also spur a lot of N loss through the volatilization process, resulting in low soil N content. Nitrogen is included in the group of essential nutrients for plants whose needs are higher than other nutrients. This is because N plays a role as a component of chlorophyll, both chlorophyll-a($C_{55}H_{72}O_5N_4Mg$), and chlorophyll-b ($C_{55}H_{70}O_6N_4Mg$), both of which play a role in carbohydrate synthesis (13). As a result, when plants experience N deficiency, most of the leaves that have formed will turn yellow, which decreases the rate of plant photosynthesis. Meanwhile, based on the results of the initial soil analysis, it was found that the total N content of the soil was low, around 0.10%. Due to these problems, N fertilization is highly recommended. However, continuous N application can damage the soil structure. The soil becomes denser and harder so the process of plant root development is disrupted [31]. Therefore, to reduce the use of N, the PGPR application is needed.

PGPR is a group of living bacteria that colonize the rhizosphere area, and these bacteria can provide and mobilize the absorption of nutrients in the soil [3]. According to [14], the microbial population is mostly located around the plant root area *(rhizosphere*) compared to other zones. This is because plant roots produce substances that contain secondary metabolites such as sugars and amino acids which function as an energy source for microbes. These bacteria are useful in plant physiological processes because they can act as biological fertilizers, biostimulants, and bioprotectants [17]. As a biofertilizer, PGPR plays a role in facilitating uptake and increasing the availability of nutrients, especially N for plants in the rhizosphere through nitrogen fixation, dissolution of mineral nutrients, mineral organic compounds, and phytohormone production [25]. Given the important role of PGPR in the availability of N, information on the right concentration of PGPR in eggplant cultivation is very much needed.

II. MATERIALS AND METHODS

2.1 Description of the study area

Field research was carried out on farmer's land in Kasin Village, Karang Ploso subdistrict, Malang City, East Java. Geographically, the experimental area is located at an altitude of 535 m above sea level, with ultisol soil type. Climatologically, the average daily temperature ranges between 23°C - 31°C with an average rainfall of 2,457 mm/year [8]. Chemically, the total N-soil, K-soil, soil organic matter, and soil C-organic content are in the low category, respectively 0.13%, 0.13 me 100 g^{-1}, 2.24%, and 1.30%. Except for P_2O_5 Olsen is in moderate status (12.27 ppm). The soil includes a dusty clay texture with proportions of sand (8%), dust (49%), and clay (43%)

2.2 Research material

The planting material used was eggplant seedlings of F1 variety that were 14 days old after sowing and had formed 2 to 4 perfect leaves. Seeds were obtained from PT East West Seed Indonesia. Polybag measuring 5 cm x 5 cm for seeding, *plant growth promoting rhizobacteria* (PGPR), chicken manure, N fertilizer (in the form of urea: 46% N), phosphorus fertilizer (in the form of SP-36: 36% P_2O_5), and potassium fertilizer (in the form of KCl: 60% K_2O). The dose of an-organic fertilizers applied is based on the initial soil analysis results and the level of N, P, and K requirements of eggplant plants. According to [21] the level of N requirements ranges from 150 - 200 kg N ha^{-1}; P fertilizer: 100 -150 kg P_2O_5 ha^{-1}, and K fertilizer ranges from 60 - 100 kg K_2O ha^{-1}. Calculating fertilizer requirements refers to equation 1 [30].

$$N = \frac{A2 - B}{A1 - A2} = \frac{N - XA}{XA - XB}$$

Where:

N: the nutrient dose that must be added according to soil criteria (kg ha^{-1})

A_1: the top content of the total soil N range (%): 0,5%

A_2: the lowest content of the total soil N range (%): 0,21%

B: the total N content of the soil (%): 0,10%

X_A: the highest value of the required dose of N plants (kg ha^{-1}): 200 kg N ha^{-1}

X_B: the lowest value of the required dose of N plants (kg ha^{-1}): 150 kg N ha-[1]

Based on equation 1 above and the experimental plot area is 5.67 m^2, the fertilization dose that must be given is as presented in Table 1. Meanwhile, the chicken manure analysis results are presented in Table 2, and the dose of chicken manure that must be applied is presented in Table 3. The calculation of chicken manure needs refers to [31] as follows:

$$\frac{\%\ \text{recommendation}}{\text{N content of chicken manu}} \times \text{N fertilizer dose/ plot}$$

Where:

The plot size:5.67 m^2

N fertilizer dose per plot: 0.269 kg

N content of chicken manure: 0.88 %

Table 1. The dose of N, P, and K fertilizer that must be applied

Source of fertilizer	The dosage of fertilizer applied		
	Kg ha^{-1}	Kg/plot	g/plant
N	218,97	0,124	1,97
(Urea)	476,01	0,27	4,29
P_2O_5	144,70	0,08	1,27
(SP_{36})	401,94	0,23	3,65
K_2O	232,00	0,13	2,06
(KCl)	386,6	0,22	3,49

Table 2. Status of physical and biological properties of chicken manure

No.	**Parameters**	**Values**	**Units**	**Methods**
1	C-organic	6.12	%	SNI 7763 :2018
2	Organic matter	10.55	%	SNI 7763 :2018
3	C/N	6.95	-	
4	Water content	25.11	%	SNI 7763 :2018
5	Macronutrients:			
	Nitrogen	0.88	%	SNI 7763 :2018
	P_2O_5	12.52	%	SNI 7763 :2018
	K_2O	0.36	%	SNI 7763 :2018
6	Supporting materials	0.31	%	SNI 7763 :2018

Criteria:

Soil properties	C-organic (%)	C/N	Nitrogen (%)	P_2O_5 (%)	K_2O (%)
Very low	< 14.50	-	< 0.60	< 0.30	< 0.20
Low	14.50 – 19.50	< 10.00	0.60 – 1.00	0.30 – 0.80	0.20 – 0.50
Medium	19.60 – 27.00	10.00 – 20.00	1.10 – 2.00	0.90 – 1.70	0.60 – 1.30
High	≥27.10	≥ 20.00	≥ 2.10	≥ 1.80	≥ 1.40

Table 3. The dose of chicken manure to be applied

Recommended dose (%)	The dose of chicken manure applied		
	Per hectare (ton)	Per plot (kg)	Per planting hole (g)
100	53.9	30.6	485
50	26.95	15.3	242.5

2.3 Experimental design

The experiment used a split-plot design by placing chicken manure doses in the main plot: (0%, 50%, and 100%) of the recommended dose. PGPR concentrations were placed in sub-plots: (without PGPR, 15 ml PGPR/L of water, and 30 ml PGPR/L of water). The experiment was repeated three times. F test at 5% is used to determine the existence of interactions or significant effect of treatment. Differences between treatments were considered Honestly Significant Difference (HSD) value at 5%. Regression analysis is used to explore relationships between two or more variables observed.

2.4 Research implementation

The initial activity of the study was soil cultivation, which aimed to obtain crumbly and loose soil. The application of organic matter (chicken manure) was given one week after soil cultivation, each amounting to 0.485 g, and 242.5 g/planting hole, for 100% and 50% of the recommended dose (Table 3). Chicken manure put into the planting hole was then stirred with the soil and left for one week to remove toxins. Transplanting is done when the plants are 14 days after sowing, and 2-4 perfect leaves have formed by placing 1 eggplant seedling in each planting hole. P fertilizer in the form of SP_{36} is applied 1 week before planting the entire dose (3,65 g/plant**)**, while N (urea) and potassium (KCl) fertilizers are given in stages. In the first stage, 1/3 of the dose is given when the plants are 7 days after transplanting, and the rest (2/3) is applied when the plants are 30 days after transplanting. Fertilizer is applied to a depth of 7 cm at a distance of 5 cm from the plant. PGPR was given in stages, first at the same time as transplanting (0; 5 ml PGPR/L water; 10 ml PGPR/L water), second when the plants were 14 days old after transplanting (0; 5 ml PGPR/L water; 10 ml PGPR/L water), and third when the plants were 28 days old after transplanting (0; 5 ml PGPR/L water; 10 ml PGPR/L water).

2.5 Data collection

Observations were carried out destructively by taking 3 sample plants/treatments at 30 days after transplanting (DAT), 40 DAT, 50 DAT, and 60 DAT, and at harvest time (70-80 DAT) including growth parameters (root fresh weight, leaf area, and total dry weight of plants), and yield parameters including fruit set, and fresh weight of fruit consumed/ha.

2.5.1 Root fresh weight

Observation of the fresh weight of the roots was carried out by weighing all the roots after they were separated from the base of the stem and cleaned from the soil, using an analytical balance.

2.5.2 Leaf surface area

Leaf surface area was measured using LAM type LI-3100 C for fully opened leaves, excluding young and old leaves. Leaf samples were placed on a glass lens in an unfolded or non-overlapping position. All leaf samples from three sample plants per treatment were recorded and then averaged. The leaf surface area value is based on the average value of the measurements multiplied by the correction factor. The correction factor is found by dividing the actual paper area measurement value (for example 100 cm^2) by the paper area value that has been measured with LAM, for example, 80 cm^2. So the correction factor value is 80 cm^2 / 100 cm^2 = 0.8

2.5.3 Total dry weight of plants

Measurement of the total dry weight of plants using an OVL oven, type 12. Roots, stems, leaves, and tubers must be separated before drying. This is because each plant part requires a different drying time to achieve a constant dry weight. The plant parts that have been separated are placed in a cement bag and then placed in the oven. Weighing was carried out using an analytical balance after a constant dry weight was achieved, and all plant parts were added.

2.5.4 Fruit set

Fruit set is a ratio between the number of fruits and the total number of flowers formed **2.5.5 Fresh weight of fruit consumed/ha**

The fresh weight of consumption per hectare is obtained by converting the fresh weight of consumption per harvest plot to hectares (ha) [31] through an equation 2:

$$\frac{\text{1 ha land area}}{\text{harvest plot area}} \text{ X fresh weight consumption per harvest plot} \times \text{correction factor}$$

Meanwhile, the correction factor is obtained by multiplying the area of the experimental plot (5.67 m^2) by the number of experimental plots (27) divided by the total area of land used (243.19 m^2) [30].

III. RESULT AND DISCUSSION

3.1 Result

3.1.1 Growth parameters

3.1.1.1 Fresh weight of roots/plants

Analysis of variance showed no significant interaction between chicken manure and PGPR treatments on the fresh weight of the root/plant. However, each factor has a significant effect on the variables (Table 4).

Applying 50% and 100% chicken manure resulted in fresh root weights that were not significantly different and were heavier by 1.91 g (61.22%) and 2.96 g (94.79%) compared to the treatment without chicken manure only reached 3.12g. In the PGPR treatment, the use of PGPR 15 and 30 ml/L water was able to produce fresh root weights that were 1.48 g (41.57%) and 2.06 g (57.94%) heavier than the treatment without PGPR, and both produced fresh weight of roots was not significantly different.

3.1.1.2 Leaf surface area

There was no significant interaction between chicken manure and PGPR on the leaf surface area variable. However, each factor had a significant effect on the variable. The average leaf surface area at various chicken manure doses and PGPR concentrations is presented in Table 5.

