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A Mini-Review of *Santalum album* L. (*Santalaceae*)

Saeed MOHSENZADEH

Department of Biology, Kazerun Branch, Islamic Azad University, Kazerun, Iran

Corresponding Author: s_mohsenzadeh@yahoo.com

ORCID: 0000-0001-6263-658X

Abstract

The *Santalum album* L., belonging to the family Santalaceae, is one of the valuable sources of natural fragrance with high medicinal and commercial values. It has fragrant heartwood and is widely cultivated in India and other countries such as Australia and Indonesia. The availability and production of the *Santalum album* have declined significantly due to overharvesting and spike disease. The *Santalum album* flourishes on well-drained and loamy soil with a pH range of 6–9. It also grows on laterite soil, but not waterlogged ground, and preferably on slopes of hills exposed to the sun. It requires a minimum of 20 to 25 inches of rainfall per year; more than 80 inches is detrimental. The species is hemiparasitic, having photosynthetic capacity, but water, mineral nutrients, and organic substances are acquired via the haustorium of the host plant. Host plants are divided into three categories, including pot, intermediate, and long-term hosts. The selection of suitable host species is critical to ensuring high levels of the *Santalum album* field survival and growth. Indian Sandalwood is extensively used as a fragrance ingredient in perfumes, creams, soaps, detergents, lotions, etc. Furthermore, it is used as a flavoring substance in food products. Indian Sandalwood possesses various medicinally significant activities such as antiviral, antimicrobial, antibacterial, antioxidant, anti-inflammatory, anti-aging, anti-hypercholesterolemia, and anti-hair loss.

Keywords: Indian Sandalwood, Host plants, Habitat, Spike disease, Traditional medicine.

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INTRODUCTION

Santalum L., belonging to the family Santalaceae, is a hemiparasitic genus with 20 species, mainly distributed throughout India, Australia, and the Pacific Islands (Jiao et al., 2018; Sanjappa and Sringeswara, 2022). The *Santalum* species are recognized as xylem tapping root hemiparasites, and they are well known for their fragrant heartwood-derived oil used to scent incense and perfumery and are generally known as “Sandalwood” (Jiao et al., 2018; Fatima et al., 2019a). Wild *Santalum* populations are endangered in many regions due to their high value and the increasing demand for Sandalwood products, habitat loss, uncontrolled fire, grazing, and illegal and excessive logging of the *Santalum* species (Radomiljac, 1998; Bunney et al., 2023).

The *Santalum album* L. is an evergreen hemiparasitic tree commonly known as white Sandalwood (English), safed Chandan (Hindi), sandal safaid (Urdu), etc. (Sultana and Rahman, 2018). This species is indigenous to peninsular India and is also found in Australia, Belgium, China, Cambodia, Fiji, Indonesia, Japan, and Madagascar (Purohit, 2018; Nurochman et al., 2018; Fatima et al., 2019b). The *Santalum album* wood is highly fragrant and is the second most expensive kind of wood in the world after African Blackwood, *Dalbergia melanoxylon* Guill. & Perr. (Santha and Dwivedi, 2015). Unfortunately, the availability and production of the *S. album* have declined significantly due to overharvesting and poaching of natural resources, so severe that it has been categorized as 'Vulnerable' by the International Union for Conservation of Nature (IUCN) in 2020 (Bisht and Kumar, 2021).

The *Santalum album* is mainly a cross-pollinating species, and the pollination is facilitated by insects such as *Apis cerana indica*, *Monomorium destructor*, and *Camponotus* spp. (Krishnakumar et al., 2018). The tendency for outbreeding in the *S. album* is reinforced by asynchronous flowering, heterostyly, insect pollination, and self--incompatibility (Veerendar et al. 1996; Kulkarni and Muniyamma, 1998). The flowers are produced twice a year, and the fruits are drupe, purple-brown when fully ripe, and single-seeded (Dutt et al., 2021). Seeds are obtained by removing the fleshy portion of the fruits, and their viability is retained for up to six months under normal conditions and then gradually diminishes (Ramya, 2010). Fresh seeds exhibit dormancy for 2–3 months (Jayawardena et al., 2015). Natural regeneration occurs using seeds, and seeds are usually dispersed by birds and normally take three months to germinate (Bhaskar, 1992; Balasubramanian et al., 2011).

Germination is hastened by osmopriming, acid scarification (e.g., sulfuric acid), coconut water treatment, and soaking seeds in 500 ppm gibberellic acid (Jayawardena et al., 2015; Priyadharshini and Lekha, 2021; Debta et al., 2023). Artificial regeneration is achieved by vegetative propagation (through stem cuttings, grafting, and root suckers) and micropropagation (axillary shoot proliferation, somatic embryogenesis, and adventitious shoot induction) (Rao and Ram, 1983; Bapat and Rao, 1999; Radhakrishnan et al., 2001; Sanjaya et al., 2006; Bele et al., 2012; Crovadore et al., 2012; Herawan et al., 2014; Peeris and Senarath, 2015; Krishnakumar and Parthiban, 2018; Patil et al., 2018; Tate and Page, 2018; Teja et al., 2023).

Most of the existing *S. album* populations are not dense. The resources of *S. album* have been declined, due to natural or unnatural reasons. Natural reasons include change calamities, fire, drought, flood, spike disease, animal grazing, invasive weeds, including *Lantana camara* L., and the spread of monoculture plantations of *Eucalyptus* L'Hér. etc., and unnatural reasons include overexploitation, unorganized cutting of the trees, illicit felling and smuggling, etc. (Rocha et al., 2014; Purohit, 2018; Sahu et al., 2021; Bunney et al., 2023; Yadav et al., 2023). The market for the *S. album* perfume has increased, but the supply of heartwood resources has decreased for the reasons mentioned above.

MATERIAL and METHOD

An electronic search of published articles was conducted from 1966 to 2024 through PubMed, Google Scholar, Scopus, Web of Science, and local databases. Furthermore, cross-references were used to find more sources. Search terms included combinations of *Santalum album*, *S. album*, Sandalwood, Indian Sandalwood, morphology, host plants, habitat, chemical compound, traditional medicine, and spike disease.

MORPHOLOGICAL CHARACTERISTICS

The *Santalum album* is a hemiparasitic medium-sized evergreen tree, glabrous with thin drooping branches, and reaching up to 20 m in height. The bark is tight, reddish, dark brown, dark gray or brownish black, smooth in young trees, rough with deep vertical cracks in older trees, and red inside. The heartwood is yellowish-brown and is strongly scented. Leaves are simple, thin, usually opposite, elliptic-lanceolate and ovate or ovate elliptical, 3–8 x 3–5 cm, glabrous and entire; tip rounded or pointed; petioles 1–1.3 cm long; venations noticeably reticulate. The *Santalum album* flowers at the beginning of two to three years. Generally, it flowers twice a year, from March to May and September to December. Flowers are small, straw-colored, violet, green, or reddish, about 4–6 mm long, and up to 6 in small axillary or terminal clusters. Perianth includes 4 campanulate limbs, valvate triangular, 4 stamens, exerted, alternating with 4 rounded scales. The ovary is semi-inferior and unilocular. Fruit is a globose, fleshy drupe, red, purple to black when ripe, about 1.3 cm in diameter, with a hard ribbed endocarp and crowned with a scar, almost stalkless, smooth, and single-seeded. Seeds are naked, lack testa, and viable seed production occurs when the tree is five years old (Sindhu et al., 2010; Kumar et al., 2015; Kumar et al., 2019).

WHITE SANDALWOOD HABITAT

The *Santalum album* grows naturally in a variety from weathers of the warm desert in Australia, through seasonally dry monsoon climate in India, Eastern Indonesia, and Vanuatu, to subtropical climate in Hawaii and New Caledonia (Applegate et al., 1990). The *Santalum album* flourishes on well-drained, and loamy soil with a pH range of 6-9 (Applegate et al., 1990). It also grows on laterite soil, but not waterlogged ground, and preferably on slopes of hills exposed to the sun (Kumar et al., 2015). It needs a minimum of 20 to 25 in. of precipitation per year; more than 80 in. is detrimental (Solanki et al., 2014). Soil moisture is a critical environmental factor for the growth of the *S. album* because it determines the soil nitrogen and carbon content (Thinley et al., 2020). The best wood grows in the driest regions, especially on red and stony ground or on rocky ground, although the trees often remain small, giving the highest yield of oil (Sindhu et al., 2010). The suitable range of annual temperature between 19–29ºC, altitude between 451–1951 m, annual rainfall between 982–1984 mm, soil moisture between 3.7–115 kg/m^2, soil pH between 3.1–7.3 and slope between 0^{O} to 70^{O} with an average slope 40.7^{O} (for avoiding waterlog condition) are reported for the growth of the *S. album* in India (Rajan and Jayalakshmi, 2017; Thinley et al., 2020).

The *Santalum album* recruitment and growth are strongly affected by drought, extreme fluctuations in rainfall, and increasing evapotranspiration rates (McLellan et al., 2021). Seedling-related traits like photochemical reflectance index, relative water content, shoot and root weight, and root–shoot ratio correlated with different climatic parameters (Madhuvanthi et al., 2024). Seedlings are very susceptible to drought and are readily killed by exposure to the sun because of disorders of the plant's physiological metabolism system (Barrett and Fox, 1994; Zhang et al., 2022). Side shade is considered most desirable at the sapling stage, and diffuse light is beneficial until plants are about five years old or 4 m tall. The *Santalum album* thrives best when young in the shade of bushes and clumps of vegetation. Overhead shade is desirable only in very hot localities. As the *S. album* becomes established, it requires abundant sunshine. Indeed, the *S. album* is a sciophil as a seedling, becoming more heliophilic once established (Barrett and Fox, 1994).

HOST KINDS OF *SANTALUM ALBUM* AND THEIR SIGNIFICANCE

The *Santalum album* is a known parasite of more than 300 species from grasses to trees, and even other sandal trees (self-parasitism) (Dutt et al., 2021). It can reach a height of 20 m by attaining a girth of 2.5 m (Sandeep and Manohara, 2019). The selection of suitable pot host species is critical to ensure high levels of the *S. album* field survival and growth (Rai, 1990). The *Santalum album* initially needs shade and later plentiful light for its growth and development. However, being a hemi-root parasite, it needs a host for survival, especially to get mineral nutrients and water, despite being able to photosynthesize. Likewise, it is specific in selecting consistent associates in nature (Doddabasawa et al., 2020). Therefore, the choice of an appropriate host assumes significance. Several studies (Radomiljac, 1998; Nge et al., 2019; Doddabasawa et al., 2020) showed that the performance of the *S. album* relies on the host features such as good root growth, an even distribution of root growth within the pot, nodule formation (Fabaceae), thin and watery lateral root system, capability to resist top pruning, low level of competition, low allopathic influences, low growth structure, hemiparasitic compatibility and persistence in the field after out planting, sparse crown, slow-growing nature, translocation of nutrients, sap flow of xylem tissue and higher water use efficiency. Also, the distance between the parasite and its host is impressive in the growth of the *S. album*. Indeed, the appropriate distance of the relationship between parasite and host eliminates competition for above-ground resources, especially for light (Doddabasawa et al., 2020). The successful growth of the *S. album* relies on the supply of nutrients from the host plant through "haustoria" and shade at the young stage (Lion, 2017). Indeed, the dependence of the *S. album* on hosts is to obtain calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), nitrogen (N), phosphorus (P), proline, sugars, amino acids, and malic acid for the synthesis of carbohydrates (Doddabasawa and Chittapur, 2021). The formation of haustorium is more or less bounded to younger roots, and originates from outer layers of rootlets, unlike lateral rootlets, which are formed deep in the hosts' tissues (Das and Tah, 2017).

For plantations, host plants are divided into three categories: pot, intermediate, and long-term hosts (Fox et al., 1996; Radomiljac et al., 1998; Radomiljac et al., 1999). In addition, host plants were considered good, medium, and poor hosts, relying on growth, biomass, and the number of haustoria produced by the *S. album* when associated with various hosts (Ananthapadmanabha et al., 1988). The studies showed that Fabaceae is one of the most preferred host families of plants for the *S. album* growth because as the *S. album* tree ages, there is an increasing demand for nitrogenous compounds, which the Fabaceae family can provide (Radomiljac, 1998; Barbour, 2008). For example, Barbour (2008) reported that *Sesbania formosa* (F.Muell.) N.T.Burb. (Fabaceae) is a suitable pot host for the *S. album* in Australia, and Srikantaprasad et al. (2022) showed that *Prosopis* L. (Fabaceae) is an appropriate host for the commercial cultivation of the *S. album* in hot semi-arid conditions. Also, Thinley et al. (2020) mention that parasitizing *Desmodium* spp. (Fabaceae) by a mature Sandalwood tree reveals a potential supply of nitrogen by the host, as the *S. album* with age needs more nitrogen. When the *S. album* seedlings are transplanted into plastic pots, seeds or seedlings of a pot host plant should also be transplanted into the pots. Host plants (pot host) could include these species: *Aerva sanguinolenta* (L.) Blume, *Albizia lebbeck* (L.) Benth., *Alternanthera ficoidea* (L.) Sm., *Alternanthera nana* R. Br., *Calotropis procera* (Aiton) W.T.Aiton, *Calliandra calothyrus* Meissn., *Casuarina equisetifolia* L., *Chromolaena odorata* (L.) R.M. King & H. Rob., *Crotalaria juncea* L., *Dalbergia latifolia* Roxb., *Desmanthus virgatus* (L.) Willd., *Mentha arvensis* L., *Pongamia glabra* (L.) Panigrahi, *Sesbania formosa*, *Terminalia catappa* L., and *Trithonia diversifolia* (Hemsl.) A. Gray (Radomiljac, 1998; Applegate et al., 1990; Taide et al., 1994; Fox et al., 1996;

Tennakoon and Cameron, 2006; Barbour, 2008; Chakraborty et al. 2020; Thinley et al., 2020). In northern Western Australia, the herbaceous *Alternanthera nana* is a great host, as it facilitates high *S. album* durability and growth following field establishment (Radomiljac et al., 1998; Radomiljac et al., 1999).
The intermediate and long-term hosts are propagated simultaneously in different nursery containers, and both host kinds are strategically placed within the plantation (Radomiljac et al., 1999).