Table 5 shows that the narrowest leaf surface area was obtained in the treatment without chicken manure, an average of 288.62 cm^2.The application of chicken manure has an impact on increasing the size of the leaf surface, respectively 203, 71 cm^2 (70.58%) for a dose of 50%, and an area of 354.25 cm^2 (122.74%) for a dose of 100% when compared with treatment without chicken manure. The leaf surface area showed no significant difference at 50% and 100% chicken manure doses. In the PGPR treatment, the narrowest leaf surface area was obtained without PGPR, with an average area of 395.46 cm^2. The application of PGPR caused an increase in the leaf surface area, respectively 111.76 cm^2 (28.26%) for 15 ml and 125.48 cm^2 (31.73%) for a concentration of 30 ml PGPR/L water, both of which showed no significant difference.

3.1.1.3 Total dry weight of plants

Analysis of variance showed that there was no significant interaction between chicken manure and PGPR in the observation of the total dry weight of plants. However, the total dry weight of the plant is influenced by these two factors. The average total dry weight of plants at various chicken manure doses and PGPR concentrations is presented in Table 6.

Table 6 shows the same pattern of results on the total dry weight of plants at all observation ages, and the highest was obtained in the application of 100% chicken manure, which was around 13.76 g/plant. Reducing the dose of chicken manure, from 100% to 50%, without chicken manure caused a reduction in the total dry weight of the plants produced, respectively by 27.62% (3.80 g) and by 60.10% (8.27 g). A reduction of 44.82% (4.46 g/plant) also occurred when the chicken manure dosage was reduced from 50% to no chicken manure. In the PGPR treatment, a higher average dry weight of plants was obtained by applying 15 ml and 30 ml PGPR/L of water, respectively 10.54 g, and 10.99 g/plant. These two values were still higher, 37.78% (2.89 g) and 43.66% (3.34 g) compared to the treatment without PGPR which only reached a weight of 7.65 g/plant.

Table 4. Average fresh root weight per plant at various chicken manure doses and PGPR concentrations at all ages of observation

Treatment	Average fresh root weight per plant (g) at age of observation (DAT)			
	30	40	50	60
Chicken manure dosage (% recommendation)				
Without chicken manure	0.47 a	1.54 a	3.99 a	6.47 a
50%	0.79 b	2.01 ab	6.73 ab	10.60 b
100%	1.20 c	2.51 b	8.38 b	12.22 b
HSD 5%	0.25	0.79	2.75	3.64
CV-a (%)	18.36	23.45	25.75	22.24
PGPR Concentration:				

Without PGPR	0.59 a	1.49 a	4.43 a	7.74 a
15 ml PGPR/L water	0.92 b	2.08 b	6.52 b	10.64 b
30 ml PGPR/L water	0.96 b	2.48 b	8.14 b	10.91 b
HSD 5%	0.24	0.53	1.66	2.49
CV-b (%)	23.87	21.14	20.82	20.35

Note: Numbers accompanied by the same letter in the same treatment and at the same age are not significantly different in the 5% HSD test. DAT: the day after transplanting

Table 5. Average leaf surface area at various chicken manure doses and PGPR concentrations at all ages of observation

Treatment	. Average leaf surface area (cm^2/plant) age of observation (DAT)			
	30	40	50	60
Chicken manure dosage (% recommendation)				
Without chicken manure	51.10 a	182.04 a	390.01 a	531.26 a
50%	122.50 b	367.84 b	681.18 b	797.48 b
100%	146.21 b	466.12 b	1003.98 c	955.15 b
HSD 5%	44.54	104.20	235.39	198.44
CV-a (%)	24.87	18.31	20.26	15.52
PGPR Concentration:				
Without PGPR	93.11 a	234.52 a	577.46 a	677.19 a
15 ml PGPR/L water	12054 b	404.38 b	704.52 b	799.42 b
30 ml PGPR/L water	10616 ab	377.10 b	793.19 b	807.29 b
HSD 5%	25.70	101.71	123.99	120.16
CV-b (%)	19.19	23.90	14.26	12.56

Note: Numbers accompanied by the same letter in the same treatment and at the same age are not significantly different in the 5% HSD test. DAT: the day after transplanting, ns: no significant effect

Table 6. The average total dry weight of plants at various chicken manure doses and PGPR concentrations at all ages of observation

Treatment	. Average total dry weight of plants (g/plant)/ age of observation (DAT)			
	30	40	50	60
Chicken manure dosage (% recommendation)				
Without chicken manure	0.33 a	1.23 a	8.84 a	11.54 a
50%	0.54 b	3.24 b	15.84 b	20.19 b
100%	0.78 c	4.10 c	27.77 c	22.38 b
HSD 5%	0.17	0.67	6.00	7.75
CV-a (%)	18.39	14.00	20.45	25.60
PGPR Concentration:				
Without PGPR	0.48	2.33 a	13.73 a	14.06 a

15 ml PGPR/L water	0.55	3.08 ab	18.46 b	20.08 b
30 ml PGPR/L water	0.63	3.16 b	20.26 b	19.97 b
HSD 5%	ns	0.80	3.85	3.94
CV-b (%)	24.61	22.55	17.55	17.39

Note: Numbers accompanied by the same letter in the same treatment and at the same age are not significantly different in the 5% HSD test. DAT: the day after transplanting, ns: no significant effect

3.1.2 Yield component

3.1.2.1 Fruit set

The results of the variance analysis showed that there was no significant interaction between chicken manure and PGPR in *fruit set* observations. The use of PGPR also does not significantly affect this variable. The fruit set was only affected by the dose of chicken manure, as presented in Table 7.

Table 7. Average fruit set at various chicken manure doses and PGPR concentrations at 60 DAT

Treatment	Average fruit set (%)
Chicken manure dosage (% recommendation)	
Without chicken manure	52.11 a
50%	63.28 b
100%	66.17 b
HSD 5%	6.88
CV-a (%)	6.78
PGPR Concentration:	
Without PGPR	59.31
15 ml PGPR/L water	61.29
30 ml PGPR/L water	60.96
HSD 5%	ns
CV-b (%)	7.97

Note: Numbers accompanied by the same letter in the same treatment and at the same age are not significantly different in the 5% HSD test. DAT: the day after transplanting, ns: no significant effect

After applying 50% and 100% doses of chicken manure, the fruit set produced was not significantly different but was significantly higher by 11.17 (21.44%) and 14.06 (26.98%) compared to the treatment without chicken manure.

***3**.1.2.2 Fresh weight of fruit consumed/ha*

The fresh weight of consumption fruit per hectare refers to equation 2. The results of the variance analysis show that there is no significant interaction between chicken manure treatment and PGPR on the fresh weight of economic fruit per hectare. However, each factor had a significant effect on the variable. The average fresh weight of fruit consumption per hectare at various doses of chicken manure and PGPR concentrations is presented in Table 8.

Table 8. Average fresh weight of fruit consumption per hectare at various chicken manure doses and PGPR concentrations at harvest

Treatment	Fresh weight of fruit consumption per hectare (ton)
Chicken manure dosage (% recommendation)	
Without chicken manure	7.83 a
50%	18.86 b
100%	26.13 c
HSD 5%	4.01
CV-a (%)	13.56
PGPR Concentration:	
Without PGPR	14.90 a
15 ml PGPR/L water	18.32 b
30 ml PGPR/L water	19.61 b
HSD 5%	2.38
CV-b (%)	10.79

Note: Numbers accompanied by the same letter in the same treatment and at the same age are not significantly

The lowest fresh weight of fruit consumption per hectare was obtained in the treatment without chicken manure, namely 7.83 tons ha^{-1}. The application of 50% and 100% doses of chicken manure caused an increase in fresh fruit weight per hectare, respectively by 11.03 tons ha^{-1} (140%) and 18.3 tons ha^{-1} (233.72%). An increase of 7.27 tons ha^{-1} (38.55%) also occurred when the chicken manure dosage was changed from 50% to 100%. The lowest fresh weight of fruit consumption per hectare was obtained in the treatment without PGPR, which was 14.90 tons ha^{-1}. The use of PGPR as much as 15 ml and 30 ml/L of water had an impact on increasing the fresh weight of fruit consumption by 3.4 tons ha^{-1} (22.95%) and 4.71 tons ha^{-1} (31.61%), respectively, but both showed not significantly different.

3.2 Discussion

3.2.1 Fresh weight of roots/plants

The study showed that the lowest fresh weight of roots/plants was obtained in the treatment without chicken manure, namely 3.12 g, compared to the application of 50% and 100% chicken manure, which had reached a weight of 5.03 g and 6.08 g. This indicates that organic matter in chicken manure is essential in ultisol soil [27]. Ultisol soil is characterized by high clay content. The nature of clay is generally smooth and soft with a dominance of micro-sized silicate minerals [2]. In dry conditions, this soil will decompose into fine grains, filling most of the soil pore space (micro and macro) with soil grains [15]. Low soil pore percentage can reduce oxygen flow, especially in the plant root zone, disrupting the plant roots' water and nutrient absorption process [28]. On the other hand, in wet conditions, the soil is sticky, and the granules that form it easily stick together and are difficult to separate [4]. Therefore, this soil is compact and hard. As a result, the ability of the roots to penetrate the soil is disrupted, and results in the inhibition of the process of plant root development.

The results of the study also showed that the lowest fresh root weight was obtained in the treatment without PGPR, an average of 3.56 g. The application of PGPR at concentrations of 15 ml and 30 ml/L of water increased fresh root weight, to 5.04 g and 5.62 g respectively (Table 4). This is closely related to the fact that PGPR is a colony of various types of bacteria so it can play a role in improving the physical properties of soil, such as ultisol [29,4]. This is closely related to the fact that PGPR is a biofertilizer or biological fertilizer, a collection of living microorganisms that function as soil conditioners. The role of PGPR as a biological fertilizer is to transform nutrients in unavailable forms into available ones for plants with the help of compounds produced by bacteria in PGPR such as fixing N elements and dissolving P elements [25,6]. Nitrogen is one of the essential nutrients for plants and is needed in greater quantities than other nutrients. This is because N is involved in the formation of chlorophyll, both chlorophyll a ($C_{55}H_{72}MgN_4O_5$) and chlorophyll b ($C_{55}H_{70}MgN_4O_6$) which causes the photosynthetic activity to take place due to the absorption of light by chlorophyll [33]. Therefore, when plants experience N deficiency, the plant's growth rate is disrupted due to low assimilation produced. It is known that assimilate is energy, and this energy is very necessary in the process of plant growth and development. Therefore, the growth speed is in line with the amount of energy available to the plant. Based on the calculation of the availability of N nutrients, the lowest value was obtained in the treatment without chicken manure and without PGPR, which was 1.90%. Meanwhile, for the treatment without chicken manure + 15 ml PGPR,and without chicken manure + 30 ml PGPR, it was 2.83% and 5.61%, respectively. The low availability of these nutrients is the cause of the obstruction of the plant root development process.

3.2.2 Leaf surface area

Leaves are an important photosynthesis organ in plants. Therefore, the leaf surface area reflects the plant's capacity to produce assimilation [22]. Based on the experiment's results, the wider leaf surface size was obtained in the application of 50% and 100% chicken manure than without chicken manure, each covering an area of 492.33 cm^2, 642.85 cm^2, and 288.62 cm^2, respectively.

The narrower leaf surface area is related to the lower fresh weight of the roots produced. Roots are one of the plant organs that play an important role in absorbing nutrients and water for plants. When the fresh weight of the roots is low, the ability of the roots to absorb water and nutrients will be limited by the weight of the roots formed. Water for plants has a function in regulating the opening and closing of stomata. Stomata will close when water is in short supply for plants [32]. As a result, the assimilates produced are low, including Cell division, elongation, and widening. Thus, the narrower leaf surface size is greatly influenced by the low fresh weight of the roots produced. The regression analysis results prove a linear relationship between fresh root weight (X) and leaf area (Y) at various PGPR concentrations through an equation: $Y = 63.73X + 172.51$; $R^2 = 0.97$. This shows that the higher the fresh root weight, the greater the leaf surface size. The high value of $R^2 = 0.97$ means that 97% of the size of the leaf surface area is greatly influenced by the fresh weight of the roots produced.

3.2.3 Total dry weight of plants

The plant's total dry weight reflects its ability to utilize factors in its growing environment and is a function of plant organs [33]. The results showed that the heaviest total dry weight of the plant was obtained in the application of 100% chicken manure, weighing 13.76 g/plant, and showed a reduction of 3.81 g/plant (27.69%) and 8.27 g/plant (60.08%) when the dose of chicken manure was reduced from 100% to 50% and without chicken manure. This is because, in the treatment without chicken manure, the fresh weight of the roots and the surface area of the leaves produced were the lowest (Tables 4 and 5). Both variables are vital parts of the plant that can be used as a benchmark for the success of a plant. Leaves are a medium for photosynthesis activity to take place, so the surface area of the leaves describes the capacity of the plant to produce assimilates through photosynthesis [23]. Meanwhile, the speed of photosynthesis is determined by plant roots' nutrient and water uptake [7]. Moreover, this research was conducted in dry land, where the soil is dominated by dust and clay fractions, making it quite difficult for plant roots to penetrate because the soil is dense and hard [15]. Based on the soil analysis results, it was found that in the treatment without chicken manure, the dust content was the highest, which was 35%, while in the treatment of 50% and 100% chicken manure, it was only around 28.33% and 26%. The high dust content in the treatment without chicken manure causes the soil to be unable to store and hold water properly, and the soil is easily eroded which causes the soil to become infertile [34]. The reduced level of soil fertility followed by the low level of water availability, causes the growth rate to be disrupted, thus impacting the low assimilates produced [35]. While assimilates describe the total dry weight of the plant. Regression analysis shows the formation of a linear relationship between the dose of chicken manure (X) and the total dry weight of plants (Y) through an equation: $Y = 8.27\ X + 5.60$; $R^2 = 0.99$. This equation explains that the higher the dose of chicken manure applied, the higher the total dry weight of the plants produced. This statement is supported by the high value of $R^2 = 0.99$, which means that the dose of chicken manure influences 99% of the total dry weight of plants.

In the PGPR treatment, the heavier total dry weight of plants was obtained in the 15 ml and 30 ml PGPR/L water treatments, respectively 10.54 g/plant and 10.99 g/plant, and the lowest was found in the treatment without PGPR, which was 7.65 g/plant. Giving PGPR up to a concentration of 30 ml, caused a decrease in dust levels, but was followed by an increase in N availability in both treatments (Table 9). The decrease in dust levels in various PGPR applications, especially at concentrations of 15 ml and 30 ml PGPR/L of water, is related to the number of bacteria in the PGPR [9]. These bacteria can act as biological agents that play a role in improving the physical properties of the soil [14]. Therefore, the more bacteria contained in the PGPR, the faster the process of changing the physical properties of the soil [10]. The soil becomes more stable, and the soil's ability to retain and store water is better than treatments without PGPR. The availability of

N nutrients also increases along with the increase in the concentration of PGPR [11]. In treatments without PGPR, the soil N content is in a low category (0.127%), while in the provision of 15 ml and 30 ml PGPR it is in moderate status, each of

which is 0,134%, and 0,147.

Table 9. Changes in dust and N nutrient content in various PGPR treatments.

Treatment	Changes in dust and N nutrient content from various soil analysis results			
	Early (%)	Middle (%)	Final (%)	Soil N- content (%)
0 PGPR	49	37,33	35,33	0,127
15 ml PGPR/L water	49	35,0	32,67	0,134
30 ml PGPR/L water	49	35,33	33,33	0,147

A more crumbly and stable soil condition will support the process of plant root development. In these conditions, plants will find their water and nutrients, which will cause the plants to become more responsive to environmental pressures. When plants face environmental pressures, they can make maximum use of environmental factors in their growth. When plants can cope with environmental stress, they can utilize environmental factors to their maximum [24]. A high total dry weight of a plant reflects the high ability of a plant to utilize factors in its growing environment and is a function of plant organs. Considering that the highest plant parts were obtained at 15 ml and 30 ml PGPR/L of water, higher total plant dry weight was also obtained in both treatments (Table 6).

3.2.4 Yield component

3.2.4.1 Fruit set

A fruit set is a ratio between the number of fruits and the total number of flowers formed. The results showed that the lowest fruit set value was obtained in the treatment without chicken manure, at 52.11%. Applying chicken manure at 50% and 100% doses resulted in higher fruit set values, respectively 63.28% and 66.17%. Considering that the formation of fruit sets is greatly influenced by energy availability (assimilate), the more energy available to the plant, the higher the value of the fruit set. Abscission is when flowers fail to become fruit due to insufficient nutrients or energy needed for the change process. Therefore, when plants do not have enough energy available (assimilate), then a plant's ability to produce fruit is also low. This is evident from the results of this study, where the lowest fruit set value was obtained in the treatment without chicken manure (Table 7). As a result of the lowest total dry weight of the plants produced (Table 6).

3.2.4.2 Fresh weight of fruit consumption per hectare

Determination of fresh fruit consumption is based on the weight of the fruit between 200 - 300 g/fruit. The research results showed that the highest fresh weight of fruit/hectare was obtained when using 100% chicken manure: 26.13 tons ha^{-1}. This result is 7.27 tons (38.55%) and 18.3 tons (233.71%) higher compared to the provision of 50% and 0% chicken manure. This is quite reasonable because the capacity of organic material decomposition is greatly influenced by the amount of organic material applied [12]. At high doses, the content of microorganisms increases and has an impact on increasing the rate and capacity of organic material decomposition in improving the physical properties of the soil [19]. The study showed that providing 100% chicken manure can reduce the highest dust content (around 7.13%) compared to the treatment without chicken manure. The reduced dust content causes the soil to be looser so that root penetration becomes deeper. As a result, the ability of the roots to absorb water and nutrient increase which causes an increase in the rate of plant photosynthesis.

Assimilate is a result of photosynthesis, and shows an increase in the treatment, while assimilate is a reflection of the total dry weight of the plant, and it is energy. Some energy will be stored in the sink as eggplant fruit, and some for growth. Therefore, the more assimilated produced, the more energy will be distributed to the fruit (sink) [16] The weight of eggplant fruit/plant in various chicken manure treatments is presented in Figure 1.

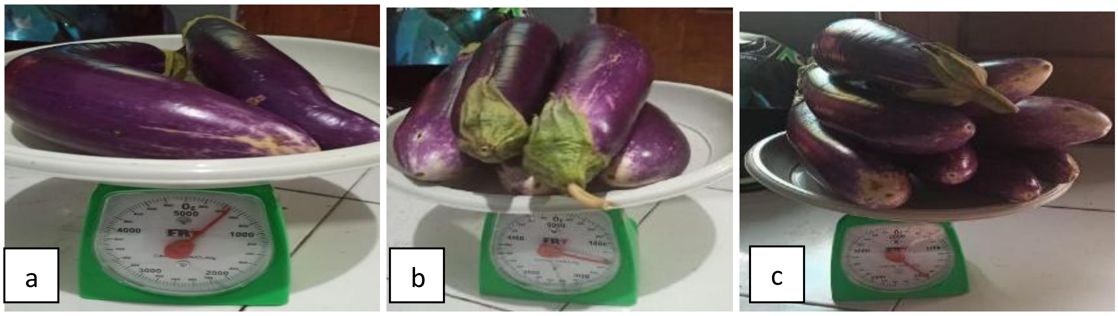

Fig.1. Fresh weight of eggplant fruit consumed in three chicken manure treatments. (a) : fresh weight of eggplant for consumption without chicken manure, (b) fresh weight of eggplant for consumption + 50% chicken manure, (c) fresh weight of eggplant for consumption + 100% chicken manure.

Figure 1 shows that the highest fresh weight of fruit was obtained from the application of 100% chicken manure (Fig. 2c), followed by 50% chicken manure (Fig. 2b), and finally without chicken manure (Fig. 2a). Regression analysis proved that there was a linear relationship between the dose of chicken manure (X) and the fresh weight of fruit for consumption per hectare (Y) through an equation:

$$Y = 18.3\ X + 8.46\ ;\ R^2 = 0.99$$

This equation explains that an increase in the dose of chicken manure is still accompanied by an increase in the fresh weight of consumed fruit per hectare. This statement is supported by the high value of the coefficient of determination (R2) = 0.99, which means that 99% of the fresh weight of fruit consumed is influenced by the dose of chicken manure.

In the PGPR treatment, the higher fresh weight of fruit consumption per hectare was obtained at a concentration of 15 ml and 30 ml PGPR/L water, respectively 18.32 tons ha_{-1} and 19.61 tons ha^{-1}, and the lowest, namely 14.90 tons ha^{-1} was obtained in the treatment without PGPR. The low yield is closely related to the low initial N-soil: 0.10%. Therefore, through the PGPR application, it will be possible to facilitate the provision and increase of nutrient uptake, especially N [26]. Providing N through chemical fertilization activities is not wise, because it will only damage the soil. The soil becomes dense and hard, and N residue causes the soil to become more acidic. Under these conditions, alkaline elements such as Mg, K, and Ca become less available to plants [12]. The Mg element is the core of the chlorophyll compound, which will determine the rate of photosynthetic activity [33]. Considering the important role of PGPR, which cannot only function as a soil conditioner but is also quite good at providing nutrients for plants, the application of PGPR is highly recommended. Figure 2 shows the fresh weight of fruit/plants at various PGPR concentrations.

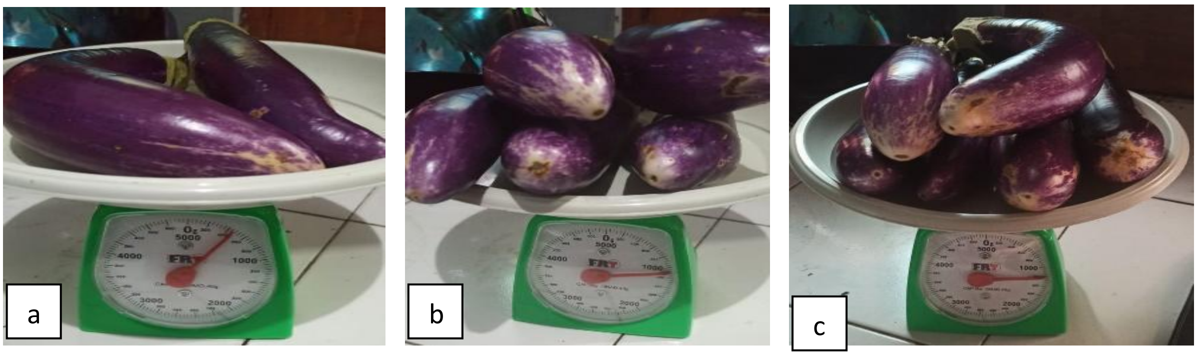

Fig.2. Fresh weight of eggplant fruit consumed in three PGPR treatments. (a) : fresh weight of eggplant for consumption without PGPR, (b) fresh weight of eggplant for consumption + 15 ml PGPR/L water, (c) fresh weight of eggplant for consumption + + 30 ml PGPR/L water

Fig. 2 shows that the fresh weight of fruit/plants produced in the treatment of 15 ml (Fig. 2b) and 30 ml PGPR/L water (Fiq.2c) is not significantly different, so regression analysis is needed to determine the optimum concentration and maximum yield. The results of the regression analysis show a quadratic relationship between the concentration of PGPR (X) and the fresh weight of fruit/hectare (Y) through an equation:

$$Y = -\ 1.067\ X^2 + 6.62\ X + 9.35;\ R^2 = 1$$

Based on this equation, it can be seen that the optimum PGPR concentration is 3.11 ml/L of water with a maximum yield of 19.62 tons of fresh fruit consumption weight/hectare.