The intermediate host functions as a `bridging agent' between the pot host and long-term host and should facilitate early the *S. album* plantation growth. Intermediate hosts finally die or become less significant following the *S. album* attachment to the long-term host, which should survive as the final host for the whole cycle length (Radomiljac et al., 1999). Intermediate hosts should be established on the plantation site before planting the *S. album* to allow a good connection to its roots and host species, and the *S. album* seedlings should be planted close to their hosts (Applegate et al., 1990). Favorable characteristics of an intermediate host are mild strength or endurance to lopping (e.g., *Paraserianthes falcataria* (L.) I.C.Nielsen), a thin canopy, long-lived, a nitrogen-fixing legume, vast enough crowns, thorny or leathery leaves to protect of grazing animals, indigenous and some other benefit for locals (e.g., fuel wood, fodder, or fruit) (Applegate et al., 1990). Combinations of the *S. album* and intermediate hosts have proven successful in the past, including *Acacia nilotica* (L.) Willd. ex Delile, *Arachis pintoi* Krapov. & W.C.Gregory, *Cajanus cajan* (L.) Millsp., *Casuarina equisetifolia*, *Desmanthus virgatus*, *Erythrina poeppigiana* (Walp.) O.F.Cook, *Murraya koenigii* (L.) Sprengel, *Pongamia pinnata* (L.) Pierre, *Sesbania grandiflora* (L.) Poiret, *Wrightia tinctoria* (Roxb.) R.Br, and *Terminalia* spp. (Applegate et al., 1990; Fox et al., 1996; Page et al., 2012; Page et al., 2018; Doddabasawa et al., 2020; Thinley et al., 2020).

The *Santalum album* tree requires a long-term host for mineral nutrient replenishment, water supplementation to support plant water potential, and tiniest competition in above-ground parts apart from adequate sunlight (Doddabasawa et al., 2020). A mature *S. album* tree parasitizes on long-term suitable such as *Acacia auriculiformis* A. Cunn. ex Benth., *Acacia oraria* F. Muell., *Acacia spirorbis* Labill., *Adenanthera pavonina* L., *Cassia fistula* L., *Cassia javanica* L., *Cassia siamea* Lamk, *Casuarina equisetifolia*, *Casuarina junghuhniana* Miq., *Hibiscus tiliaceus* L., *Leucaena leucocephala* (Lam.) de Wit, *Paraserianrhes falcataria* (L.) Nielsen, *Pinus roxburghii* Sarg., *Prosopis juliflora* (Sw.) DC., *Pterocarpus indicus* Willd., *Senna formosa* H.S. Irwin & Barneby and *Citrus* L. species (orange, pamplemousse, lime or lemon) (Radomiljac, 1998; Fox et al., 1996; Page et al., 2012; Page et al., 2018; Doddabasawa et al., 2020; Thinley et al., 2020).

INDIAN SANDALWOOD AND USES

The *Santalum album*, naturally known as Indian Sandalwood, is one of the valuable sources of natural aroma with high therapeutic and commercial values (Bisht and Kumar, 2021). All parts of Indian Sandalwood, such as wood, root, bark, leaves, and fruits have been used in medicine and industry. For example, its fruits are edible, the seed contains fatty oil, which is suitable for the manufacture of paint, and the bark contains approximately 12-14% tannin and has profitable potential in the tanning industry (Kumar et al., 2015). A wide variety of articles, such as cabinet panels, hand fans, boxes, letter openers, combs, jewel cases, card cases, picture frames, bookmarks, and pen holders are made from Indian Sandalwood (Arun Kumar et al., 2012). Also, Indian Sandalwood has religious and ritual significance in a few countries, especially in India and Nepal (Bahadur, 2019).

For example, rich Hindus place pieces of Indian Sandalwood in the funeral pile, or the heartwood and sapwood are powdered together to produce incense or joss sticks used in religious ceremonies (Kumar et al., 2019). However, Indian Sandalwood is mainly grown for its heartwood to obtain fragrant oil. The essential oil of Indian Sandalwood develops in the heartwood and root of the trees, and this process needs about 15 to 20 years, but fully matured trees of 60 to 80 years produce the grandest oil content with high quality and a high level of fragrance (Santha and Dwivedi, 2015). Indian Sandalwood oil is acquired by steam distillation of the fragrant heartwood of Indian Sandalwood (Francois-Newton et al., 2021). Sandalwood oil is highly ranked for its sweetly fragrant, persistent, spicy, warm, woody note, tenacious aroma, and fixative properties. (Divakara et al., 2017). The chemical components reported in Indian Sandalwood oil are sesquiterpenes, terpenes, phenols, and lactones (Burdock and Carabin, 2008). More than 100 constituents that belong to different chemical classes have been identified in the heartwood, and the main constituents are α-santalol (up to 50% of the natural Indian Sandalwood oil) and β-santalol (up to 30% of the essential oil) (Brocke et al., 2008). Indian Sandalwood oil is vastly utilized as a fragrance ingredient in perfumes, creams, soaps, detergents, lotions, etc. (Sultana and Rahman, 2018). Furthermore, it is used as a flavoring substance in food products such as baked food, frozen dairy desserts, gelatin, candy, pan masala, puddings, and alcoholic and non-alcoholic beverages (Sanyal and Sikidar, 2016). Indian Sandalwood oil is authorized for food use by the United States Food and Drug Administration (FDA), Flavor and Extract Manufacturers Association (FEMA), and Council of Europe (CoE) (Burdock and Carabin, 2008).

The Sandalwood tree and its products have been utilized to cure various diseases since ancient times. Pedanius Dioscorides, a Greek botanist, authored De Materia Medica an encyclopedia in Greek on medicinal plants, which was the source for all modern pharmacopeias. It consists of five volumes and studies 600 plants. The *Santalum album* was recorded by Dioscorides in De Materia Medica, since then, it has been continually cited and used in various traditional systems of medicine, such as the Ayurvedic system of medicine, the traditional Chinese medicine (TCM) and the Unani system of medicine (Sultana and Rahman, 2018).

In the Indian traditional medicine system Ayurveda, Indian Sandalwood has mainly been used as a demulcent, expectorant, diuretic, antiseptic, antispasmodic, cooling, antipyretic, diaphoretic, antidiabetic, aphrodisiac, carminative, cicatrisant, antiseptic, antiphlogistic, astringent and in the treatment of urinary infection, herpes zoster, psoriasis, urethritis, palpitations, heart weakness, eye infections, biliousness, sunstroke, hyperacidity, acute dermatitis, intrinsic hemorrhage, bleeding piles, urticaria, vaginitis, fever, poisoning, vomiting, bronchitis, dysuria, bleeding piles, hiccoughs, inflammation of umbilicus poisoning, the initial phase of pox, and gonorrheal recovery (Banerjee et al., 1993; Paulpandi et al., 2012; Arun Kumar et al., 2012; Misra and Dey, 2013; Kumar et al., 2015; Sharma et al., 2017; Sneha and Mujumdar, 2020; Francois-Newton et al., 2021). In traditional Chinese medicine (TCM), Indian Sandalwood (=Tan Xiang) is utilized by herbalists to treat anxiety, nervous tension, immune booster, skin diseases, eczema, acne, frigidity, fatigue, dysentery, gonorrhea, impotence, cystitis, vomiting and stomachache (Misra and Dey, 2013; Santha and Dwivedi, 2015; Kumar et al., 2015; Kumar et al., 2019). Also, according to Chinese medicine, Indian Sandalwood functions in any kind of chest aches originating either from the lungs or heart (Misra and Dey, 2013; Kumar et al., 2015). In the Unani system of medicine, it has anti-inflammatory, antiseptic, analgesic, blood purifier, cardio tonic, exhilarant, nerving tonic, and expectorant properties, and it is helpful to treat cardiac, liver, skin, gastric ulcers, gastrointestinal, respiratory disorders, and locomotor diseases (Ahmed et al., 2013; Sultana and Rahman, 2018).

In addition, Pharmacological studies showed that Indian Sandalwood and its oil possessed various biological effects ranging from antiviral (Benencia and Courreges, 1999), aromatherapy (Heubeger et al., 2006), antimicrobial (Kumar et al., 2006), anticancer (Bommareddy et al., 2007), antibacterial (Misra and Dey, 2012), anti-hyperglycemic (Misra et al., 2013), anti-ulcer (Ahmed et al., 2013), antioxidant (Shamsi et al., 2014), anti-proliferative (Sharma et al., 2017), anti-inflammatory (Sharma et al., 2018), anti-aging (Francois-Newton, 2021), anti-hypercholesterolemia (Rasheed et al., 2023), and anti-hair loss (Montoli et al., 2023).

SPIKE DISEASE

The Spike disease of Indian Sandalwood has attracted worldwide attention due to its destructive nature (Gowda and Narayana, 1998a). For a long time, spike disease was assumed to be viral because of the disease syndrome and its graft-transmissibility, but electron microscopic studies showed that spike disease of the *S. album* is due to a mycoplasma-like organism (MLO) (Gowda and Narayana, 1998b; Hull et al., 1969; Disjktra and le, 1969). Phytoplasmas (formerly known as mycoplasma-like organisms) are bacterial plant pathogens that can cause devastating yield losses in cultivated crops and other plants (Wang et al., 2022). They are obligate symbionts of plants and insects and in most cases require both hosts for diffusion in nature (Hogenhout et al., 2008). In plants, these pathogens are seen exclusively in the sieve tubes of phloem tissues of leaves, petioles, stem, and root (Balasundaran and Muralidharan, 2004) and spread throughout the plant by moving through the pores of the sieve plates that divide the phloem sieve tubes (Hogenhout et al., 2008). Insect vectors of phytoplasmas are phloem feeders of the Order Hemiptera, mostly psyllids, leafhoppers, and planthoppers (Weintraub and Beanland, 2006). The symptoms of spike disease are similar to those of so-called 'yellow diseases' (Gowda and Narayana, 1998b). It is distinguished by an extreme reduction in the size of leaves, stiffening and reduction of internodes, the occurrence of short dead branches, yellowing and stiffening of leaves, and the occasional occurrence of tufts of axillary shoots arising from the main branches in the advanced stage, the whole shoot looks like a chimney brush (Ananthapadmanabha, 1998; Gowda and Narayana, 1998a, b; Sunil and Balasundaran, 1998).

Spiked trees usually die within 12–36 months (Sunil and Balasundaran, 1998). Several attempts have been made to detect the diseased plants by determining the length/breadth ratio of leaves (Ananthapadmanabha, 1998), staining techniques by light and fluorescent microscopes such as aniline blue (Ghosh et al., 1985), Dienes' stain (Ananthapadmanabha et al., 1973), Mann's stain (Parthasarathi et al., 1966), Hoechst 33258 (Ghosh et al., 1985), and A DNA-specific fluorochrome, 4,6-diamidino-2- phenyl indole (DAPI stain) (Sunil and Balasundaran, 1998), electrophysiological studies using Shigometer (Ghosh et al., 1985), Immunological techniques using Enzyme Linked Immunosorbent Assay (ELISA) (Balasundaran and Muralidharan, 2004), and molecular techniques such as restriction fragment length polymorphism analysis (RFLP) (Sunil and Balasundaran, 1999). Spike disease caused by MLO-like organisms is sensitive to tetracycline (Ananthapadmanabha, 1998). Infusion of an aqueous solution of 500 mg of tetracycline antibiotics, dissolved in 500 ml of water, in spiked trees, gave remission of disease symptoms lasting for three to five months (Ghosh et al., 1985).

CONCLUSION

The research on the *S. album* has been a subject of interest for many scientists. Many of them confirmed its traditional use and found even new possibilities for its potential use. Scientists have documented that it is a strong antiviral, antimicrobial, anti-inflammatory, and antioxidant, which are the reasons for its use in the cosmetic, pharmaceutical, perfume, and alimentary industries. Indian Sandalwood studies confirm that environmental factors influence the growth, development, and quality of the heartwood of Indian Sandalwood. Indian Sandalwood plants require host plants to meet their nutritional needs to grow and flourish. By knowing the types of host plants, both at the nursery level (pot host) and planting in the field (intermediate and long-term hosts), communities can make a selection for cultivating Indian Sandalwood in the future. The *Santalum album* is a vulnerable species, according to the IUCN being detrimentally affected by unnatural (e.g., overharvesting) and unnatural (e.g., spike disease) reasons. Conservation of the *S. album* should be done since planting in the field includes shade, flood, drought, fire avoidance, avoiding grazing animals, inhibiting overexploitation, and preventing pest and disease attacks.

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Threats of Climate Change and Floods in South Sudan

Musa KOSE

College of Natural Resources and Environmental Studies, University of Juba, Juba, South Sudan.

Corresponding Author: musakose053@gmail.com

ORCID: 0009-0009-2679-6784

Abstract

South Sudan, one of the least developed countries, is vulnerable to the losses and social damage caused by climate change since its people depend on climate-sensitive natural resources for their livelihood. Everyone is impacted by fluctuations in a number of climate-related parameters, including variations in temperature and the rate of precipitation. The aim of this review is to investigate the potential threats of climate change and floods in South Sudan. Sea surface temperature shows a positive and negative correlation with rainfall variability. Rainfall varies with time; therefore, skillful monitoring, predicting, and early warning of rainfall events is indispensable. Severe climatic events, such as droughts and floods, are critical factors in planning and managing all socioeconomic activities. Where Excessive rainfall may immediately lead to floods that destroy crops and infrastructure. Floods can have conflicting effects on food security at different spatial scales. The necessity for managing substantial runoff volumes has been identified, with a decade of rainfall data employed to accommodate annual variability. Rainfall spatiotemporal assessment is crucial for water resource management, agricultural productivity, and climate change mitigation.