IV. CONCLUSION

Based on the results of the study it can be concluded that to get high growth and yields in the cultivation of eggplant in ultisol soils, chicken manure and PGPR applications are very necessary. The application of 100% chicken manure can increase the total dry weight of the plant by 133.62%, and the fresh weight of fruit consumption per hectare by 233.72% than without chicken manure. In the PGPR treatment, to get a fresh weight of the maximum consumption fruit of 19.62 tons ha^{-1} requires the optimum PGPR concentration of 3.11 ml/ L water.

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AUTHOR'S CONTRIBUTIONS

Nur Edy Suminarti as the main researcher, played a role in determining the experimental design, treatment, observation parameters, observation time, and writing this manuscript.

Nurul Aini as a co-researcher, plays a role in assisting operations in the field, including determining treatment and observation

Nando Aldiansyah as a research assistant, contributes to determining the location of research, applying research in the field, and helping observation in the field, as well as data analysis.

Musofan Prasetianto contributes to writing this manuscript.

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Digestive Behavior of Minerals in Infant Formulas: An In Vitro Study of Casein Phosphopeptides, 1,3-Dioleoyl-2-Palmitoylglycerol, and Lactoferrin Fortification

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Abstract— *The bioavailability of minerals in breast milk (BM) and infant formula (IF) plays a crucial role in infant nutrition and development. This study investigated the effects of casein phosphopeptides (CPP), 1,3-dioleoyl-2-palmitoyl-glycerol (OPO), and lactoferrin (LTF) on mineral content and bioaccessibility following in vitro gastrointestinal digestion. In vitro dynamic digestion was performed, and the mineral content was quantified using inductively coupled plasma mass spectrometry (ICP-MS). The results revealed that the combination of CPP, OPO, and LTF significantly increased the bioaccessibility of calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe) compared to that in the control sample. The bioaccessibility values are 12.4–20.7% (Ca), 11.3–55.2% (Fe), 13.6–28.2% (Mg), and 12.7–25.6% (Zn). These findings suggest that incorporating CPP, OPO, and LTF into infant formulas may enhance mineral bioavailability, potentially supporting better mineral absorption and improving infant nutrition.*

Keywords— ***Breast milk, digestion, infant formula, minerals, bioaccessibility***

I. INTRODUCTION

Minerals play critical roles in infant growth, bone development, immune function, and metabolic processes. Essential minerals, such as calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn), contribute to skeletal formation, enzymatic activity, oxygen transport, and immune defense [1]. Their bioavailability depends not only on dietary intake but also on interactions with other food components during digestion [2]. Breast milk (BM) is considered the gold standard for infant nutrition, providing minerals in highly bioavailable forms [3]. This superior bioavailability is attributed to the specific bioactive components present in BM, including casein phosphopeptides (CPPs), structured lipids such as 1,3-dioleoyl-2-palmitoyl-glycerol (OPO), and lactoferrin (LTF). However, replicating this bioavailability in infant formula (IF) remains challenging because of compositional and structural differences [4].

Casein phosphopeptides (CPPs) are phosphorylated peptides released during casein digestion, characterized by their ability to bind divalent cations like calcium [5]. The formation of soluble CPP-mineral complexes prevents mineral precipitation at alkaline pH, facilitating their intestinal absorption [6]. For instance, research has shown that CPP supplementation improves Ca absorption in infants and adults [7]. CPPs' protective effect of CPPs on minerals during digestion makes them promising ingredients for formula fortification. 1,3-dioleoyl-2-palmitoyl-glycerol (OPO), a structured lipid designed to mimic the triglyceride composition of human milk fat, also influences mineral absorption in infants. In BM, palmitic acid is predominantly esterified at the sn-2 position, which promotes Ca absorption by minimizing the formation of insoluble calcium soaps in the intestine [8]. A previous study has shown that sn-2-palmitate-enriched formula feeding promotes weight gain and bone mineral accumulation and reduces stool fatty acid soap content compared to the standard formula. No significant differences in these outcomes were observed when compared with human milk [9]. Lactoferrin (LTF) is an iron-binding glycoprotein abundantly present in BM, playing a multifaceted role in Fe metabolism and immune function. It facilitates Fe absorption by binding free iron and maintaining it in a soluble form suitable for uptake in the intestine [10]. By maintaining Fe in a soluble state, LTF enhances its bioavailability and exerts antimicrobial effects by depriving pathogenic bacteria of iron [11]. Studies have shown that lactoferrin-supplemented formulas improve the Fe status in infants without causing adverse gastrointestinal effects [12].

Although the individual effects of CPP, OPO, and LTF on mineral absorption are well documented, their combined impact remains unclear. The interaction of CPP with minerals, combined with the structural benefits of OPO and iron-binding properties of LTF, may exert synergistic effects on mineral bioavailability. This study aimed to investigate the influence of these components on mineral content and bioaccessibility following in vitro gastrointestinal digestion. Using ICP-MS, we compared the mineral profiles of BM, a control formula (CF), two formulas containing different combinations of CPP, OPO, and LTF, and one formula containing OPO and LTF without CPP. These findings provide insights into optimizing formula composition to improve mineral bioavailability and better mimic the nutritional properties of BM.

II. MATERIAL AND METHODS

2.1. Materials

2.1.1. Samples

Five samples were analyzed in this study, including BM collected from 10 healthy lactating mothers in Changsha, Hunan Province, between 1 and 9 months postpartum. Milk was obtained using an electric breast pump in the morning, with 30 mL aliquots stored at −80°C and transported on dry ice to Jiangnan University for analysis. Informed consent was obtained from all participants, and the study was approved by the Medical Ethics Committee of Jiangnan University (ethics approval number: JNU20220901IRB15, Wuxi, Jiangsu, China). Mothers with a history of smoking, alcohol or drug use, infectious diseases, cancer, or other chronic conditions were excluded from the study. All other samples were stage 3 formulas, including CF, a commercially available standard formula, and three experimental formulas, TF1, TF2, and TF3, provided by Ausnutria Dairy (China) Co., Ltd. The composition of the formulas is presented in Table 1. All samples were prepared according to the manufacturer's guidelines, homogenized, and subjected to in vitro gastrointestinal digestion. BM samples were thawed at 4°C and mixed gently to maintain homogeneity before analysis.

Table 1. Infant Formula Composition

Milk samples	OPO (g/100g)	CPP (mg/100g)	LTF (mg/100g)
CF	-	-	-
TF1	4.1	-	100
TF2	4	166	65
TF3	4.1	200	65

2.1.2. Chemicals

All chemicals used in this study were of analytical grade and supplied by Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Enzymes for simulating gastrointestinal digestion were procured from Sigma-Aldrich Co. (St. Louis, MO, USA), including pepsin (P7125, from porcine gastric mucosa) for gastric digestion and pancreatin (P7545, from porcine pancreas) along with bile salts (48305) for intestinal digestion. Enzyme solutions were freshly prepared to preserve optimal activity during digestion. Nitric acid (HNO_3, trace metal grade) and hydrochloric acid (HCl, trace metal grade), were obtained from Merck KGaA (Darmstadt, Germany).

2.2. Methods

2.2.1. In-vitro Dynamic Digestion

The simulated digestion solution was prepared using the appropriate electrolyte stock solutions, enzymes, calcium chloride ($CaCl_2$), and water, following the method described by M. Minekus with minor modifications [13]. All digestive fluids, including 0.5 M HCl and 1 M $NaHCO_3$, were preheated and maintained at 37°C using the integrated water bath of the Human Stomach-Intestine System IV (DHSI-IV), developed by Xiao Dong Pro-health (Suzhou) Instrumentation Co., Ltd. (Suzhou, China). This system replicates gastrointestinal conditions by simulating physiological processes, such as pH variations, enzymatic activity, and peristaltic movements, in a dynamic controlled environment.

For the gastric phase, pepsin and lipase were dissolved in simulated gastric fluid (SGF), which contained 7.80 mmol/L K^+, 0.90 mmol/L $H_2PO_4^-$, 25.50 mmol/L HCO_3^-, 70.20 mmol/L Cl^-, 0.10 mmol/L Mg^{2+}, 1.00 mmol/L NH_4^+, 72.20 mmol/L Na^+, and 0.15 mmol/L Ca^{2+}, with the pH adjusted to 3.2. The final volume of the SGF was set to 100 mL, resulting in pepsin activity of 400 U/mL and gastric lipase activity of 120 U/mL. Digestion progressed continuously to the intestinal phase, during which pancreatic enzymes and bile salts were dissolved in simulated intestinal fluid (SIF). The SIF contained 7.60 mmol/L K^+, 2.80 mmol/L $H_2PO_4^-$, 85 mmol/L HCO_3^-, 55.50 mmol/L Cl^-, 0.33 mmol/L Mg^{2+}, 123.40 mmol/L Na^+, and 0.60 mmol/L Ca^{2+}, with the pH adjusted to 6.5. The final volume of the SIF was adjusted to 100 mL, yielding a pancreatic enzyme concentration of 20 U/mL and a bile salt concentration of 10 mM. Milk samples (125 mL) diluted to a protein concentration of 10 mg/mL were introduced into the digestion chamber to initiate gastrointestinal digestion. The process continued for 120 min without interruption, mimicking the continuous transit of food through the gastric and intestinal phases. Samples were collected at 0 min (before digestion) and subsequently at 120 min to monitor the dynamic changes in mineral content and bioaccessibility. After collection, the samples were centrifuged at 10,000 × g for 30 min at 4°C to separate the bioaccessible (soluble) and non-bioaccessible (insoluble) fractions. The supernatant was stored at −80°C until further analysis.

2.2.2. ICP-MS Mineral Determination

The mineral content of the digested samples was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS**).** For sample preparation, 3 mL of the sample was mixed with 4.5 mL of concentrated nitric acid (HNO_3, trace metal grade) in a digestion tube and allowed to digest overnight. After complete digestion, the mixture was diluted to 50 mL with ultrapure water in a volumetric flask, thoroughly mixed, and transferred to a 10–15 mL centrifuge tube for analysis. The solution was then filtered through a syringe filter into a clean centrifuge tube to obtain 3–5 mL of the clear filtrate. The filtrate was further diluted 10-fold, 100-fold, and 1000-fold as needed for subsequent mineral analysis. ICP-MS analysis was performed using a Thermo Fisher iCAP Q ICP-MS system (Thermo Fisher Scientific, Waltham, MA, USA**).** The ICP-MS was operated under the following conditions: RF power: 1550 W, plasma gas flow rate: 15 L/min, nebulizer gas flow rate: 1.05 L/min, collision/reaction gas: helium (He), and dwell time: 100 ms per isotope.

2.3. Statistical Analysis

All experimental data were analyzed using SPSS Statistics version 27.0**.** The results are expressed as the mean ± standard deviation (SD) from three independent replicates. Comparisons between groups were performed using one-way analysis of variance (ANOVA)**,** with $p < 0.05$ considered statistically significant. All graphs were generated using OriginPro 2024 software**.**

III. RESULTS AND DISCUSSION

3.1. Calcium Content

Ca retention varied significantly among the milk samples ($p < 0.0.5$), highlighting the impact of compositional differences on mineral solubility during digestion (Fig. 1). BM, which had the lowest initial calcium concentration (252.36 ± 12.23 mg/L), retained a relatively high amount of calcium post-digestion (49.49 ± 11.05 mg/L), reflecting its superior natural bioavailability. This finding is consistent with that of previous studies [3]. In contrast, CF, which lacked bioactive components, initially contained the highest calcium concentration (887.23 ± 13.25 mg/L) but retained only 109.71 ± 2.85 mg/L after digestion, suggesting significant precipitation at intestinal pH. Among the experimental formulas, TF1 had a lower initial calcium concentration (669.4 ± 131.3 mg/L) than CF but retained 92.22 ± 2.99 mg/L, suggesting that OPO helped to prevent calcium precipitation. TF2 demonstrated the highest Ca retention (129.71 ± 7.81 mg/L) despite starting with a lower concentration (626.78 ± 114.9 mg/L), likely due to the presence of CPP in the formulation. TF3, which contained the highest CPP concentration, started with the lowest calcium content (362.54 ± 45.16 mg/L) and retained 51.54 ± 8.03 mg/L after digestion. Although CPP enhances calcium solubility, its effectiveness depends on the initial calcium concentration, as observed in previous studies [14]. Overall, these results confirm that OPO prevents calcium precipitation, whereas CPP enhances retention, particularly when sufficient calcium is available, supporting their role in improving the formula composition to better mimic human milk.

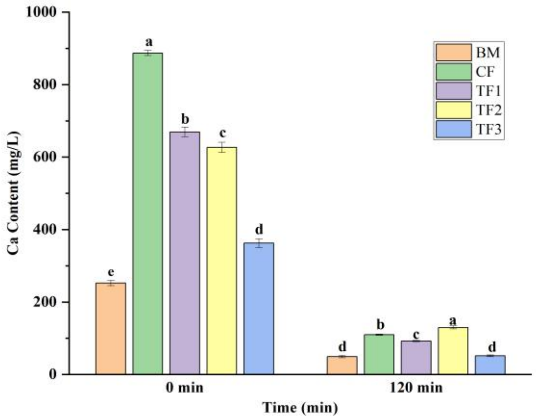

Fig. 1 Changes in Calcium Content Before and After In-Vitro Gastrointestinal Digestion

3.2. Magnesium Content

Mg is a vital mineral involved in over 300 enzymatic reactions, neuromuscular function, and bone development, making its bioavailability crucial for infant growth [15]. BM is recognized for its superior magnesium bioavailability due to its association with casein micelles and citrate, which help maintain solubility during digestion. The changes in Mg content before and after gastrointestinal digestion are presented in Fig. 2. In this study, BM, despite having the lowest initial magnesium concentration (29.29 ± 1.29 mg/L), retained 8.25 ± 0.12 mg/L post-digestion, supporting previous findings that magnesium in human milk remains highly bioavailable owing to its interaction with organic ligands [16]. In contrast, CF, which initially contained a significantly higher magnesium concentration (89.78 ± 3.15 mg/L), retained only 16.05 ± 1.68 mg/L ($p < 0.05$), indicating significant precipitation under intestinal conditions and reduced solubility compared with BM. TF1 had the highest initial magnesium content (107.3 ± 13.32 mg/L) but retained only 14.6 ± 2.32 mg/L, demonstrating no significant improvement over the CF. In contrast, TF2 exhibited the highest Mg retention despite a lower initial content (86.01 ± 2.75 mg/L). TF3, despite containing the highest CPP concentration, had a lower initial magnesium content (56.99 ± 7.96 mg/L) and retained 9.61 ± 1.01 mg/L, showing lower magnesium retention than that of TF2. This suggests that while CPP enhances magnesium solubility, its effectiveness depends on the initial mineral concentration and its interactions with other formula components. Previous studies have reported that Mg absorption is influenced by the presence of chelating peptides; however, its retention is also affected by intestinal pH and competing mineral interactions [17,18]. These findings highlight that CPP plays a key role in magnesium solubility; however, optimal fortification strategies must consider the initial mineral concentrations to maximize the absorption efficiency.

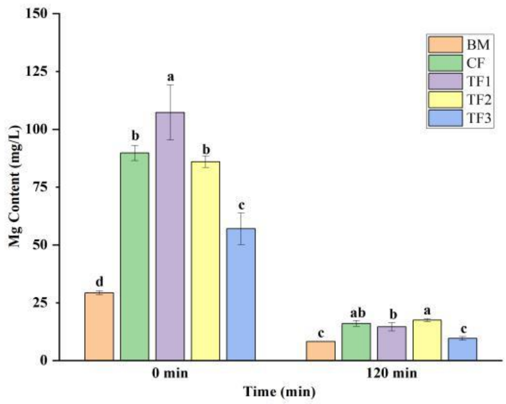

Fig. 1 Changes in Magnesium Content Before and After In-Vitro Gastrointestinal Digestion

3.3. Zinc Content

Zn is a critical micronutrient essential for immune function, growth, and enzymatic activity in infants [19]. Human milk is recognized for its highly bioavailable zinc, which is bound to casein and low-molecular-weight ligands, preventing its precipitation during digestion [20]. The changes in Zn content before and after gastrointestinal digestion are presented in Fig. 3. In this study, BM had an initial zinc concentration of 1577.53 ± 153.45 mg/L, with 404.67 ± 41.25 mg/L remaining after digestion. A significant loss of zinc during digestion is expected, as free zinc tends to precipitate at higher pH levels during the intestinal phase. CF, with a considerably higher initial Zn concentration (5660.12 ± 219.59 mg/L), retained only 803.54 ± 0.6 mg/L, indicating that a substantial portion of Zn was lost after digestion. Among the test formulas, TF1 initially contained 5075.41 ± 731.22 mg/L but retained only 695.02 ± 151.73 mg/L, showing no significant improvement over CF ($p < 0.05$). However, TF2 demonstrated the highest Zn retention (1267.51 ± 149.76 mg/L), despite its lower initial concentration (5682.19 ± 257.6 mg/L). Conversely, TF3, which contained the highest CPP concentration, started with 5603.14 ± 532.22 mg/L but retained only 710.65 ± 157.6 mg/L after digestion. Overall, these findings confirm that OPO, CPP, and LTF synergistically enhance Zn solubility, making them valuable components for improving mineral bioavailability in infant formulas.

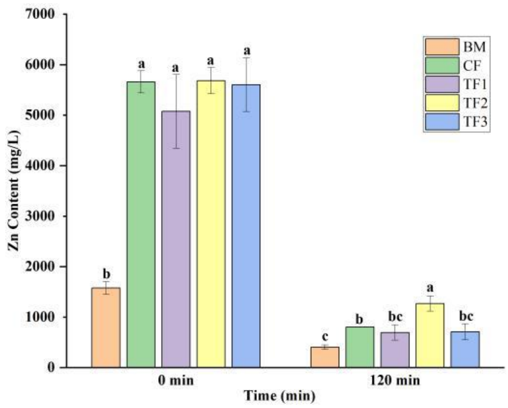

Fig. 1 Changes in Zinc Content Before and After In-Vitro Gastrointestinal Digestion

3.4. Iron Content

Fe is a critical micronutrient required for oxygen transport, cognitive development, and immune function in infants [21]. However, its bioavailability is often limited because of its tendency to form insoluble precipitates at intestinal pH or bind to dietary inhibitors [22]. The changes in Fe content before and after gastrointestinal digestion are presented in Fig. 4. BM exhibited a lower initial iron concentration (429.73 ± 21.68 mg/L) than the formula samples but retained a substantially higher proportion after digestion (237.18 ± 6.86 mg/L). This superior retention is attributed to LTF, an iron-binding glycoprotein that protects Fe from oxidation and enhances its intestinal uptake by binding to specific receptors in the infant gut, as previously reported in studies on BM composition [23]. CF had the highest initial iron concentration but retained only 1,397.03 ± 181.26 mg/L post-digestion, indicating significant Fe loss. This suggests that, in the absence of bioactive iron-binding proteins, iron precipitates more readily, leading to reduced bioaccessibility. TF1 showed a similar trend, suggesting that OPO alone did not significantly improve iron retention. In contrast, TF2 demonstrated the highest Fe retention among the formulas (1,887.87 ± 253.73 mg/L), despite a lower initial Fe content (13,350.23 ± 416.14 mg/L). This suggests that the combination of LTF and CPP plays a crucial role in maintaining the Fe solubility. Interestingly, TF3, which contained the highest CPP concentration, retained less Fe (1,355.24 ± 770.24 mg/L) than TF2, despite its similar initial iron content (12,059.3 ± 1412.95 mg/L). This suggests that excess CPP may not proportionally enhance Fe bioaccessibility, possibly due to competitive mineral binding or interactions that affect Fe solubility. Similar findings have been reported by Petry et al. (2016), who observed that high doses of dietary peptides do not always improve Fe absorption and may interfere with mineral interactions [24]. This supports the notion that optimizing formula composition, rather than simply increasing fortification levels, is essential for improving iron bioavailability in infant nutrition [25].

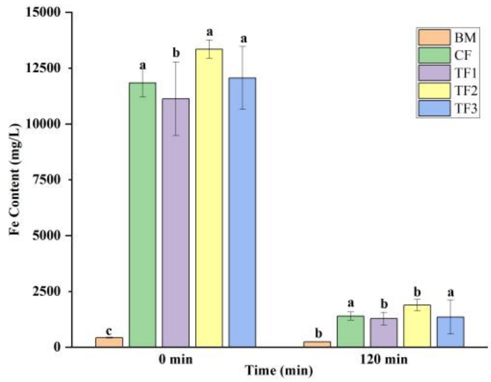

Fig. 1 Changes in Iron Content Before and After In-Vitro Gastrointestinal Digestion

3.5. Mineral Bioaccessibility

Mineral bioaccessibility, which refers to the fraction of a nutrient that remains soluble and available for absorption after digestion, plays a critical role in determining the nutritional efficacy of IF [26]. In the present study, the bioaccessibility of Ca, Mg, Zn, and Fe was determined, and the results are shown in Table 2. The Ca bioaccessibility values ranged from 12.4% to 20.7%. Mg showed higher bioaccessibility than Ca, with BM at 28.2% and TF2 at 20.4%, likely due to its lower precipitation. Mg is known to be bioavailable and well utilized by animals (approximately 80%), i.e these elements are more soluble under gastrointestinal conditions [27]. Thus, these Mg bioaccessibility values are higher than those of Ca. The bioaccessibility values for Fe and Zn were, on average, higher than those for the other elements. It is well known that the bioaccessibility of essential minerals is highly dependent on the food matrix.