Keywords: South Sudan, Climate change, Floods, Precipitation.

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INTRODUCTION

Floods are serious dangers, and in order to lessen the number of lives lost and the loss of livelihoods they cause, adaptation methods are required. Human actions, such as rising development in floodplains and the construction of flood mitigation infrastructure, are altering the regions that experience floods, their characteristics, and the people who are vulnerable to them (Tellman et al., 2021). Improved observations—including more frequent temporal sampling and the capacity to cover wide areas at high spatial resolution—are needed to better comprehend flooding patterns. This sort of information is necessary, for instance, to properly implement suitable flood mitigation measures for a particular location. Due to a paucity of observational data, previous estimates of the populations vulnerable to worldwide floods have been hampered and have instead relied on highly unreliable models. By using satellite data, flood dynamics and extent may be more thoroughly estimated, which in turn helps determine the long-term effects on human populations worldwide. Increased precision in estimations will benefit hydrological models utilized by several stakeholders and numerical models that provide inundation forecasts, lowering uncertainties in such models (Downs et al., 2023). Globally, and especially in developing nations, flooding events are becoming more common due to climate change.

In 2020, record-breaking floods ravaged most of Africa, displacing millions of people across borders, destroying infrastructure, and escalating public health issues within the COVID-19 pandemic. Although flooding is a regular seasonal occurrence in riverine areas of Africa, there is a growing awareness of the extent, magnitude, and duration of flooding as well as its effects, particularly from humanitarian organizations and in relation to ex post relief and ex ante preparation operations (Reed et al., 2022). While global warming persists, the primary area of worry for scientists and policymakers is how climate change will affect water resources. A third of the world's population lived in countries that were deemed to be under water stress and were utilizing more than 20% of their available water supplies, according to the UN assessment of the world's freshwater resources conducted in 1997. According to the study, by 2025, as much as two-thirds of the world's population might live in countries that lack access to clean water (Jubek et al., 2019). Given the limited land available for new agricultural developments and the growing concerns about deforestation and climate change (Bagdatli et al., 2015; Bagdatli & Belliturk, 2016a), many studies have examined the many aspects of climate change in Sudan and South Sudan. Most of the study that was done and the future forecasting effort focused on temperature and precipitation changes, which are the two most significant climatic features and severe occurrences (Nasreldin and Elsheikh, 2022). Flooding has a significant negative influence on agriculture and food security, especially in areas where the seasonality or character of flood episodes may be changing or rising.

Founded on July 9, 2011, South Sudan is the world's newest country. The nation is split into six agro-ecological zones based on geomorphology, which provides a variety of agricultural possibilities (such as maize, sorghum, wheat, and so on) and an abundance of water resources, such as lakes, rivers, and rains. Even with this potential, there is rarely enough grain produced to fulfill demand. A serious barrier to production that lowers yield is the low quality of productive inputs and support services, low-quality and inefficient technologies, and ultimately a lack of infrastructure (Caruso et al., 2017). The South Sudanese subtropical area, which has dense vegetation and frequent heavy rains. In Sudan and South Sudan, seasonal variations in temperature are minimal; nonetheless, precipitation and the duration of the rainy season are sharply declining (Elsheikh, 2021a). Dry north-easterly winds cause practically little rainfall over the nation from January to March. As the wet south-westerly’s reach South Sudan by early April, the rainy season begins there. By August, the south-westerly flows approach the borders of Northern Sudan (Mohamed et al., 2021). In South Sudan, an area with a complex ecosystem made up of forests, marshes, and high plant cover that contributes to the flux of moisture into the atmosphere, the rainy season begins first. In Central Sudan, the whole northward movement of moisture from all of these sources is essential to the rainy season. A number of studies and observations document the deforestation and ensuing deterioration of Sudan's natural environment; however, fewer studies evaluate the implications of this degradation for the country's climate (Elagib and Mansell, 2000). Many investigations show that changes in vegetation have a major impact on surface temperature and precipitation in both the southern and central regions of the country. This suggests that land use in Southern Sudan has a major impact on precipitation in Central and Southern Sudan and that deforestation has both local and non-local implications for regional climate. as though For the desert scenario and the grass scenario, the affected region had a reduction in precipitation during the rainy season of around 0.1–2.1 mm d^{-1} and 0.1–0.9 mm d^{-1}, respectively. In the case of the grass and the desert, the surface temperature rises by around 1.2 and 2.4 °C, respectively. Thus, in addition to being local, the decrease in precipitation also affects Central Sudan and its surrounding areas (Salih et al., 2013).

South Sudan has noticed greater effects of climate change, which is changing precipitation patterns and making environmental challenges greater. Therefore, this study examines the risks posed by flooding and climate change in South Sudan.

EFFECT of CLIMATE CHANGE and FLOODS in SOUTH SUDAN

According to Elsheikh et al. (2023), one of the continent’s most susceptible to climate change is Africa as a whole. There is ample evidence of the ways in which climate change and extreme weather have affected African nations, particularly those in North, South, East, and Central Africa. Extremes of climate change, in particular warming, and unpredictable rainfall, both in terms of distribution and volume, pose significant development concerns for Africa. El Niño and La Niña are partially responsible for the intensity of the floods and droughts in the Horn of Africa, which includes South Sudan (Haile et al., 2021). In East-Central Africa, South Sudan is a landlocked country that makes up 96% of the Nile River Basin. It borders the Democratic Republic of the Congo (DRC) and Uganda in the south, Sudan in the north, Ethiopia and Kenya in the east, and the Central African Republic in the west. The tropical area that spans latitudes 3.5° to 12° North and longitudes 24° to 36° East is where South Sudan is situated. It is 658842 km2 in total. Throughout the country, vast grasslands, marshes, and tropical forests are the norm. Its natural resources include abundant agricultural, mineral, water, wildlife, forestry, and energy resources (Jubek et al., 2019). With less than 13 people per square kilometer, the country has one of the lowest population densities in sub-Saharan Africa. The primary sources of income in the northern desert zones include pastoralism, fishing, hunting, and seasonal agriculture (Elsheikh, 2021b). Many options for a living are provided by the low, forested savannahs in the country's center. The nation is divided into three parts, once ancient provinces: Equatorial in the south, Bahr el Ghazal in the northwest, and Greater Upper Nile in the northeast (MOE, 2015). Water availability in the upstream and downstream areas of trans-boundary river basins is a particularly sensitive topic. Due to its location in the "middle" of the Nile Basin, between the upstream Nile Equatorial Countries (Burundi, the Democratic Republic of the Congo, Kenya, Rwanda, Tanzania, and Uganda) and the downstream Eastern Nile Countries (Egypt, Ethiopia, and Sudan), natural water retention, water withdrawals, and development activities in the upstream countries affect the quantity and quality of water in South Sudan (Fernando and Garvey, 2013). There are two ways that lateral water transfer moves from positive to negative locations: floods and groundwater movement. Since every nation and water-use sector in the trans-boundary Nile Basin monitors water statistics, such as withdrawals, stocks, wastewater return flows, and groundwater-well yields, it is difficult to assess the state of the water flows throughout the basin. Earth observation data at the ecosystem scale provide comprehension of the principal water flows and fluxes in the Nile River Basin (Bastiaanssen et al., 2014).

Land deterioration, water depletion and pollution, and a lack of grazing might be directly caused by climate change and extreme weather events, including floods, droughts, and temperature swings (Bagdatli et al., 2023; Bagdatli & Balli, 2019). Moreover, it may also refer to secondary biophysical and human-caused risks like warfare, the transmission of illnesses, disruptions of infrastructure and services like healthcare and transportation, and the worsening of the conditions of the weaker members of society. It is anticipated that the effects of extreme weather and climate change will worsen in the future. Because of its subtropical position, South Sudan experiences a lot of rainfall. The region is characterized by year-round heat and is covered in a thick layer of tropical forest and savanna grass (Lukwasa et al., 2022).

Figure 1 shows the observed annual average mean surface air temperature of South Sudan, 1981–2022. Temperatures typically reach highs of over 35°C, especially during the dry season (January to April), and average around 25°C. The capital city of Juba has 34.5°C average highs and 21.6°C average lows annually.

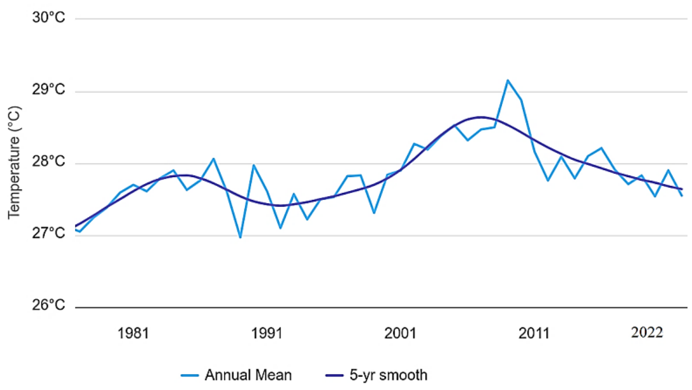

Figure 1. Observed annual average mean surface air temperature of South Sudan, 1981–2022 (World Bank Group, 2021).

There are differences in the amount, timing, and distribution of precipitation in South Sudan. Between 700 and 2200 mm of rain fall there each year. Rainfall quantity and duration often decrease from the country's northeast to southwest regions. Rainfall in South Sudan is unimodal in the northern region and bimodal in the southern, western, and central regions. The northern region of the nation has rainy months from May to October. The first rainy season in South Sudan fell in the country's west and center from April to June, while the second rainy season runs from August to November. While the Central and Western regions of the nation have longer annual growing seasons, ranging from 280 to 300 days, the northern section of the country experiences a shorter annual growing season (130–150 days). Rainfall in South Sudan has been falling and becoming less intense in the north. The cultivation schedule and agricultural choices may be impacted by this (Elagib and Elhaj, 2011). The Inter-tropical Convergence Zone (ITCZ) and the corresponding air mass movement control the amount of rainfall in South Sudan. Tropical south-westerly winds carry precipitation from the Atlantic and Indian seas. The meeting point of the Southeast and Northeast trade winds is this region of low air pressure. The ITCZ travels toward the Southern Hemisphere and reaches South Sudan from September to February. Moist air is driven upward when these winds converge in the area, generating a section of the Hadley cell. Water vapor condenses and descends as rain when the air rises and cools. Wet and dry seasons originate from the ITCZ migrating northward once more between February and May, causing rainfall. This movement occurs in South Sudan (Lukwasa et al., 2022). South Sudan is generally the most vulnerable to political crises and direct and indirect biological and hydro-meteorological disasters brought on by climate change. These underlying causes, in addition to a lack of adaptive ability, have made food insecurity worse and are driving migration and population displacement. Thus, controlling and minimizing the effects of hydro-meteorological hazards and devising community capacity-building intervention methods require knowledge of precipitation behavior and the identification of flood and drought hot spot locations (Colin et al., 2019). In order to provide readers with a general understanding of the geographical and temporal fluctuations in South Sudan's rainfall and to pinpoint regions that are susceptible to drought and flooding, we have attempted to shed light on climate change in this article, particularly as it relates to rainfall.

Evaluating the impact of climate change on different elements of the water cycle is strategically important in the management of this vital resource as water supplies become even more stressed owing to rising levels of societal demand (Elsheikh et al., 2022a; Bagdatli & Arslan, 2019; Bagdatli & Can, 2019). A few water management strategies that could be considered to assist with climate change adaptation include demand management, operational changes, and infrastructure modifications (Bagdatli & Belliturk, 2016b; Bagdatli & Arikan 2020a). Climate change may have an impact on the design and operational assumptions that are used to calculate resource supply, system demands, system performance requirements, and operational limits (Levi et al., 2009; Bagdatli & Balli, 2020). Since 1970, the average global surface air temperature has risen dramatically. The estimated change in the Earth's surface average temperature is computed using information gathered from hundreds of weather stations, ships, buoys, and satellites located all around the world. These measurements are compiled, analyzed, and processed separately by several research teams. The data processing procedure involves a number of important steps (Elsheikh et al., 2022b, Belliturk & Bagdatli, 2016). Numerous research institutions throughout the world have generated estimates of changes in surface temperature on a global scale (Bagdatli and Can, 2020; Bagdatli & Arikan 2020b). The warming trend evident in all of these temperature records is corroborated by additional independent observations, including the melting of the Arctic sea ice, the retreat of mountain glaciers on every continent, decreases in the amount of snow cover, an earlier springtime bloom of plants, and an increase in the melting of the Greenland and Antarctic ice sheets. A feedback loop is created when snow and ice melt because they reflect solar radiation and absorb additional heat as they do so (Trenberth et al., 2007). The risk of droughts and floods is expected to grow throughout a significant area of the planet due to forecasted increases in dryness and wetness extremes. As was previously said, this is expected to continue. Precipitation tends to be concentrated into bigger episodes on a warmer planet with longer dry periods between (Jubek et al., 2019). The required steps should be implemented as quickly as possible to mitigate the impacts of climate change.