Table 2. Bioaccessibility of the Minerals from the Breast Milk and Infant Formulas

Samples	Ca (%)	Mg (%)	Zn (%)	Fe (%)
BM	19.60±0.82^{a}	28.17±0.66^{a}	25.62±0.61^{a}	55.22±2.43^{a}
CF	12.36±0.10^{c}	17.90±1.19^{bc}	14.21±0.54^{b}	11.77±0.90^{b}
TF1	13.78±0.04^{b}	13.65±1.53^{d}	13.72±2.58^{b}	11.42±0.86^{b}
TF2	20.70±0.22^{a}	20.38±0.17^{b}	22.26±1.63^{a}	14.13±1.74^{b}
TF3	14.22±0.66^{b}	16.94±1.68^{b}	12.58±1.62^{b}	10.84±5.15^{b}

[1]*The results are expressed as mean ± standard deviation (n=3)*

[2] *Mean values with different letters differ significantly at p <0.05.*

BM demonstrated the highest bioaccessibility across all measured minerals, consistent with prior research indicating that BM contains naturally optimized mineral-binding components that enhance mineral solubility and absorption [28]. Among the formula samples, TF2 consistently exhibited the highest bioaccessibility for all four minerals, surpassing CF, TF1, and TF3 values ($p < 0.05$). Specifically, TF2 demonstrated the highest bioaccessibility for Ca (20.7%), Mg (20.38%), Fe (14.13%), and Zn (22.26%), indicating that the combination of CPP, OPO, and LTF significantly improved mineral solubility. This finding is supported by a finding, which reported that structured lipids, such as OPO, enhance Ca absorption by reducing Ca soap formation, whereas CPP improves divalent cation retention [29]. Finally, the bioaccessibility of minerals in IFs is lower than that in BM. However, the high bioaccessibility values for the IFs studied in the present work can be considered satisfactory, since the elements are quite soluble; therefore, it could result in suitable absorption by the infants. These findings highlight the importance of optimizing CPP, OPO, and LTF concentrations to enhance mineral bioavailability in IF, bridging the gap between human milk and formula nutrition.

IV. CONCLUSION

This study demonstrates that casein phosphopeptides (CPP), structured lipids (OPO), and lactoferrin (LTF) enhance mineral retention and bioaccessibility in infant formulas (IFS), helping to better mimic breast milk (BM). BM exhibited the highest mineral bioaccessibility, whereas TF2 showed the greatest retention of calcium, magnesium, iron, and zinc among the formula samples, confirming the synergistic role of these bioactive components. CPP improved the solubility of calcium, magnesium, and zinc; LTF enhanced iron bioavailability; and OPO contributed to calcium retention by reducing precipitation. Despite TF3 containing a higher CPP concentration than TF2, its slightly lower mineral bioaccessibility suggests that excessive CPP levels may interfere with mineral interactions, emphasizing the need for optimized fortification rather than excessive supplementation of the product. These findings support the inclusion of CPP, OPO, and LTF in IF to enhance mineral absorption, though further in vivo studies and clinical trials are needed to confirm their long-term benefits for infant growth and development.

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Use of ASMC seeder prototype by women: Assessing the use of donkey (*Equus asinus*) as animal power source in agricultural mechanization in Hauts-Bassins region of Burkina Faso

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Abstract— *The present study aimed to evaluate the technical and socio-economic impact of using donkeys (Equus asinus) in agricultural production to facilitate the adaptation of the "ASMC" seeder for smallholder women farmers in western Burkina Faso. A survey consisting of eighteen (18) representative farms in ten (10) villages located in two (2) provinces formed the basis for semi-structured interviews with groups of women registered with the Regional Union of Cereal Producers. Descriptive statistics and correlation analysis were used to evaluate the survey data. Based on the survey results, the representative farms were primarily family farms with two methods of seeding maize: manual sowing and partial or exclusive use of the ASMC mechanical seeder. The draft donkey ownership rate was 68% on the manual and 41% on the mixed-method of seeding farms. Donkeys provided a significant reduction in the time needed for tillage and planting operations for 74% of the respondents, thereby improving the timeliness of farming activities. There was a positive correlation between total land use for farm activities and the number of draft donkeys on the farm. 67% of the women farmers believed that sowing with a pair of oxen was faster ($P<0.05$) than with one donkey power, as they usually do. The cost of sowing with the oxen was slightly higher compared to the donkey, but the cost of adoption was significantly greater for oxen ($P<0,05$). Based on this study, donkeys in these farming systems can increase productivity and improve women farmers' welfare.*

Keywords— ***agricultural mechanization, animal traction, ASMC-Seeder, donkey, women.***

I. INTRODUCTION

Burkina Faso is a landlocked country in West Africa with one long dry season (8 months) against one short rainy season (4 months). The country's economy is based mainly on agricultural pursuits, which employs nearly 85% of the working population, with an agricultural (GDP) growth rate estimated at about 9% against 4.35% for sub-Saharan Africa [1]**,** Agricultural products are produced primarily on family farms that remain poorly mechanized despite many attempts to mechanize agricultural production in the country's western regions before and after independence, similar to many developing countries [2, 3]. Timely crop establishment is challenging due to unpredictable rainfall and poor soil. The current preference of producers is for early sowing of crops to capture early season rains, but early planting is challenging to achieve with labor-intensive manual cultivation.

Sowing crops is mainly women's activity in western Burkina. It is still manual work requiring a large workforce, often resulting in low plant densities and crop yields due to inconsistent planting depth and spacing [4]. A mechanical seeder would speed up the planting process. Mechanization refers to tractors and combine harvesters and the small and medium-sized agricultural implements used in producing, processing, and transporting agricultural products [5] . Mechanical seeders have been introduced on farms in the past, but farmer training and on-farm demonstration work were insufficient to support widespread adoption.

In 2016, the Appropriate Scale Mechanization Consortium (ASMC) project, part of the feed the future lab and funded by USAID (United States Agency for International Development) was launched to improve agricultural mechanization in Burkina Faso. At that time, Stakeholders identified the need for appropriate and cost-effective animal traction tools suitable for both men and women. Tillage and planting equipment were identified as high priorities for development. The ASMC team worked side-by-side with local farmers and artisans to evaluate, build, and repair a conservation maize seeder using locally available materials.

The seeder features included specialized seed plates, furrow openers, furrow closers, and press wheels for minimally tilled, residue-covered soil. It was initially tested with oxen at the power source [6]. Compared to hand planting, the seeds were placed at a uniform depth and constant spacing; seeds germinated faster and emerged at a consistent rate. Because women were not confident handling oxen, the ASMC team aimed to evaluate the suitability of donkeys as a source of draft power for women.

Donkeys have played an essential role in agricultural activities in smallholder farms [7, 8]. Among other advantages of the donkey, women are generally more comfortable handling donkeys since they often use them for other tasks such as household and farm transport, riding, or trading [9, 10]. In recent years, considerable efforts have been made to scale up the use of draft donkeys in Burkina Faso. From 2018 to 2021, [11] reported that four training teams of five members each taught draft donkey usage to about 11000 farmers in the Imasgo, Tiogo, Sabouna, and Koalma regions in Burkina Faso.

The ASMC seeder was tested in 2017 with convincing results on the farms of five (5) producers in the Hauts-Bassins region [6]. Between 2018 and 2020, several ASMC seeders were given to cereal producers using oxen in cotton production areas to promote maize production in the region. The objective of this study was to evaluate the perception of the technical and socio-economic impact of the use of donkeys (*Equus asinus*) with the ASMC seeder among farmers who used this device to promote donkey-drawn seeders in the cropping system to improve planting timeliness and safety, and to ease the burden of smallholder women farmers Burkina Faso.

II. MATERIALS AND METHODS

2.1 Study site

The Hauts Bassins region in western Burkina Faso covers a total area of 25,479 km², or 9.4% of the national territory [12]. This region was one of the country's first agricultural production areas, mainly cotton and cereals. Its geographical location makes it an essential hub for domestic trade in agricultural products to neighboring Mali, Ghana, and Cote d'Ivoire. The region has a Sudanese-type climate characterized by the alternation of a dry season with a more marked rainy season than most of the country. The average rainfall level in the Hauts Bassin region is 1,043 mm in the south and 960 mm in the north. The study included eighteen farms representing ten (10) villages over 2 provinces (Tuy and Houet provinces) in the Hauts-Bassins region. The boundaries of the study area were based on the geographical distribution of the current users of the ASMC seeder. The areas visited were located using GPS and placed on base maps using the BNDT database [13] (Fig. 1)

2.2 The surveys and semi-structured interviews

The surveys included nine (9) farms using the ASMC seeder in each of the two provinces, totaling eighteen (18) farms among the ten (10) villages for the study (5 villages per province). Twenty-seven (27) people were surveyed in each province, totaling 54 respondents. The interviews took place in the localities of Lena and Bouéré, as well as at the FEPA-B headquarters of the regional farmers' union. Fifty-two (52) women participated, and 31% used the seeder (Fig. 2) on their farms. The questionnaire addressed the socio-economic characteristics of the producer as well as the perception of women about the seeder used with oxen or donkeys, as shown below:

Sowing time was the perception of the total duration of the time taken to complete the sowing per hectare.

Uniformity of sowing was measured as the spacing uniformity between crop rows, depth of seed placement, and plant spacing uniformity.

Ease of driving refers to perceiving the ease of hitching, animal handling, managing, and operating the seeder.

Operational cost compares manual (by-hand) seeding and mechanical seeding (ASMC seeder), based on cost per hectare. This includes the daily salary per woman for sowing activities and food expenses for the duration of the work. The cost of sowing with the seeder includes the driver's payment per day.

The cost of adoption was assessed as the purchase price/depreciation of the seeder and the animals (oxen or donkeys), the annual maintenance costs (theoretically estimated at 10-15% of the purchase price), and the average annual costs for the maintenance of draft animals (feed and health care).

2.3 Description of the seeder

The mechanized maize sowing system is the current innovation, replacing the manual one. It consists of a seeder, draught animals, two operators (male/female that can be improved to one if draft animals are well trained) and the seed, on prepared soil. The system innovation involves the design of a multi-purpose single-row seeder with single seeding hole, which operates in rows and is designed to be easy to handle, practical and suitable for small-scale farmers. It can be designed entirely by artisans using local materials. This system compensates the manpower shortage in a context where it takes five adults three days to sow a hectare of maize, compared with 04 to 06 hours with the seeder. It is also suitable for sowing sorghum, millet and cowpeas (beans) using a plate (Fig. 2).

2.4 Data collection and analysis

The evaluation criteria were qualitative and based on the opinions expressed by the women survey respondents. For each question, the most frequent response was selected as the most representative of the opinion of the producers.

Data were analyzed using MINITAB (MINITAB Statistical Software, 22.1.0.0, 2024 Minitab.LLC), for basic descriptive statistics, 2-t-test and pearson's correlation. Observation frequencies and Chi-Square analysis were done using Epi Info (Epi InfoTM 7.2.4.0; CDC, Atlanta, GA, USA).