The Eastern and Western Flood Plains, which make up the majority of the Northern States of South Sudan and are subject to both droughts and floods, have nearly identical climates, according to Tiitmamer et al. (2018). Additionally, the Ironstone Plateau's conditions are nearly the same across the zone, extending from Juba in the south to Raga in the northwest. The findings show that South Sudan has less rainfall in November and more rainfall in April on average. This is expected since the two distinct seasons—dry and wet—usually begin in November and April, respectively. July and August get the most rain, which is consistent with the nation's long-standing seasonal variations. The yearly rainfall varies greatly, with an average of 53 millimeters in 1990 and 85 millimeters in 2014 (Figure 2). Although it varies depending on the region, the rainy season usually lasts from April to November. Rainfall in the lowland regions of Bahr el Ghazal, the Upper Nile, Jonglei, and Eastern Equatoria ranges from 700 to 1,300 mm per year. About 200 mm are received by Eastern Equatoria's southeast point. The southern upland regions receive the most rainfall, which decreases towards the north. Rainfall in Western Equatoria and the highlands of Eastern Equatoria ranges from 1,200 to 2,200 mm per year (World Bank Group, 2021). Over the course of 45 years, the country has received 69 millimeters of rain on average. Renk had the least amount of rainfall in the region—43 millimeters—as opposed to 84 in Wau and 80 in Juba. When the three stations are combined, the average temperature across the country is around 35 degrees. The monthly average temperature has ranged from 32.11 degrees in August to 38.25 degrees in March. The same data shown annually shows a range of values that are closely grouped together, suggesting little change in the temperature. In a similar vein, there are almost no differences in temperature between the three biological zones—Renk experiences temperatures between 34 and 35 degrees—in Juba and Wau (Tiitmamer et al., 2018). Rainfall that is either above or below normal nationally or in a particular location can cause both regional and national droughts and floods in South Sudan. The Nile River and its tributaries overflow in August and September, which is when flash floods usually occur. Changes in the climate have affected the spatiotemporal distribution of rainfall. Thus, understanding the meso- and micro-level factors contributing to the spatiotemporal rainfall variation should be useful for planning water-development strategies.

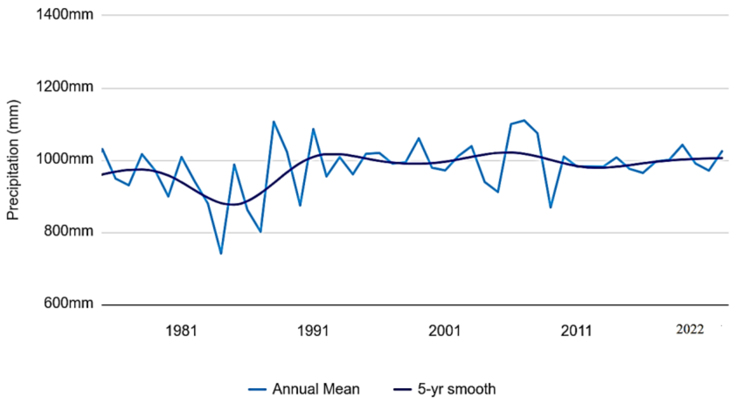

Figure 2. Observed annual Precipitation of South Sudan, 1981–2022 (World Bank Group, 2021).

In South Sudan, the Sudd wetland stretches from south to north. The temperature and amount of precipitation varied greatly. In the southwest, Sudd wetland is wetter and colder; in the northeast, it is drier and warmer. Sudd Wetland is an important environment both locally and globally. The Sudd Wetland, which supports millions of pastoralists and farmers, as well as the internationally renowned Ramsar Wetland, are under pressure from population growth and climate change extremes such as flooding and drought (Zeleke et al., 2024). Previous studies have revealed that the Sudd wetland basin has large-scale seasonal flood events that span between 10 and 30,000 km2. Throughout the rainy season (May to October), flooding happens naturally (Lukwasa et al., 2022). Floods are a potentially catastrophic hydro-meteorological hazard that may kill people and seriously harm livelihoods, infrastructure, and the environment. They can also disrupt services and inflict extensive damage. The flood phenomenon has an impact on the pastoralists living in the Sudd wetland. While the wetland's central and northern regions showed dry events, the wetland's north and south regions showed predominantly wet occurrences. Alternating dry and wet occurrences were also seen in the wetland's central and southern parts. The overall outcome demonstrated an unpredictable pattern of precipitation. This outcome was amply supported by related studies. The Sudd wetland is characterized by an increased frequency of floods and droughts, variable precipitation, and uncertain seasonal timing (Zeleke et al., 2024). The World Food Programme (WFP) of the United Nations has issued a warning, stating that as the country's climate crisis deepens, floods in South Sudan may result in extremely high levels of malnutrition in the first half of 2024. The worst incidences of malnutrition are seen in communities devastated by flooding because of the development of water-borne illnesses, cramped living conditions, and restricted access to food and employment opportunities (WFP, 2023). Since information may be utilized to take preventative steps to enhance resilience to climate change, the study of large-scale seasonal flood occurrences and the potentially catastrophic impacts of floods is particularly essential.

CONCLUSION

With the growing impact of climate change, particularly the wide range of temperatures and the intricate patterns of temporal and geographical variability in precipitation, the dynamics of the atmosphere across the seas and large-scale pressure systems are impacted. Nonetheless, over the previous fifty years, South Sudan's rainfall has both dropped and increased in variability. It has been raised how South Sudan is projected to be affected by climate change, with particular attention paid to rainfall and potential flood hazards in this research. In the absence of planned adaptation and mitigation methods, the repercussions have had an influence on development, livelihoods, and ecosystems. Extreme occurrences like floods may result from this, since seasonal flooding has occurred in many parts of the world, including South Sudan. Thus, in order to adequately prepare for such occurrences, it is imperative to conduct a comprehensive investigation of climatic changes, particularly the catastrophic events that may transpire.

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Smart Agricultural Approach and Good Agricultural Practices in Sustainable Development Goal

Ceren UNLUKAL[1], Gokhan Onder ERGUVEN[2*]

[1]Faculty of Engineering, Department of Industrial Engineering, Munzur University, Tunceli, Turkey
[2]Faculty of Economics and Administrative Sciences, Department of Political Science and Public Administration, Department of Urbanization and Environmental Issues, Munzur University, Tunceli, Turkey*

[*]Corresponding Author: gokhanondererguven@gmail.com

[*]ORCID: 0000-0003-1573-080X

Abstract

Environmentally sustainable development and agricultute strive to integrate ecological practices into life, fostering a culture of environmental responsibility among people. In these sustainable cities efforts are made to reduce the ecological footprint by implementing energy-efficient technologies, waste reduction strategies, eco friendy production of agricultural products and green agriculture applications. Renewable energy sources, such as solar panels and wind turbines, are often incorporated to meet energy needs while minimizing the impact on the environment. Biodiversity conservation is another focus area, with green spaces, native plantings, and wildlife-friendly landscaping contributing to the overall ecological balance. Sustainable development and construction practices are aiming to achieve energy efficiency and minimize resource consumption. Green agricultural building certifications and eco-friendly materials contribute to the creation of environmentally responsible infrastructure. In the modern era, the concept of sustainable agricultural buildings has emerged as a transformative force, leveraging technology to enhance urban living. This paradigm shift is characterized by the integration of information and communication technologies to optimize various aspects of city life, including mobility, health, safety, and productivity. The doubling of technology investments in these cities from 2018 to the present demonstrates a concerted effort to reduce costs, minimize environmental impact, and enhance internal city efficiency. As interested cities continue to join the movement, the smart cities that integrated with sustainable agriculte activities market share is anticipated to be seven times larger by 2030 compared to the present day. The ongoing technological revolution in these cities force shaping the future of urban living. This study provides examples of sustainable city applications implemented in recent years globally.

Keywords: Biodiversity, Eco friendly, Native plantings, Sustainable development

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INTRODUCTION

The rapidly increasing trend of urbanization today necessitates making cities more efficient, sustainable, and livable. In response to this need, the concept of "environmentally friendly smart cities" has emerged, aiming to significantly ease urban life by integrating various technological solutions and smart infrastructures. Environmental sustainability is a major priority in sustainable agricultural practices (Coulibaly and Diakite 2021).

The management of smart energy sources and their usage in sustainable agriculture increases energy efficiency, thereby reducing the negative impact of agricultural activities on the environment. Similarly, smart agricultural waste management optimizes waste collection and recycling processes, contributing to sustainability goals (Dudley and Alexander, 2017).

The management of agricultural structures within smart farming simplifies the daily lives of individuals (Basso and Antle, 2020). Energy-saving smart building systems support a more sustainable lifestyle in agricultural activities. Increased community engagement and communication enhance the interaction of smart buildings with their inhabitants. This transformation aims to enable agricultural regions to respond more effectively to future challenges and to provide a better quality of life for their residents (McNeill, 2019).

Smart farming practices focus on the principles of sustainability and livability, aiming to minimize environmental impact and provide a higher quality living experience for city residents. In this context, digital solutions and services are also developed to enhance citizen participation, strengthen transparency, and improve the overall well-being of the community (Ayres et al., 2001).

The key elements include sensor networks, big data analytics, the Internet of Things energy management, and digital governance. These elements enable city administrations to manage resources more effectively based on real-time data, optimize production and marketing methods, reduce energy consumption, and improve public health services.

Every day, more than 180,000 people move to live in a city. The Organisation for Economic Co-operation and Development. predicts that by 2050, the world population will reach 9 billion, with 70% living in urban centers rather than rural areas.

They use Information and Communication Technologies (ICT) and big data to manage everything effectively and sustainably, from transportation to the use of energy and water resources, public spaces, and communication with city residents. The goal is to reduce energy consumption, decrease CO_2 emissions, and enhance the well-being of the residents.

One of the sustainable development goals endorsed by the United Nations is the commitment to environmental sustainability. The most striking aspect of this commitment is the measures taken to reduce the consumption of natural resources.

There are several steps that an agricultural production region can take to adopt sustainable agriculture policies and develop its production stages with this understanding. These steps include:

Energy Efficiency and Green Energy Use: The first step in conducting sustainable agricultural activities is to ensure energy efficiency and transition to renewable energy sources. Building insulation can be improved, energy-efficient lighting systems can be installed, and agricultural machinery for irrigation, fertilization, spraying, or plowing can be utilized. For this purpose, renewable energy sources such as solar, wind, or hydroelectric power can be employed. Alongside all these practices, energy monitoring and management systems can be implemented to track energy usage and crop yield efficiently.

Sustainable Transportation: Sustainable transportation options should be encouraged for personnel engaged in agricultural activities. Opportunities such as electric tractors and vehicle charging stations, public transportation options, and support programs can be provided to minimize carbon footprint.

Agricultural Waste Management: Policies and infrastructures related to agricultural waste management processes should be established. Practices such as waste separation and recycling programs, waste reduction campaigns and trainings, and composting of organic waste should be implemented.

Green Areas and Biodiversity: Creating green areas within agricultural activities allows farmers to have closer contact with nature. Additionally, various afforestation and landscaping projects can be carried out to protect local plant species and increase biodiversity.

Sustainable Agricultural Structures: Targeting energy-efficient design and green building certifications through construction compliant with Leadership in Energy and Environmental Design and similar certifications contributes to the sustainability of agricultural structures. This includes utilizing natural light, energy-efficient building insulation, and the use of renewable, recyclable, and environmentally friendly materials.

Environmental-Friendly Farming Awareness and Education: To support efforts towards environmentally friendly sustainable agriculture, training should be provided to producer farmers, personnel in provincial agriculture directorates, and consumers on environmentally friendly integrated farming practices and sustainable agriculture topics. Awareness campaigns and events can be organized within the community to promote the adoption of these values. Sustainable agricultural practices provide a range of advantages and outcomes by focusing on environmental sustainability, energy efficiency, and public health. These outcomes include:

Energy Efficiency and Conservation in Agriculture: Energy efficiency measures in agriculture contribute to budgetary savings by reducing energy costs associated with agricultural activities. Through practices such as the use of renewable resources for more efficient production, the adoption of energy-efficient production methods, and the cultivation of more productive crops, energy savings and efficiency are achieved, thus promoting sustainable agricultural production.

Environmental Sustainability: Practices such as preserving agricultural biodiversity, managing water resources for irrigation, and reducing agricultural waste create a model for environmentally friendly sustainable development, thus preserving natural ecosystems. Additionally, the sustainable preservation of clean air and water sources, green spaces and biodiversity enhances awareness of environmentally friendly farming practices (Farley and Smith, 2020).

Community Health and Well-being: Sustainable agricultural activities support overall community health by creating a healthier living environment for agricultural producers and consumers. This, in turn, leads to cleaner air, greater biodiversity, healthy products, green spaces, and healthy agricultural structures, all of which reduce stress, improve mental health, and enhance overall well-being.

Low Carbon Footprint: Sustainable agricultural practices create positive impacts in combating climate change by reducing carbon footprint. As a result, sustainable agriculture minimizes agricultural carbon footprint through the use of renewable resources and energy efficiency in the agricultural production chain.

Education and Awareness: Developing leadership skills in sustainability by providing agricultural producers and consumers with awareness of sustainable agriculture and environmental consciousness. The development of these skills contributes to the creation of a culture of sustainability within the community, supported by various training programs and awareness efforts.

Sustainable agricultural practices include projects highlighted by various universities focusing on sustainable and environmentally friendly approaches in agriculture. Many universities in Turkey and around the world have aimed to create an environmentally friendly agricultural activity area by adopting sustainable agricultural practices. Some of the examples for these universities are; Bogazici University, Middle East Technical University, Sabanci University.

MATERIAL AND METHOD

In this study, data for 2022 regarding good agricultural practices in Turkey are presented in Table 1 and evaluated within the scope of the concept of sustainable agriculture.

Table 1. Good agricultural practices in Turkey by geographical regions (Anonymous, 2024)

GOOD AGRICULTURAL PRACTICES PRODUCTION AREAS				
REGIONS	**Provinces**	**2022**		
		Number of Producers	**Production Area (da)**	**Production Quantity (kg)**
Marmara Region	**Balıkesir**	269	89.305	105.299.104
	Bilecik	15	149	322.500
	Bursa	152	29.896	154.529.734
	Çanakkale	152	27.512	35.443.773
	Edirne	189	108.651	84.946.101
	İstanbul	12	40	757.159
	Kırklareli	18	4.878	7.433.723
	Kocaeli	3	875	5.090.006
	Sakarya	257	8.963	7.063.928
	Tekirdağ	9	2.848	7.828.307

Table 1. Good agricultural practices in Turkey by geographical regions (Anonymous, 2024) (Continued)

Marmara Region	**Yalova**	9	262	745.000
Black Sea Region	**Amasya**	38	10.149	67.653.708
	Artvin	10	91	81.700
	Düzce	169	4.786	1.456.891
	Çorum	16	2.158	6.316.844
	Bolu	1	3	555
	Bartın	1	191	152.602
	Bayburt			
	Giresun	35	735	146.051
	Kastamonu	25	281	281.202
	Gümüşhane			
	Karabük	6	33	1.185.450
	Ordu	136	7.811	1.331.431
	Sinop	4	105,517	454806,3125
	Rize			
	Samsun	96	2532,875	8601975
	Trabzon	4	129,828	10600
	Zonguldak			
	Tokat	10	892,795	4192342
Central Anatolia Region	**Aksaray**	115	13651,639	47485597
	Ankara	179	41196,3612	158849170,9
	Çankırı	11	412,135	824270
	Eskişehir	47	11647,695	60404674,2
	Karaman	40	19781,699	88592178
	Kayseri	163	38670,513	73690656,24
	Kırıkkale	17	829,736	85000
	Kırşehir	5	5023,475	34712956
	Konya	308	130220,088	759856602,9
	Nevşehir	47	11727,118	55980180,01
	Niğde	314	68018,324	295375724,1
	Yozgat	3	4374,341	17161760
	Sivas	4	979,983	6621824
Aegean Region	**Afyonkarahisar**	54	7128,86	92515935
	Aydın	232	44641,281	96816380
	Denizli	160	26486,282	49716849
	İzmir	339	41947,105	107673599
	Kütahya			
	Manisa	286	73002,524	104074762
	Muğla	273	32362,215	67859173,4
	Uşak	18	3179,808	4771502
Eastern Anatolia Region	**Elazığ**	12	862,298	844093
	Malatya	3	2294,147	10827846
	Ağrı	1	37,6	1203200
	Erzurum	13	236,52	160100
	Erzincan	9	1131,668	140259
	Hakkari			
	Ardahan	90	2858,797	571757

Table 1. Good agricultural practices in Turkey by geographical regions (Anonymous, 2024) (Continued)

Eastern Anatolia Region	**Muş**			
	Bingöl	11	95,435	5900
	Kars	23	937,089	187414
	Van	1	6,3	850000
	Tunceli			
	Bitlis	1	49,25	343000
	Iğdır	10	164,75	183697
Southeastern Anatolia Region	**Batman**			
	Şırnak			
	Diyarbakır	3	1371,466	5880542
	Adıyaman	103	16156,7974	30899662,74
	Gaziantep	841	172034,807	31315511
	Kilis	5	2001,836	840000
	Mardin			
	Siirt	19	4945,225	2451244,1
	Şanlıurfa	1.350	255393,581	27288128,68
Mediterranean Region	**Adana**	1.512	451164,3827	1680444490
	Antalya	199	29854,689	219185388,1
	Burdur	27	2117,792	20251025,43
	Hatay	255	41471,975	118818870
	Isparta	79	15088,452	112778841
	Kahramanmaraş	220	36161,216	19939250
	Mersin	495	136270,871	367264700,9
	Osmaniye	37	17665,337	59182399
TOTAL		**9.570**	**2.068.933**	**5.336.251.605**

RESULTS AND DISCUSSION

Looking at Table 1, the region with the most producers is the Mediterranean Region with 2.824 producers; on the other hand, the region with the fewest producers is the Eastern Anatolia Region with 174 producers. When evaluated in terms of production area, the region with the largest area is the Mediterranean Region with 729.795 decares; On the other hand, the region with the least production area is the Eastern Anatolia Region with 8.674 decares. Considering the total amount of products, the region that produces the most is the Mediterranean Region with approximately 2,6 million tons; on the other hand, the region with the least production is the Eastern Anatolia Region with 15.317 tons.

Pretty et al. (1996) suggest that sustainable agriculture follows these principles: (i) fully integrating natural processes such as nutrient cycling, nitrogen fixation, and predator-prey relationships; (ii) minimizing the use of external and non-renewable inputs that harm the environment or the health of farmers and consumers; (iii) involving farmers and rural communities in problem analysis, technology development, adaptation and dissemination, monitoring, and evaluation processes; ensuring more equitable access to productive resources and opportunities; (iv) making more efficient use of local knowledge, practices, and resources; integrating various natural resources and enterprises; and (v) increasing self-confidence among farmers and rural communities. Efforts by countries to increase production for better nutrition and competitiveness have led to an increase in the use of intensive inputs in agriculture. The interest in conventional agriculture, which relies on intensive input use, has persisted for many years worldwide.

However, with the emergence of environmental problems caused by conventional agriculture, the impact of chemical input use on sustainable agriculture has been debated. As a result, to mitigate the harmful effects of conventional agriculture, good agricultural practices, one of the sustainable agriculture systems, have gained importance. It should be emphasized that sustainable agriculture does not represent a return to low technology, backward, or traditional farming practices, but rather a combination of the latest innovations, which may originate from scientists, farmers, or both (Velten et al., 2015). The rural economy is not only about food production; it is also concerned with enhancing the capacity of rural people to be self-reliant and resilient in the face of change, as well as building strong rural organizations and economies (Sumberg and Giller, 2022).

Efforts to increase countries food security and competitiveness have led to an increasing use of intensive inputs in agriculture. The long-standing focus on conventional agriculture, which relies heavily on intensive input use, has persisted for many years. However, with the emergence of environmental issues associated with conventional agriculture, discussions have begun regarding the impact of chemical input use on sustainable agriculture. As a result, in order to mitigate the harmful effects of conventional agriculture, there has been a growing importance placed on good agricultural practices, which are one of the sustainable farming systems.

The inability to fully address food security and poverty issues in Turkey has delayed the emergence of environmental concerns and, consequently, the widespread adoption of good agricultural practices. In terms of the number of producers and the area under cultivation, the Southeastern Anatolia Region ranks first in implementing good agricultural practices. Considering the importance of protecting human health and the environment, it is necessary to increase farmer awareness of good agricultural practices in other provinces as well.

As a result, increasing smart agricultural approaches and good agricultural practices is vital to achieve sustainable development goals. These strategies not only increase efficiency and productivity in farming, but also support environmental sustainability, economic sustainability and social equity. This paragraph have to be in discussion section

CONCLUSIONS

Looking at current practices, it appears that agricultural policies do not aim for a fundamental shift towards strong sustainability. While sustainable agriculture creates more opportunities for developing countries, they face many challenges on the path to this goal. Governments of these developing economies need a proper and comprehensive assessment of the level of digital transformation implementations and the sustainability of the agricultural sector.

There may be additional channels, such as the effectiveness of government policies, the level of economic development, and the performance of economic complexity and digitalization, which impact sustainable agriculture to varying degrees of significance.

Smart farming technologies enable farmers to optimize resource use, reduce waste and increase crop yields. These innovations contribute significantly to food security and the resilience of agricultural systems in the face of climate change and other challenges.

Meanwhile, good agricultural practices provide a framework for sustainable agriculture that ensures the health and safety of both producers and consumers. By adhering to standards, farmers can produce quality, safe and environmentally friendly products. These practices cover a range of activities including soil management, water conservation, pest control and animal welfare, all of which are essential for sustainable agriculture.

Expanding smart farming approaches offers a holistic solution to many problems facing modern agriculture. It supports the creation of a more sustainable food system that can meet today's needs without compromising the ability of future generations to meet their own needs.

Ultimately, successful implementation of these practices requires collaboration between governments, private sector stakeholders, and the agricultural community. Policies that support innovation, education and infrastructure development are vital to facilitate the adoption of smart technologies.

By fostering an environment that encourages sustainable agricultural practices, we can take important steps towards achieving the sustainable development goals, ensuring a healthier planet and prosperous future for everyone.

Future research should consider these issues to provide more insightful lessons for economists and policymakers in designing policies that promote digital transformation and sustainable agriculture in these economies.

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Research Methodology: An Agricultural Perception

Suleiman USMAN[1*], James O. JAYEOBA[2], Muhammad Maikano ARI[2], Sani Mathew AMANA[2]

[1*]*Department of Soil Science, Faculty of Agriculture, Federal University Dutse (FUD), Jigawa State, Nigeria.*

[2]*Department of Agronomy and Animal Sciences, Faculty of Agriculture, Nasarawa State University Keffi, Nasarawa State, Nigeria*

[*]*Corresponding Author: labboallugu@yahoo.com*

[*]*ORCID: 0000-0002-7108-2213*

Abstract

Research methodology is a combined principle that focuses on 'research' and 'methodology'. The term research was considered a systematic activity directed towards discovery and the development of an organized body of knowledge, whereas methodology was considered a concept that refers to the overall approach taken in a piece of research. This concept was viewed as a scientific procedure for solving various problems related to research objectives and questions. This paper discussed the concept of research methodology from an agricultural perspective as a qualified and supportive profession in an academic environment. The context has provided an advanced explanation of important subjects that focused on solving many simple and complex glitches in agriculture and sciences. The paper maintained that this research was a systematic and theoretical analysis with different scientific methods, different principles, and different applications. From a universal perspective, a logical scientific approach has been developed to help provide an advanced understanding of the general meaning and complex theories involved in the field of research and its scientific methodology. To expand this advanced understanding, different types and classes of research, farming system research (FSR), and theories related to research and experimental designs, steps involved in achieving the best scientific research, research hypotheses, statistical analysis, and research software, are covered. Soil testing techniques have been used as specialized examples to demonstrate the relevance of various laboratory research approaches and to allow researchers to ensure that findings and data information are valid and scientifically accurate.

Keywords: Research, Methodology, Experimental Design, Statistical Hypothesis

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INTRODUCTION

Research methodology is a compound word that combines the general meaning of two important words, 'research' and 'methodology'. In agriculture and related sciences, research methodologies include specific research methods, which play key roles in conducting experiments in the areas of mixed cropping, weed control, fertilizer use, crop physiology, irrigation and trials on perennial crops, animal and poultry management, forest and fishery productivity, and soil and environmental analyses.

It is a scientific approach that also employs the use of statistical hypotheses and tests of significance, including a review of correlation studies (linear and quadric), experimental designs, partial and multiple regression analyses, analysis of variance, and descriptive analyses of different kinds (Govindasamy, 2023). Today, research methodology is advancing, as it becomes all-inclusive, inviting many different technologies into it. Computer applications in agriculture and other fields of science (Kumar & Sarkar, 2015; Borrelli et al., 2021), statistical analysis and software applications (Honfo et al., 2019), mobile apps and their procedures (Choudhary et al., 2022), and remote sensing and practical applications (Usman et al., 2020) are becoming increasingly popular research methodologies. Many research objectives have been achieved with the theories and practices of research methodology. This has emphasized the critical need to understand the true meaning of the words 'research' and 'methodology' in global academic clarifications. This is important because it can help researchers better plan studies by identifying the most suitable approaches and techniques involved in research (Kapoor, 2016; Kothari, 2019; Lau, 2023). At this junction, the two questions that need to be answered are 'what is research' and what is 'methodology'. This paper is logical and based on the different opinions and contributions of several authors to help answer these two important questions. This is in addition to different types of research and research methods in relation to field and laboratory techniques for soil testing and soil data evaluation. The experimental design, statistical hypotheses and software used for the tests of significance are also covered. This section discusses the comprehensive meaning of what research is and how it is important for academic development, economic development and decision-making.

RESEARCH: *CONCEPT AND RATIONAL*

The concept of research is very broad and comprehensive because of its relevance to all areas of study, academically, as well as its original contribution to the existing stock of knowledge in various subjects. Research may be broadly defined as the systematic gathering of data and information and its analysis for the advancement of knowledge in any subject (Kothari, 1985). The term 'research' is believed to comprise defining and redefining problems; formulating hypotheses or suggested solutions; collecting, organizing and evaluating data; making deductions and reaching conclusions; and, at last, carefully testing the conclusions to determine whether they fit the formulating hypothesis (Clifford Woody, 1884-1948). This principle has included the manipulation of things, concepts or symbols for the purpose of generalizing to extend, correct or verify knowledge, whether that knowledge aids in the construction of theory or in the practice of an art (Slesinger & Stephenson, 1930). Thus, research can be regarded as an activity that leads us to find new facts and information, assisting us in verifying the available knowledge and in making us, question things that are difficult to understand as per existing data (UOU, 2010).

Waltz & Bausell (1981) considered research to be a systematic, formal, rigorous and precise process employed to gain solutions to problems or to discover and interpret new facts and relationships. John (2005) defines research as a systematic activity directed towards discovery and the development of an organized body of knowledge. Academic researchers are scientific and provide valuable information for knowledge propagation. Gilmor et al. (2023) noted that scientific research aims to answer questions and acquire knowledge concerning natural phenomena and to describe, predict, and explain these natural phenomena.

Through research, specific goals can be achieved by outlining an objective, deciding which discipline to study, and understanding which different lab techniques can produce data for a chosen hypothesis; this is important because the continual growth of knowledge drives development and new advances for a stronger future and better understanding of the global economy, food security, climate change, sustainability and human health development (Gilmor et al., 2023).