III. RESULTS AND DISCUSSION

3.1 Structural characteristics of smallholder farms and use of the ASMC seeder

Descriptive data on farm characteristics (TABLE 1) revealed that smallholder farms were mainly family farms with a hectare-to-worker ratio of 12:6 in small and medium-sized farms and 28:13 for large farms. Grouping by this method for seed sowing provided two (2) main types of farms: type 1 using manual sowing exclusively, and type 2 using mixed (by-hand and seeder) or exclusive use of the seeder for sowing. The representative cropland (ha) or the harvested agricultural area revealed by the survey were 7.3 ± 3.8 and 18.5 ± 13.1 ha, respectively, for the by-hand-only and mixed seeding farms. Land use for all farm activities (functional agricultural area) ranged from 11 ± 5.02 ha (by hand) to 26.9 ± 19.1 ha (mixed). Two (2) or three (3) pairs of draft animals (oxen or donkey) (9.5±9.1 animals) were typical for type 2 (mixed/mechanical) farms compared to one (1) pair (2.5±1.7 animals) on type 1 (manual) farms ($P<0.05$). Draft donkey ownership rates were 68% for by-hand seeding farms and 41% for mixed seeding farms. Sowing with the ASMC seeder represented about 11 % of the total land use for farm activities (functional area) (TABLE 1), with a strong positive correlation between total land use for farm activities and number of draft donkeys on the farm ($P<0,05$) (TABLE 2). There was a positive correlation between cropping areas or the harvested agricultural areas and the areas sown with the seeder ($P<0.05$) (Fig. 3). A positive correlation was also seen between the areas sown with the seeder and the number of draft oxens (Fig. 4), while the corresponding correlation was negative for the number of draft donkeys (Fig. 5).

All the women questioned were married, and their average age was estimated to 41.7±5.25 years. They owned draft animals with a percentage of 75% of donkeys and 25% of oxen. The women also owned private lands, with a mean area of 0.5±0.35 ha, while the mean land area of the households was estimated to be 10.7±6.89 ha. 75% of the women using the ASMC seeder used it in their private land only, while 25% used it on both private land and the household one. Women used the seeder for sowing mainly maize, and barely rice or groundnut.

In general, awareness of and availability of suitable agricultural machines and other forms of mechanization are low in Burkina Faso. At the outset of the ASMC seeder (seeder) project in 2016, an advisory group of stakeholders, including farmers, technical service providers, educators, farmer union representatives, and others, projected that the process of training and adoption of new cropping system technologies would take five years on average; time for seeder development and testing, two successful crop campaigns and time for education and training. Developing a reliable seeder at a reasonable cost and level of complexity, including field testing and training local artisans to build the Seeder, required two cropping seasons. At the farm and village level, Seeder adoption included on-farm testing and evaluation, financial support, workshops in machine/tillage/seeder use, adjustment and function of components, and development of on-farm demonstration/training sites with the backing of influential, leading farmers.

Currently, there is a low level of use of the ASMC seeder in crop-livestock farms in the Hauts-Bassins region because the seeder was only recently introduced. Only 11% of the total cultivated areas, one seeder / 43, 5 ha was sown with the ASMC seeder between 2017 to 2019. This rate is low compared to [14], who reported a use ratio of one seeder / 6.5 ha in the Groundnut Basin of Senegal, where the local seeder was well established. However, the positive correlation seen between the harvested areas and the areas sown with the seeder in the present study is an indicator of the contribution of the seeder in increasing crop production in smallholder farms. Furthermore, the negative correlation seen between the areas sown with the seeder and the number of draft donkey in this study confirms that most of the farmers in type 2 farms did the sowing using draft oxens instead of draft donkey, and this was confirmed by the positive correlation seen with the number of draft oxens. Nevertheless, this survey aimed to understand women's perception of the ASMC seeder to guide further seeder design and training efforts. Few active demonstration sites as well as extension and educational programs had been developed. Extension and training strategies were based on the findings of the project. They prioritize the needs of low-income, smallholder women farmers, who were a key target group for seeder development. Women feared working with oxen, and they lacked access to them early in the planting season because they were in poor physical condition, and men typically had priority access [9,10]. Therefore, there is a need to develop seeders suitable for donkeys drawn and the full range of agricultural activities.

3.2 Social impacts of the presence of donkeys on the farm

Monitoring agricultural calendar: for 74% of the respondents, using oxen for plowing and transporting inputs or equipment is difficult because of their poor physical condition due to scarce feed supplies at the start of the growing season. The use of donkeys reduces the preparatory work before the planting activities begin which improves the timeliness of planting throughout the agricultural calendar.

Fodder collection and storage for animal nutrition: 100% of farms owning donkeys also use them for domestic transport (water, construction aggregates, general goods, etc.). These extra-agricultural services are provided in the form of rental but also by mutual aid between families within the village. In addition, the capacity of the farms with donkeys to collect and store crop residues was greater than that of farms without donkeys since it was possible to make at least 2 trips/day for transporting and storing fodder for animal feeding during the dry season.

The survey results highlight the advantage of donkeys in the early rainy season, which leads to the timely completion of fieldwork, as well as the poor condition of oxen during the same period [15]. This is a natural zootechnical characteristic of donkeys, allowing them to be used more efficiently in farming than oxen (hardiness, endurance, maintenance cost) [16]. The social impact of the donkey on the farm results from the facilitation of domestic transport, an essential activity in the life of families in rural areas (water, construction materials, travel, goods, etc.) [7,8]. The use of donkeys as draft power along with oxen draft to advance the mechanization of small and low-income family farms should be supported. From a gender perspective, the survey results confirmed that women found the seeder easier to handle and cheaper with donkeys than oxens.

3.3 Women's perception of the ox-drawn versus donkey-drawn seeder

Women's perception of the seeder used with a pair of oxen compared to one donkey (as it was usually done in farming activities) is shown in TABLE 3. Sixty-seven percent (67%) of the respondents reported that the sowing time with oxen was faster compared to donkey power ($P<0.05$), with better animal tendency to stay on the row ($P > 0.05$). The uniformity of row width and plant spacing was perceived to be unchanged. For 51% of the observations, handling and operating the tool with a donkey was very easy compared to oxen, but not statistically significant. The cost of sowing with oxen traction was slightly higher compared to the donkey for 51%, while the cost of adoption was very high with oxen compared to the donkey for 78% of the observations ($P<0,05$).

The survey revealed that for most women, sowing with donkey traction was slower than bovine traction (5-6 h / ha with bovine traction compared to 8-10 h / ha with donkey traction). The travel speed of the oxen is faster than that of the donkey team. However, the difference in travel speed does not have a significant impact on the sowing schedule. Early prototypes of the ASMC seeder were tested with ox power, so it may be possible to modify the seeder for efficient donkey use.

The donkey's ability to pull agricultural equipment is more limited due to its low weight [16]. Donkeys are increasingly used for working with plows, seeders, and small plows in light soils, and many development projects use these possibilities [17, 11]. The ASMC seeder's average draft or pulling force was about 22-kilogram force (kgf), while donkeys typically weigh between 100 to 140 kg and can pull about 16-20% of their body weight [18, 19]. [20] in 1997 reported a draft capability of 12-25% of liveweight in donkeys. The ASMC seeder draft is within the capability of a draft donkey. The evaluation of the two power units (oxen and donkey) concluded that other performance parameters were similar, apart from the slightly shorter sowing time with bovine traction. Donkeys can be harnessed in pairs or larger teams for heavy work [17]. For example, up to eight donkeys in Botswana were used to pull a large plow [21].

Based on the survey, using the ASMC seeder with donkey traction may be the best way for women to sow. Moreover, farm mechanization policies and programs targeting female household members can reduce the gender-adoption gap, ultimately enhancing farm yield and profitability [22].

The cost of using the mechanical seeder with bovine traction is higher than that of donkey traction. This is based on the fact that the cost of use among producers is judged more on the profit made than the actual cost. In any case, the cost per hectare for mechanized sowing remains much lower than that for manual sowing, regardless of the type of traction used.

Regarding the cost of adoption, women unanimously concluded that adoption would be higher with bovine traction than with donkey traction. This calculation includes the cost of acquiring draft oxen and the annual maintenance costs (food, health, etc.), which were significantly higher than for donkeys. In Cameroon, donkey traction was shown to be more economical to purchase and maneuverable in cramped and stony plots than bovine traction **[23]**.

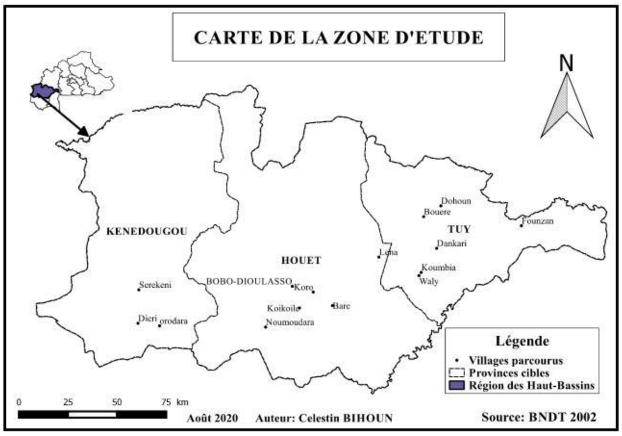

Fig.1: Map of the study site

Fig.2: The ASMC seeder (Barro et al., 2022).

Table 1: Characteristics of farms in the Haut-Bassin region according to the method used for sowing

Variable	Sowing type	N	Mean	SE Mean	StDev	Minimum	Median	Maximum	P-value

Family Size	Manual	27	11.1	0.84	4.40	6	11	29	0.035
	Mixed	27	17.4	2.3	14.4	0	15	54	
Number of active workers	Manual	27	6	0.3	1.6	3	6	11	0.021
	Mixed	27	9.1	1.3	6.6	0	8	26	
Functional agricultural area.	Manual	27	11	0.9	5.02	5	11	25	0.00
	Mixed	27	26.9	3.6	19.1	0	21	70	
Harvested agricultural area	Manual	27	7.3	0.7	3.8	3	6	17	0.00
	Mixed	27	18.5	2.5	13.1	0	14	52	
Number of draft animals	Manual	27	2.5	0.3	1.7	0	2	7	0.00
	Mixed	27	9.5	1.7	9.1	0	6	31	
Area sown with the seeder (%)	Manual		0						
	Mixed		11						
Possession of draft donkey (%)	Manual		68						
	Mixed		41						

Table 2: Correlation between draught donkey numbers and land use by farmers using the ASMC seeder in the Hauts-Bassin region from 2017 to 2019 (N = 54)

Parameter	**Drought donkey number**		**Comments**
	Significance (bilateral)	**Pearson's Correlation**	
Land use for maize cultivation	0.615	0.070	weak positive correlation
Land use with the seeder	0.888	- 0.020	Weak negative correlation
Functional area	0.000	0.575**	strong positive correlation