Methodology of research: *an overview concept*

Methodology can be defined as a concept that refers to the overall approach taken in a piece of research (Sim & Wright, 2002). It can also be defined as a scientific procedure for solving various problems related to research (Top4u, 2022). This finding indicates that the research methodology is a supportive profession in the academic research environment that focuses on solving many simple and complicated problems in agriculture and sciences. It is the systematic and theoretical analysis of the methods applied to a field of study and comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge (UOU, 2010). This means that the research methodology employed the use of many research methods and experimental designs, which help researchers, achieve objectives of great value in different fields of study. It has been considered a field of science that guides researchers in conducting studies in both the field and laboratory, both in situ and ex situ based, digital or computer based. Research methodology also consists of theories and practices that help researchers conduct assessments either practically or theoretically, and this has been the result of two major research papers – a review paper and a non review paper. Thus, the scientific method that is adopted for conducting any type of research either in agriculture or any field of science is called methodology (Kothari, 2019). It generally involves the reporting and interpretation of data, as well as guidelines for the detailed application of various methods and collection of results (Norris et al., 2015; Larson-Hall & Plonsky, 2015). The critical study of the methodology adopted in various laboratory and field techniques (Safdar et al., 2016; Lau, 2023) has involved the use of different advanced approaches and procedures, which support soil and plant analyses, animal studies, forest assessments, environmental observations, and medical health care systems (Harris et al., 2006; Kothari, 2019).The research methodology can be understood as a set of specific procedures or techniques used to identify, select, process, and analyse information about a topic (UOU, 2010).

Research: *its basic characteristics*

The characteristics of research determine whether the research is free of biases, partialities, prejudices, favouritism, preferences and subjective errors. They control the purity of the research and make it pure and original. These characteristics can be summarized as follows: (a) generalized (degree to which the result of a study can be applied to a larger population), (b) controlled (measured, defined and precise), (c) rigorous (relevant, appropriate and justified), (d) empirical (experimental, observed and realistic), (e) systematic (organized, efficient and logical), (f) ethical (abided by ethical standards), (g) reliability (repeatability of a study, tool, procedure, or instrument), (h) validity (suitability and efficiency of the research instrument or procedure), (i) hypothesis (assumption and formulation of theories), (j) analytical and accuracy (correctness of instruments, procedures and tools), (k) credibility (trustworthy of all the sources), and (l) critical (scrutiny of the procedures used and the methods employed, foolproof and free from drawbacks) (UOU, 2010; Top4u, 2022).

These wide ranges of research characteristics make the research unique and exceptional. They stand firm to assist and guide the researcher to achieve their set of objectives and purposes. They ensure that the research contributes to global scientific knowledge, economic development, and decision making.

Research on farming systems: *a theoretical concept*

Farming system research (FSR) is aimed at verifying the technological options for ensuring food security and improving the welfare of a growing population worldwide. SRFs are considered by Upton (1987) to have four main characteristics, which can be described as scientifically focused on (a) farm households recognizing that rural changes and development ultimately depend on rural people whose existing practices are well adapted to environmental constraints and household objectives, (b) specific localities where large differences between these localities exist in the resource base and in the farming systems practiced, (c) holistic systems that are concerned with the whole farming system and its interdependencies rather than with individual elements, and (d) multidisciplinary systems that integrate the perceptions of both the technical and the social sciences to analyse existing systems and to identify options for improvement. A complete depiction of these four main characteristics of FSR is shown in Figure 1. However, four main stages are involved: description and diagnosis, design of improved systems, testing and evaluation of improved systems, and implementation and extension of promising alternatives (Upton, 1987).

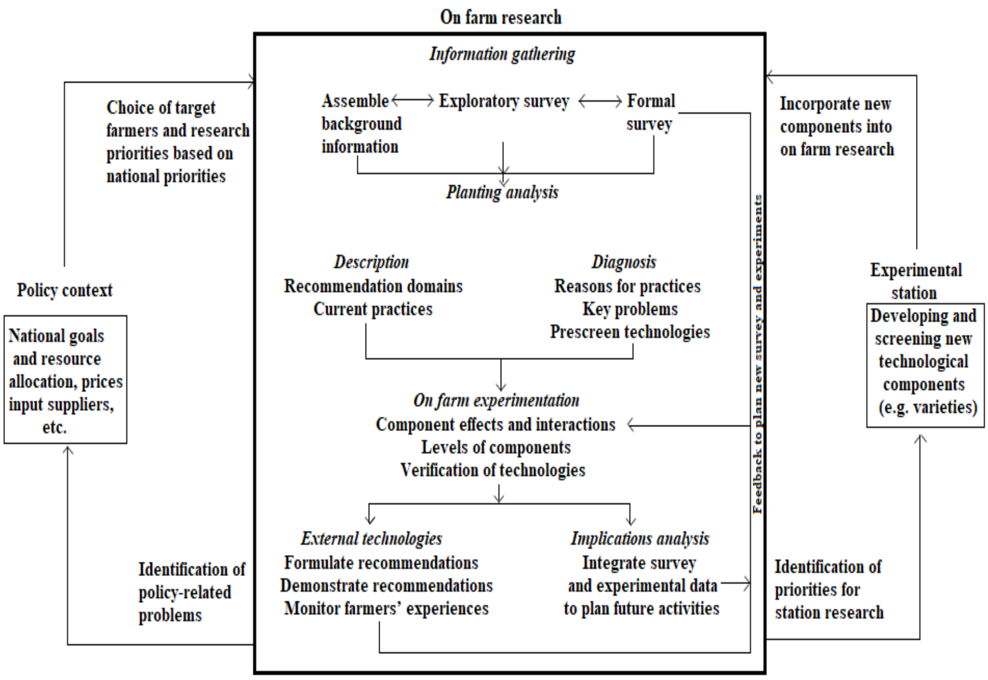

Figure 1. Farming system research cycles (reconstructed by S. Usman after Upton, 1987)

Research methodology: *various types*

Different established research methodologies can be employed to explore a research problem or to help researchers validate hypotheses through clearly defined parameters, environments and assumptions (Physiopedia, 2023). However, these various types of research can be used for the detailed achievement of farming system research cycles, as depicted in Figure 1.

We described and modified them below based on the combined information obtained from different texts (Hedrick, et al., 1993; UOU, 2010; Kapoor, 2016; Suresh, 2016; Safdar et al., 2016; Kothari, 2019; Lau, 2023).

- ***Descriptive research:*** This research methodology entails conducting surveys and fact-finding investigations across various domains to elucidate the contextual factors pertinent to a specific study. Ex post facto research methodology has been utilized to expand upon this approach in diverse fields such as agriculture, environmental science, and biology. Its defining characteristic lies in the researcher's lack of direct control over variables, thus limiting them to reporting observed or past occurrences within the study. For instance, agricultural studies could be employed to examine the disparities in soil fertility decline and food security threats between the populations of northern Nigeria and north eastern Nigeria. In these two instances, the researcher observed that the soil fertility declined as a result of poor management and lack of good vegetation cover, and the high cost of rice was the result of production scarcity in the region. Researchers could further hypothesize that poor management practices and bare vegetation are the main reasons for the decline in soil fertility. Similarly, he could also hypothesize that production scarcity is a factor in the high cost of rice. The techniques to be employed in these hypotheses can be decided upon by the researcher based on the descriptive nature of these studies. Selection can be made from various techniques available and suitable for the environment where the research is to be conducted.
- ***Analytical research:*** This type of research employs the use of the facts, information and data that are already available and that can be restudied, observed and analysed by the sources to make a further detailed hypothesis for the evaluation of the materials involved. It involved more logical investigation and questioning. This is illustrated by methodological data on rainfall, temperature, and relative humidity, which can be analysed to determine why drought occurs, what factors are responsible for sudden climate change, why flooding increases, etc.
- ***Applied research:*** This type of research refers to finding a solution for a specific and practical problem that is faced by an individual, society or an industrial or business organization. A typical example is how to control erosion or deforestation, what are the most advanced soil and water conservation techniques for irrigation projects, what measures can be used to increase food production, etc. This means that the main aim of applied research is to determine a solution for some critical practical problems.
- ***Fundamental research:*** Fundamental research, also known as *basic research*, is primarily concerned with the summary and formulation of a given research theory. It is a basic type of research that focuses on, for example, whether plant stunting or deformation influences how crop yield decreases or how soil fertility decreases influences how nutrients are limited in soil. This means that fundamental research is management towards finding information that has a wide sense of applications to the already existing organized body of scientific knowledge. It basically takes one of these forms – discovery (finding new explanations or ideas), invention (designing new methods) or reflection (analysing theories, models and techniques).
- ***Quantitative research:*** This type of research is based on quantity, amount, measurement, extent, size and magnitude. It is related to an object that can be expressed in terms of quantity and can be measured. Systematic experimental analysis of something that can be observed and counted through statistical analysis, mathematical calculation or computational techniques, especially in a numerical form, is generally used.

Examples include the measurement of percentage soil texture (sand, silt and clay), the measurement of gully erosion (in cm or m) in terms of width, depth, length or size, the measurement of soil nutrient budgets, the measurement of plant parameters (stem height, leaf size, root depth, etc.), and even the counting of the number and population size of forests and vegetation. Most of these studies can be digitally and computationally measured in more detail.

- ***Qualitative research:*** This type of research is concerned with qualitative and valuable phenomena. It is significantly related to quality, values and variety of something, e.g., the colours of the soils, quality of seeds, and values of rice. These research phenomena are characteristically descriptive and imaginative and, as such, very difficult to assess in terms of quantity. This means that qualitative research is primarily focused on visual assessment of the natural appearances of something in a more descriptive manner. It is not the same as numerical analysis where data can be measured or calculated. Examples include the classification of vegetation types based on physical and natural appearances and the definition of soil based on its natural colours and morphological properties.
- ***Conceptual research:*** This type of research is related to theoretical and intangible ideas, which can be built as a general concept towards achieving given objectives. Conceptual research is a theory that focuses on perception and philosophy, which can explain a particular concept being studied. It is generally used by logicians, philosophers and theorists, primarily to develop new concepts or to support and back existing theories. Examples include environmental security theory, the soil quality concept, the theory of diminishing returns, the theory of water quality, etc.
- ***Empirical research:*** Empirical research is a type of research that greatly relies on experience, practice, assessment and pragmatics. Research that helps researchers gain more knowledge by means of direct and indirect observation or experience. This means that empirical research skills are built and acquired through regular observations and, as such, can be regarded as an experimental type of research.
- ***Correlation research:*** This type of research defines the relationship among two or more variables without necessarily determining the cause and effect of this relationship. Examples include a correlation between dryland soils and fadama soils, a correlation between drought and rainfall scarcity, and a correlation between soil fertility and crop yields. This type of research helps researchers collect much information on a wide range of variables from different parts for a detailed explanation, although information regarding the causes is very limited.
- ***Ethnographic Research:*** This type of research involves the study of culture, values, religion and norms of people, society or nation. It comprises a systematic narration, collection, description, and detailed analysis of data for the development of theories of cultural behavior in society. This involves the sociological assessment of people's ethnic groups, agricultural values and culture, social welfare characteristics, and customs. In many cases, this type of research is conducted through questionnaires or verbal interviews, observations and descriptive data gathering.
- ***Experimental research:*** Experimental research is a type of research that focuses on the objectives, purposes and systematic of study. It is primarily established to predict and control phenomena. It also includes investigating, scrutinizing, and examining the probability and causality among variables. Example of an explanation of the dependent and independent variables of different soil samples. This type of research is important for determining the main causes and effects of the relationships between these different soil samples, although artificiality, feasibility, and unethical issues may exist.

- ***Exploratory research:*** This type of research is established for a given problem that has not been clearly defined. It basically helps to regulate the best research design, the best data collection method and the best subjects' selection for the research, and it is also quite informal and relies on secondary research. Example?
- ***Generalized research:*** This type of research exists in a situation where a researcher usually divides the identified population into smaller samples depending on the resource availability at the time of the research. This sample is understood to be the appropriate representative of the identified population, so the findings should also apply to the entire population.
- ***Structured research:*** Structured research is usually classified as quantitative research. This is because everything that forms the research process, such as objectives, design, sample, and questions, is predetermined. It is more appropriate to determine the extent of a problem, issue or phenomenon by quantifying the variation, e.g., how many soil samples have a microbial organism or plant biomass?
- ***Unstructured research:*** Unstructured research is usually classified as qualitative research because it allows flexibility in all aspects of the research process. This means that it is more appropriate to explore the nature of a problem, issue, or phenomenon without quantifying it.

Other research types: *environment-based opinions*

Similarly, research can be classified as *in situ* or *ex situ*, field or laboratory, social or scientific, or digital or analogue, depending on the nature, conditions and objectives of the research. Likewise, research can be classified based on a given subject area of study, e.g., soil research, crop research, animal research, forest research, fish research, water quality research, biological research, geological research, criminological research, environmental research, and clinical research. They can also be classified based on resources, e.g., natural resource research, vegetation research, petrochemical research, crude oil research, and gold research. These different types of research are established based on their individual nature and period; for example, field-setting research, laboratory research or classical research can be conducted. In this regard, the research is fully dependent upon the environment where it is decided to be conducted. For example, in soil science research that employs soil surveys (Usman & Usman, 2013; Usman, 2016), the type of research in this regard is fully dependent upon the nature and objectives of one of the following types of survey research: detailed (digital and detailed mapping), reconnaissance (maps based on observations), and detailed-reconnaissance (semi-detailed maps based on traditional procedures and scientific theories) (Usman et al., 2020). The type of research in this survey can be detailed research or descriptive research, which, in any option, has to employ the comprehensive stages and methodologies required (Usman et al., 2020).

However, because these illustrations are limited to various studies conducted in the field of agricultural science, many studies have shown them as an exemplary concept. For instance, for studies published in 2020, significant contributions have been made. Typical examples of these studies include conservation agriculture for regenerating soil health and climate change mitigation (Jat et al., 2023); advancing climate change mitigation in agriculture while meeting global sustainable development goals (Lal, 2020); assessing the impact of climate change on dryland agricultural systems (Ahmed et al., 2022); assessing soil quality for the rehabilitation of salt-affected agro-ecosystems (Basak et al., 2022); advancing soil and water management for dryland areas (Biazin et al., 2023); determining the future of soil, water, and air conservation (Delgado et al., 2020); estimating the global potential of water harvesting from successful case studies (Piemontese et al., 2020); applying big data processing technologies in agriculture (Ayyappan & Gnanasekaren, 2022); sustainable intensification in cropping systems through the inclusion of legumes (Lalotra et al., 2022); setting innovation free in agriculture (Sheldrake, 2021); identifying pesticides in soils and plants (Usman, 2020); and investigating cropping systems in agriculture and their impact on soil health (Yang et al., 2020). These volumes of studies have been achieved through the adaptation of methodologies and procedures/techniques involved in the various types of research highlighted above. A detailed understanding of these procedures or methodologies has helped researchers understand the techniques involved in conducting their various studies. These techniques require specific attention when conducting research (Kothari, 2019).

Research: ***its classification and significance***

The various types of research presented above can be classified further into categories depending on the viewpoint under which the research activity is initiated and conducted (UOU, 2010). This classification grouped them into three categories: (a) application of research study, (b) objectives in undertaking the research, and (c) inquiry mode employed for research. The application of research study comprises the pure, basic, fundamental, applied or decisional types of research. The objectives include descriptive, exploratory, and correlation, among others. The inquiry mode covered both saturated and unsaturated research. Similarly, research can be classified based on its methodology, which includes both quantitative and qualitative research. Additionally, research can be classified according to its nature, such as systematic activity, empirical evidence, logical processes, and control (Top4u, 2022). However, on the basis of the extent of the theory, research can also be classified as theoretical or empirical. Therefore, research has a wide range of significance in the sciences and policy development. According to some studies (e.g., Kapoor, 2016; Kothari, 2019), research plays a significant role in providing vital information for academics, economic development and policies or decision-making. Management in these three areas can be substantially improved in the following ways (Top4u, 2022):

- **Recognizing the potential opportunities and threats:** Research is a tool or an X-ray machine that can help management scan its environment and identify various existing opportunities and problems. This means that it is important for management to be successful in formulating strategies in accordance with these situations to overcome the prevailing problems and exploit the opportunities available to the completes.
- **Assessment of problems and opportunities:** Research allows managers to identify the existing problems and the factors responsible for the problems. It helps them to identify, explore, refine and quantify the opportunities existing in the environment and to set priorities in the case of multiple opportunities.
- **Selection of the best alternative action:** This research can assist managers in selecting the best among the alternative courses of action. This means that through research, various alternatives can be evaluated using specific evaluation criteria set by the researcher.
- Evaluating the course of action: Research allows managers to estimate the extent to which a given activity or project is executed according to the direction. This helps them to identify the potential factors that can affect the execution and control the strategies implemented for this execution.
- **Analysing competition:** This research allows managers to formulate strategies that can help them achieve their targets.

Research: ***step-by-step process***

The general body of research and its components, types and classifications require a step-by-step process to make it unique and scientific (Kapoor, 2016; Kothari, 2019). This step-by-step process is important because of its relevance to research objectives, research questions, methodology, and result interpretation. We described and modified these steps below based on agricultural perspectives, as reviewed in the literature (Upton, 1987; Hedrick et al., 1993; Kapoor, 2016; Kothari, 2019; Gilmor et al., 2023).

- **Selecting the research topic:** Selecting the research topic in agriculture must be related to its major machineries, which include agronomy, animal science, agricultural extension, forestry, fishery and soil science. Any topic to be selected needs to have these major agricultural machinery elements. For example, studies related to soil science should focus on the nature, properties and conditions of soils, such as assessments of soil erosion, soil profile diagnoses, or measurements of soil infiltration rates.
- **Defining the research problem:** Ensuring food security and animal productivity is crucial. Therefore, the agricultural research problem should be defined clearly and precisely because it can serve as a solution to whole-body problems. For example, research that focuses on soil erosion should define all the problems that have contributed to the occurrence of erosion and the methodology to be used for solving them.
- **Objectives of the research:** Identifying the objectives of the research is vital because it prevents the research from going outside the main context for which it was purposely established. When research objectives are outlined, it will be easy for a researcher to know the basic research questions involved and the direction for solving them. This will guide him in selecting appropriate methods and techniques for the research.
- **Literature review:** A review of the related and relevant literature on the topic selected is crucial. This will allow the researcher to examine previous studies that have been conducted in this area. The survey of the studies in the area of the topic selected will equip the researcher to develop excellent research by choosing the best methods to conduct his own assessment. Indeed, a literature review is the backbone of any research.
- **Design of hypothesis:** Identifying the potential variables of the study is the first step in formulating the hypothesis. Designing the theory for the research will help the researcher understand the real meaning of objectives and how research questions can be answered through more detailed analysis.
- **Research design:** The research design will help the researcher determine the necessary tasks to perform at each step of the research. It will guide him in outlining the various methods and techniques required as well as ensuring that these methods and techniques are appropriate for the research.
- **Sample design:** The sample design defines the number of items to be best included in the sample. It will help the researcher determine how the research design should be performed before the data are collected.
- **Data collection:** This step is the backbone of the research data. The results should be collected according to the objectives of the research. The data collected should be the answers to the research questions formulated. This information should be gathered for analysis and detailed discussion and interpretation. Data collection plays a vital role in merging theories with their practical applications in research.

- **Implementation of the research project:** This step ensures the correctness and reliability of the collected data. The use of questionnaires, which are scheduled for collecting factual information in tabular or lists form, is vital. This will allow the researcher to generate more vital information regarding the data collected through either question-and-answer sessions or verbal interviews. The data collected will be coded in this regard for detailed analysis.
- **Data analysis:** This step employed the use of statistical analysis of the data collected. It will guide the researcher to understand the true meaning of the data collected, how relevant it is to the general context of the topic studied, and the true answers to the objectives and questions of the research. Different formats are available for this analysis, and the data can finally be visualized with the help of tables, graphs, charts, etc.
- **Hypothesis testing:** The hypothesis can be tested using certain statistical calculations to check the accuracy of the data and results. In this regard, a hypothesis is said to be accurate if it shows the true differences and does not contain an error or fault.
- **Result interpretation and discussion:** General discussion can be made from the data analysed and hypothesized. The research should be able to explain all aspects of the results and relate them to the context of previous and present literature. He will be able to generate the real meaning of the study and explain what exactly observed.
- **Research report:** This step is the final step and involves the preparation of the overall report, which can be published or printed as a reference for decision-making, forthcoming research, academic records, and teaching purposes.

VARIOUS LABORATORY TECHNIQUES: *A WAY FORWARD*

Research, as a scientific tool to study many things (John, 2005) can be carried out using various methods and techniques, which are referred to as 'research methods' or research methodologies (Kothari, 1985). This means that research methods are tools and techniques for analysing and collecting data to solve many problems in academics, economics and decision-making (Top4u, 2022). The types of data collected using the various research techniques are primary and secondary. The primary data are original data that have been collected specifically for the purpose in mind, whereas the secondary data are collected by anyone other than the user (UOU, 2010). Thus, understanding various techniques involved in research would allow the researcher to ensure that findings and data information are valid and, inevitably, troubleshoot when results are not obtained (Gilmor et al., 2023). Laboratory techniques are the backbone of evaluating soil and plant nutrients, biological phenomena, and microbes (Gilmor et al., 2023). The laboratory techniques also include the use of chromatography (liquid chromatography, gas chromatography, or high-performance liquid chromatography) for separation purposes and a spectroscopic technique (UV–visible spectroscopy, NMR, or MS) for detection (Shafi & Zahoor, 2021). These techniques provide us with new opportunities to access natural products in a metabolic context and serve as potential untouched goldmines for future herbal-based medicine and pharmacologically active compounds (Shafi & Zahoor, 2021).

Many modern laboratory techniques have been developed and used for different research. There are significant developments in the fields of agriculture, health, and computer sciences. For example, in the field of animal science, Bellairs & Osmond (2014) reported the use of modern laboratory techniques with chick embryos, including 'milking' of hens to obtain cleavage stages by inducing early laying, incubation procedures, traditional and modern labelling techniques that are particularly useful in gastrulation studies, ex-plantation of the blastoderm, whole embryo culture methods, *in ovo* techniques, grafting of tissues, injection methods, the preparation of serial sections and the handling of early stages during the preparation of embryos for electron microscopy. These methods have provided advanced procedures in poultry and animal production for a wide range of economic development. In human health science, Kalaitzopoulos et al. (2016) noted that advanced laboratory techniques and progress in clinical diagnosis technologies have led to an unprecedented increase in the real-time production of data that are large in terms of volume (large amount), variety (different types/sources), velocity (massive output), variability (high inconsistencies), veracity (great range of qualities), and complexity (substantial interconnections). This has also led to automated genome sequencers becoming less expensive in such a way that even small labs can turn into generators of big data on their own since these data sets are generated at high velocities where data are captured, analysed, and shared (Kalaitzopoulos et al., 2016). These advancements in generating various data from the laboratory have also occurred in the field of soil science, where big data for physical, chemical and biological soil properties are captured and shared for soil and water conservation, irrigation, plant health and protection, and yield performance (FAO, 2020). This is quite true for most laboratory studies, such as biomedical analysis, plant analysis and biophysical analysis. To this end, it is important to demonstrate some of the advanced laboratory techniques applicable to agriculture and its major components, especially soil and crop science.

Soil testing techniques: *specialized examples*

This collection of soil testing techniques is part of a global farmer-to-farmer training initiative and student–student practical analyses, which aim to increase the knowledge of farmers across the world on soils through training (FAO, 2020). There are two-way rounds that are more or less related to rapid and laboratory analysis. According to the FAO (2020), analytical work in a soil testing laboratory mainly involves standard chemical methods that are suitably modified to permit the handling of a large number of soil samples with the required degree of accuracy and speed, many of which are carried out more conveniently with the help of common and more sophisticated instruments. On the other hand, rapid soil-testing kits, which are critical to soil health - a theoretical concept of on-farm soil testing - has been developed to simplify the analysis of soil physical, chemical and biological parameters in the field (FAO, 2020). This concept employed the use of the Soil Doctors Toolkit and Soil Testing Kit (STK) (FAO, 2020), Soil Colour Charts (Munsell, 1975), Field Book for Describing and Sampling Soils (USDA-NRCS, 2002), Keys to Soil Taxonomy(Soil Survey Staff, 2010), Visual Soil Assessment: a Field Guide (Shepherd et al., 2008), Guidelines for Soil Descriptions (FAO, 2006), Practical Pedology: Studying Soils in Field (McRae, 1988), and Soil Quality Test Kit Guide (USDA, 2001). These sets of soil testing kits and guidelines for soil descriptions in the field contain some equipment (e.g., measuring tape, pH kits, chemical kits, soil augers, shovels, poles, etc.) and resource information that is commonly used to take a deeper look at soils in the field (FAO, 2020).

Many methods have been considered for the assessment and analyses of soil physical, chemical and biological properties in the field (USDA, 2001; McKenzie et al., 2002; Rodrigues de Lima & Brussaard, 2010; Mylavarapu et al., 2020). These include the following as highlighted by FAO (2020):

- ***Physical property methods:*** These methods include the Feel method, Ribbon method, and Shaking test method for ‘Soil texture’; the Core method, Excavation method and Clod method for ‘Bulk density’; the gravimetric water content method, volumetric water content method, Feel and appearance method, and soil moisture determination by tensiometry for ‘Soil moisture’.

- ***Chemical property methods:*** These methods include the soil pH meter method, color card methods, soil pH test strips, and Vinegar and baking soda tests for soil pH; electrical conductivity, electrical conductivity using a saturated paste, electrical conductivity using the 1:1 ratio method, the presence of sulfates and chlorides, and field symptoms (visual symptoms of soil salinity) for soil salinity.
- ***Biological property methods:*** These methods include the earthworm density method, litter decomposition (tea bag method), active/labile carbon method, and soil respiration (soda lime) method.

However, laboratory techniques, which are largely based on diverse assessments of physical, biological, and chemical properties, employ the use of advanced instruments that, in many cases, use reagents and electrical light spectra for the detection of a particular nutrient or property (King et al., 2003; Robards & Ryan, 2022). The different soil laboratory instruments used were manufactured by Hoskin Scientific Ltd. (2013) and ICAR-DCR (2017). Typical examples of some of these instruments being applicable to most of the soil science laboratories in Africa are explained below.

- ***UV–Visible Spectrophotometer (Double beam):*** This instrument is used to measure P, Mo, and B in soil, plants, water, manure, fertilizers, and pesticides. It is also used for qualitative and quantitative DNA, RNA, and protein analyses. The instrument has third-dimensional spectrum utility for sample analysis and possesses various operational modes, such as standard, photometric, spectral, quantitative, kinetic, time scan, DNA and protein quantitation, in standalone and PC modes.
- ***Microwave digestion system:*** This instrument is used for the digestion of various materials in soil, plant, manure, sediment, food, and rock samples. The microwave power rating was 1900 Watts, and the cavity size was 70 litres.
- ***Refrigerated centrifuge:*** This instrument is used for isolating and separating suspensions and immiscible liquids. It is also used for DNA preparation and macromolecular separation. It can be used simultaneously for the removal of unwanted debris to make a clear solution for analytical use in spectrophotometers, HPLC, and GLC.
- ***Water distillation system:*** This instrument has two forms of applications: single and double. The two applications served the same purpose: the preparation of distilled water.
- ***Top loading precision balance:*** This instrument is used for accurately weighing soil samples and chemicals.
- ***pH meter:*** This instrument is used to measure soil pH and reagents.
- ***Digital conductivity meter:*** This instrument is used for measuring electrical conductivity and salt concentration in soil and solution.
- ***Water bath shaker:*** This was used for shaking and mixing the soil sample at the desired temperature.
- ***A magnetic stirrer with a hot plate*** was used to mix reagents with the help of a stirring bar, and heating was used to increase the solubility.
- ***Rectangular plate with a thermostat:*** This thermostat is used to heat chemicals, solution, and media.
- ***air oven:*** This instrument is used for drying plant samples, estimating soil moisture, and frying glassware and plastic waste.
- ***A vortex mixer:*** This was used to mix the samples quickly in the test tube.
- ***Labline Centrifuge:*** This instrument served the same purpose as a Hot plate rectangular with a thermostat, i.e., to heat chemicals, solution and media.