**. Significant positive correlation at 1% level.

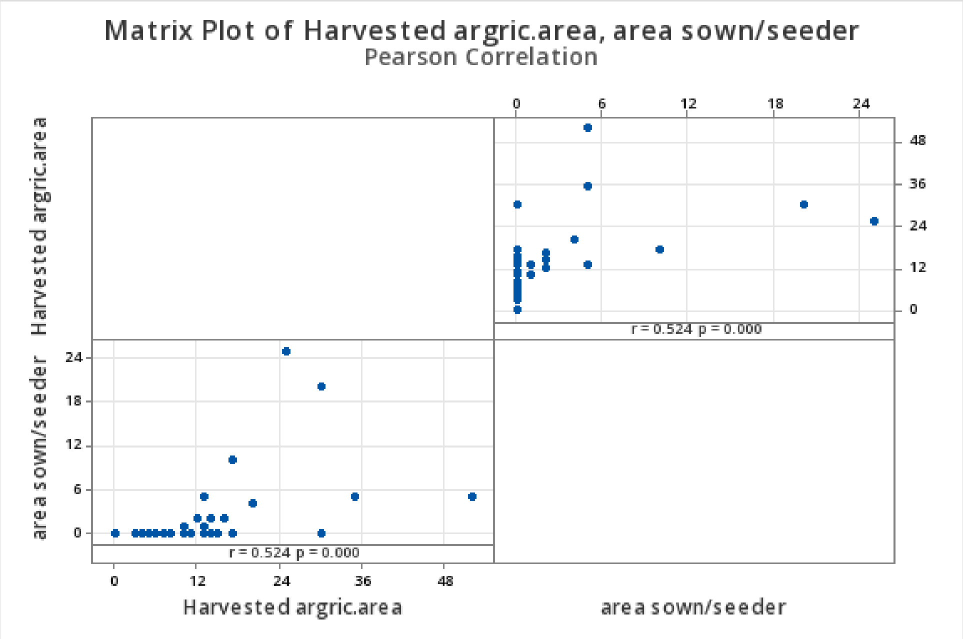

Fig.3: Correlation between harvested agricultural areas and areas sown with the seeder

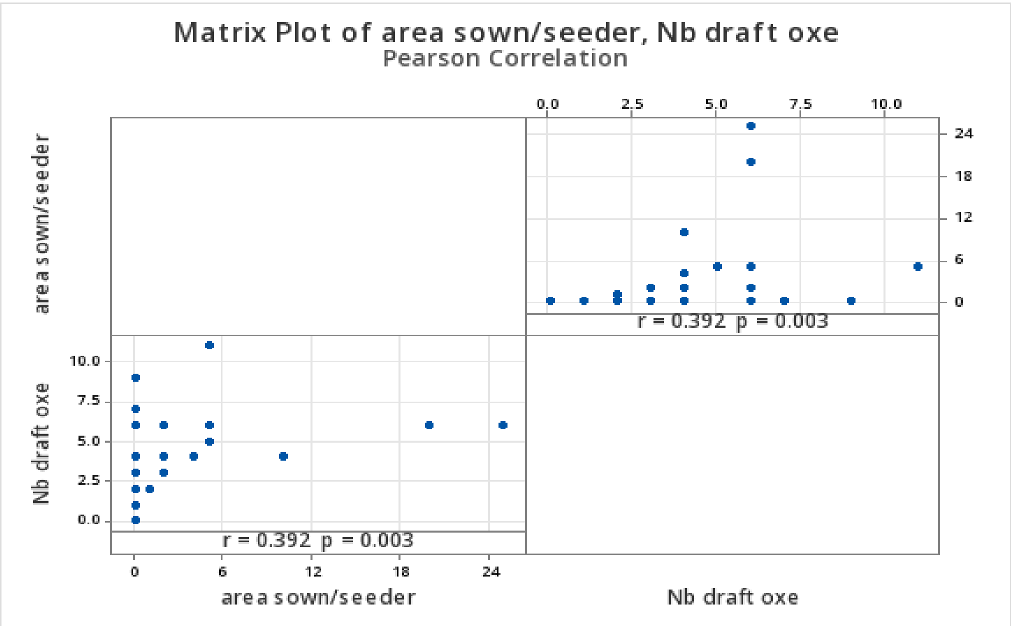

Fig.4:Correlation between areas sown with the seeder and the number of draft oxen

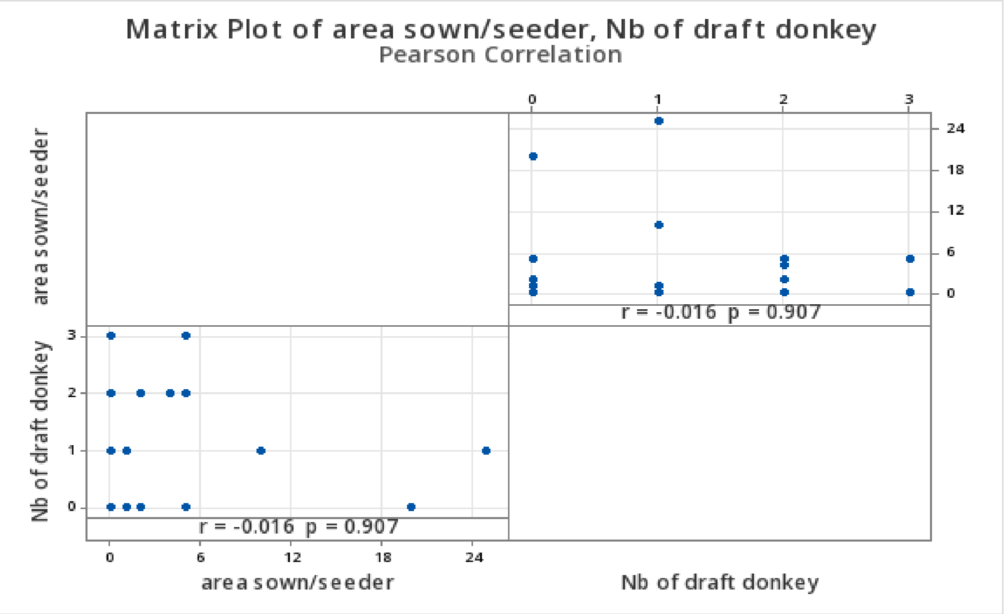

Fig.5:Correlation between the area sown with the seeder and the number of draft donkeys.

Table 3: Women's perception of the use of the seeder with oxen versus donkeys (%, N = 52)

Parameters	**Oxen**	**Donkey**	**P-value**
Sowing time			
Very short	67**a**	2**b**	P = 0.001
Short	31	33	P = 1.000
High	2**b**	65**a**	P = 0.002
Handling and operating the seeder			
Very easy	20	51	P = 0.667
Easy	29	25	P = 1.000
Less easy	51	24	P = 0.231
Animal tendency to stay on the row			
Good	67**a**	15**b**	P = 0.001
Not good	29	25	P = 1.000
Bad	4**b**	60**a**	P = 0.010
Draft power			
Very High	61**a**	14**b**	P = 0.000
High	25	25	P = 1.000
Low	14**b**	61**a**	P = 0.000
Regularity of sowing			
More regular	26	23	P = 1.000
Similar	52	50	P = 1.000
Less regular	22	27	P = 1.000
Cost of use			
Very High	51	33	P = 0.961
High	6	6	P = 1.000
Less high	43	61	P = 0.998
Cost of adoption			

Very High	78**a**	3**b**	P = 0.001
High	3	15	P = 0.964
Less high	19**b**	82**a**	P = 0.019

In the same row, values with different letters are significantly different at 5% level

IV. CONCLUSION

Adopting the ASMC seedeer with donkey (Equus Asinus) traction by women and small family farms with limited income can significantly reduce the drudgery of smallholder women farmers when seeding maize and other row crops while increasing grain yields. Introducing donkeys with the ASMC seeder system can improve the farm's work efficiency and socio-economic performance. Low-income women farmers successfully used the equipment with donkeys. The results of this study are guiding efforts to scale up the seeder distribution to farmers in Burkina Faso and throughout the region. A key aspect of scaling up the seeder is strengthening artisans' and blacksmiths' technical and operational capacities to improve and adapt the local repair, maintenance, and manufacturing capacity of the ASMC seeder suitable for donkey traction.

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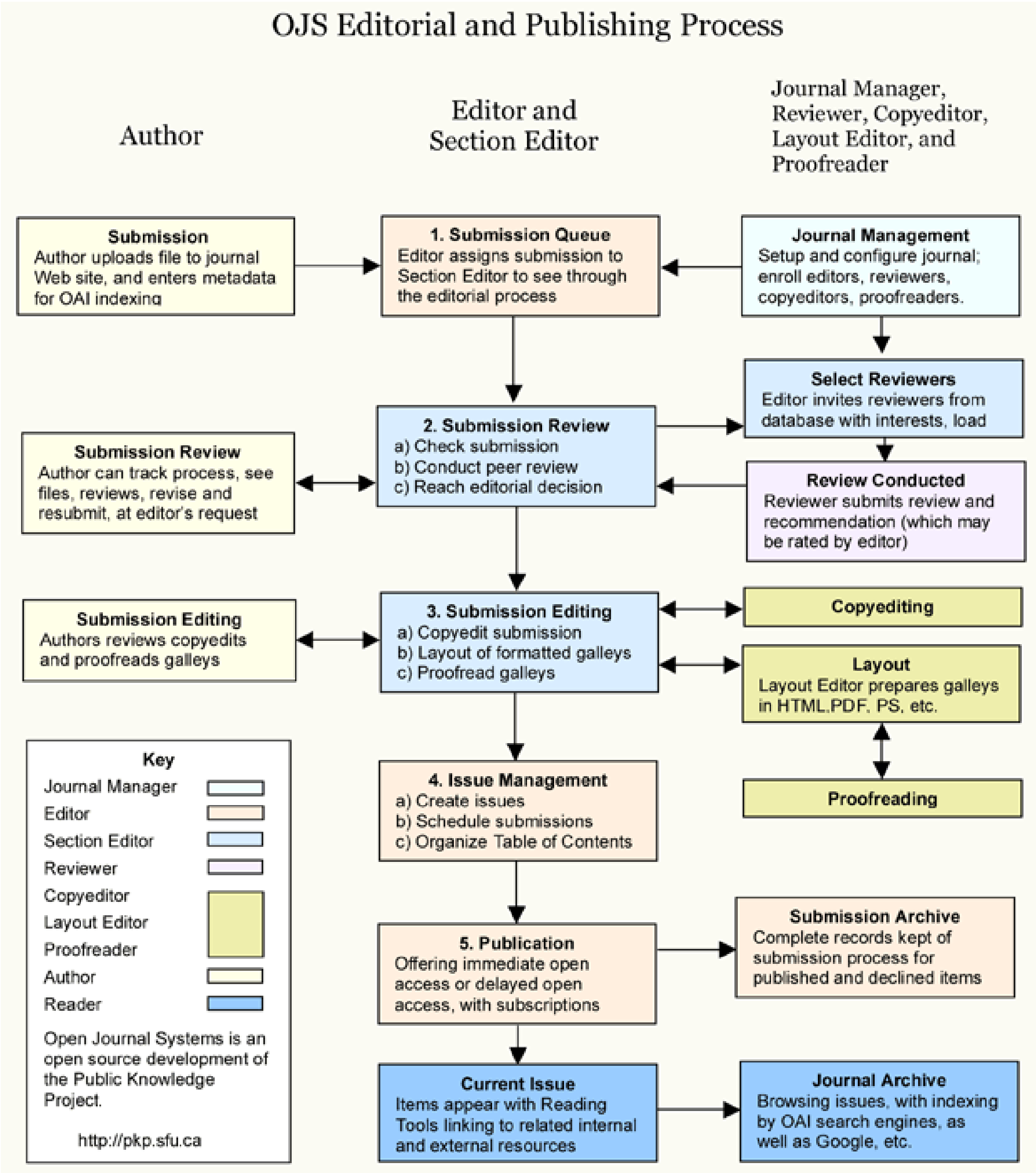

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