- ***DK 20 Digestor (plant sample digestion system):*** This instrument is used for the digestion of plant samples for elemental analysis and the digestion of soil samples for total nutrient analysis.
- ***The nitrogen analyser*** and refrigerated water-cooling circulation system was used to estimate the different forms of nitrogen in the soil and the nitrogen and protein contents in the plants.
- ***Horizontal Rotary Shaker:*** This instrument is used for shaking soil, plant samples and chemicals. It is closely related to the use of a water bath shaker.
- ***BOD Incubator:*** This indicator is used for the estimation of biological oxygen demand.
- ***Microwave oven:*** This oven is used for media preparation and reheating.
- ***Laminar air flow chamber:*** This chamber is used for providing contamination-free areas for microbiological studies.
- ***UV face shield:*** This shield is used for eye protection and safe operation under radiation.
- ***A colony counter (Digital)*** was used for counting the colonies.
- ***Microscope:*** This instrument is used for normal visualization of soil particles and soil organisms.
- ***Soil Gas Lance:*** This instrument is used for extracting soil gas from unsaturated soils. It has a semi-permeable hydrophobic membrane that is permeable only for gas and not for solution; thus, it has the functional power of not picking even moisture from the soil.

The detailed context of the general procedures and step-by-step analysis of physical, chemical and biological soil properties, using the above soil instruments in the laboratory, can be accessed from various soil laboratory manuals, such as Determination of total, organic, and available forms of phosphorus in soils by Bray & Kurtz (1945); Techniques for measuring soil physical properties by Archer & Marks (1977); Methods of soil analysis by Klute & Page (1982); Total carbon, organic carbon and organic carbon by Nelson and Sommers (1982); Soil plant analysis by Estefan & Rashid (2002); Soil Science Laboratory Manual by King et al. (2003); Determination of soil nutrients (NPK) using optical methods by Revati et al. (2021); Planar chromatography: Principles and Practice of Modern Chromatographic Methods by Robards et al. (2022); etc.

EXPERIMENTAL DESIGN AND HYPOTHESIS

Experimental/research design can be defined as the conceptual structure within which research is conducted, and its function is to provide for the collection of relevant information with the smallest possible input in terms of effort, time, and money (UOU, 2010). However, in the book Statistical Procedures for Agricultural Research by Gomez & Gomez (1984), the statistical hypothesis and experimental design are explained in a much harmonized scientific manner. According to these authors, theoretical considerations are vital in playing a major role in arriving at a hypothesis; for example, it can be theoretically shown that a rice crop removes more nitrogen from the soil than is naturally replenished during one growing season. Therefore, in this case, one may hypothesize that to maintain a high level of productivity on any rice farm, supplementary nitrogen must be added to every crop. However, once a hypothesis is framed for possible testing (e.g., Figure 2), the next step is to design a procedure for verification, which usually consists of four phases:

- The appropriate materials for testing were selected.
- Specifying the characters to measure,
- Selecting the procedure to measure those characters, and
- Specifying the procedure to determine whether the measurements made supported the hypothesis.

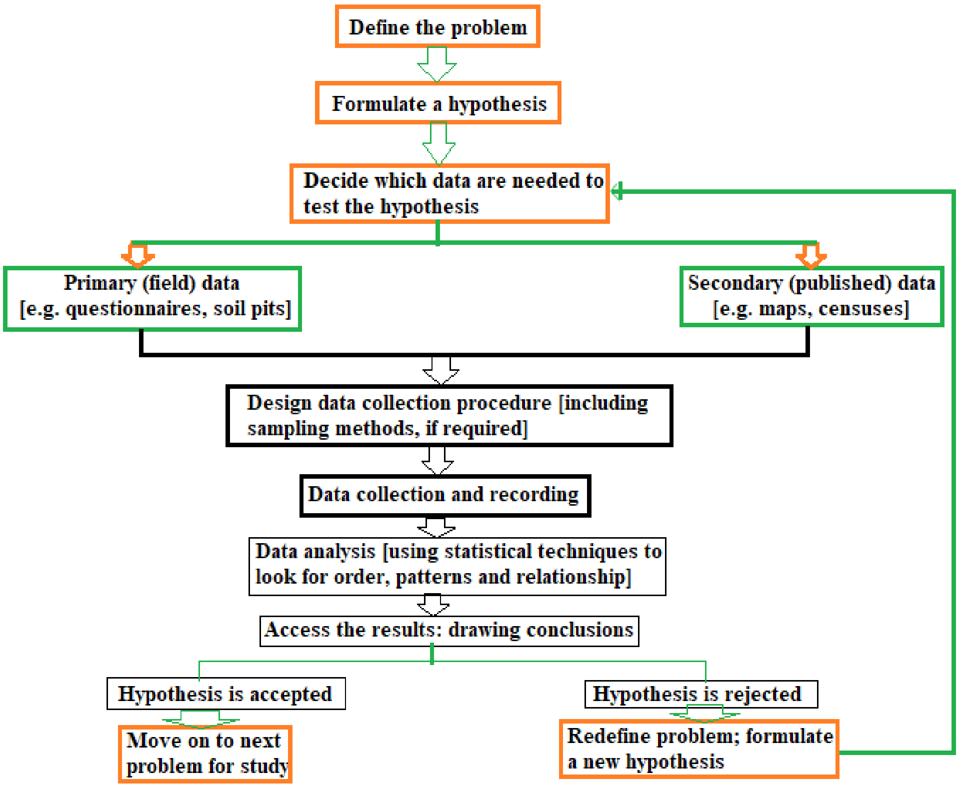

Figure 2. Hypothesis testing (Reconstructed by S. Usman after Waugh, 2000)

On the other hand, the procedures regarding how the measurements are to be made and how these measurements can be used to prove or disprove a hypothesis depend heavily on techniques developed by statisticians. According to Gomez & Gomez (1984), these two tasks constitute much of what is generally termed the design of an experiment, which has three essential components: (a) estimate of error, (b) control of error, and (c) proper interpretation of results. The scale and duration of the design stage depend upon whether appropriate technologies have already been developed and available on the shelf to be taken down and used when needed (Upton, 1987). This means that if this is not the case, then substantial scientific and technical research programs may be required to produce new technology (Upton, 1987). Therefore, the standard error of an experiment may be used either to estimate a confidence interval for the population mean or to test a hypothesis regarding the population mean (Freund, 1979). This error is defined as the difference among experimental plots treated alike and is the primary basis for deciding whether an observed difference is real or just due to chance (Gomez & Gomez, 1984). This clearly means that every experiment must be designed to measure the experimental error. In other words, every sampling method chosen must be free from bias and error. However, in agriculture, three commonly used techniques for controlling experimental error are highlighted: blocking, proper plot technique, and data analysis (Gomez & Gomez, 1984).

According to these authors, error control can be achieved through blocking by putting experimental units that are as similar as possible together in the same group (known as blocks) and by assigning all treatments into each block separately and independently. This blocking design ensures that the variation among blocks is measured and removed from the experimental error. Likewise, a proper plot technique is essential in this regard so that all factors other than those considered treatments can be maintained uniformly for all experimental units (Gomez & Gomez, 1984).

To this end, proper interpretation of the results is important because it is regarded as an important feature of the design of experiments because of its ability to uniformly maintain all environmental factors, which are not a part of the treatments evaluated. This means that maintaining this uniformity is vital to the measurement and reduction of experimental error, which are essential in hypothesis testing. This feature critically limits the applicability of the experimental results and is always considered in the interpretation of results (Gomez & Gomez, 1984). This shows that an experimental design is important because it guides the researcher to identify the correct methods of data collection and analysis, conditions in which the activity of research shall be carried out and approximation of the funds to be utilized for it, maintaining its connectivity to the purpose of research (UOU, 2010). Hence, the design of a sample is identified as a fixed plan or system to enable a researcher to obtain data of smaller sizes from parts of a larger population known as samples and includes the modules, techniques or procedures to be used in identifying the items for the sample (UOU, 2010). In other words, a sample design is used to define the number of items to be included in the sample. Therefore, a good experimental or sample design is expected to be proportional (truly representative of the sample population), free from error and bias, budgeted and generalized.

Experimental design: *one-factor, two-factor and three-factor classifications*

There are scientific advancements that have been detailed in the book Statistical Procedures for Agricultural Research by Gomez & Gomez (1984). This exciting development in the field of agricultural statistics has provided an opportunity for understanding three different classes of experiments, as highlighted below:

a. *One-Factor Experiment:* This class of experiment involves a single factor. According to Gomez & Gomez (1984), these experiments are designed so that only a single factor varies while all others are kept constant. This accounts for the treatments consisting solely of the different levels of the single variable factor, whereas all other factors are applied uniformly to all plots at a single prescribed level. For example, Gomez & Gomez (1984) indicated that most crop variety trials are single-factor experiments in which the single variable factor is variety and the factor levels or treatments are different varieties. Thus, in this context, only the variety planted differed from one experimental plot to another, while all management factors (fertilizer, insect control, and water management) were applied uniformly to all plots.
b. *Two-Factor Experiments:* This class of experiment focuses on a factorial experimental design where two or more variable factors are handled simultaneously. For example, Gomez & Gomez (1984) showed that the response of biological organisms, which are simultaneously exposed to many growth factors during their lifetime, to any single factor may vary with the level of the other factors, and single-factor experiments are often criticized for their narrowness. Thus, when the response to an a factor of interest is expected to differ under different levels of the other factors, a researcher is advised to avoid single-factor experiments and instead consider the use of a factorial experimental designed to handle two or more factors (Gomez & Gomez, 1984).

c. *Three-or-More-Factor Experiments:* This class means that a two-factor experiment can be expanded to include a third factor, and a three-factor experiment can include a fourth factor, depending on the nature and objectives of the research. In this situation, Gomez & Gomez (1984) indicated that two important consequences are related to a rapid increase in the number of treatments to be tested and an increase in the number and type of interaction effects; for example, a three-factor experiment has 4 interaction effects that can be examined, while a four-factor experiment has 10 interaction effects.

Sampling methods: *theoretical examples*

Sampling is a process used in statistical analysis in which a predetermined number of observations are taken from a larger population, and the methodology used to sample from a larger population depends on the type of analysis being performed (UOU, 2010). There are various sampling methods used for FSR. These sampling methods include replication, randomization, systematic, stratification, clustering, multistage sampling, and simple random sampling. Let us look at the concept of some of the most common sampling designs in agriculture. However, the detailed step-by-step procedures and complete designs can be found in the literature (refer to Freund, 1979; Gomez & Gomez, 1984; Upton, 1987). The conceptual idea and description presented below are based on the theories observed in the book of Statistical Procedures for Agricultural Research by Gomez & Gomez (1984).

- ***Completely randomized design (CRD):*** This sampling design is one that is assigned completely at random so that each experimental unit has the same chance of receiving any one treatment and can take care of any difference among experimental units by receiving the same treatment, which can be considered an experimental error (Gomez & Gomez, 1984). This type of sampling is a single-factor design and is more appropriate for experiments with homogeneous experimental units, such as laboratory experiments for soil chemical analysis. The environmental effects in this laboratory are relatively easy to control and manage. Similarly, in field experiments where there is generally large variation among experimental plots, for environmental factors such as soil, CRD is rarely used (Gomez & Gomez, 1984).
- The analysis of variance involved two sources of variation among the '*n*' observations obtained from a CRD trial – the treatment variation and an experimental error; however, the relative size of the two is used to indicate whether the observed difference among treatments is real or is due to chance. In this regard, the treatment difference is said to be real if the treatment variation is sufficiently larger than the experimental error (Gomez & Gomez, 1984). This simplicity in the computation of analysis of variance is a major advantage, and this advantage is even greater when the number of replications is not uniform for all treatments.
- ***Randomized Complete Block (RCB):*** This design is among the most widely used experimental designs in agricultural research. The design is especially suited for field experiments where the number of treatments is not large and the experimental area has a predictable productivity gradient. The primary distinguishing feature of the RCB design is the presence of blocks of equal size, each of which contains all the treatments; however, the purpose of this blocking is to reduce experimental error by eliminating the contribution of known sources of variation among experimental units (Gomez & Gomez, 1984).The randomization process is designed both separately and independently for each of the blocks.

- The analysis of variance involved three sources of variability in an RCB design: treatment, replication (or block), and experimental error.

- ***Group balanced block design (GBBD):*** The primary feature of the group balanced block design is the grouping of treatments into homogeneous blocks based on selected characteristics of the treatments. In a group-balanced block design, treatments belonging to the same group are always tested in the same block, but those belonging to different groups are never tested in the same block. This shows that the precision with which the treatments are compared is not the same for all comparisons, and the treatments belonging to the same group are compared with a higher degree of precision than those belonging to different groups (Gomez &Gomez, 1984).
- ***Latin Square Design (LSD):*** The major feature of the Latin square (LS) design is its capacity to simultaneously handle two known sources of variation among experimental units, and it can treat the sources as two independent blocking criteria instead of only one, as in the RCB design (Gomez & Gomez, 1984). Two-directional blocking, known as 'row-blocking' and 'column-blocking', is accomplished by ensuring that every treatment occurs only once in each row block and once in each column block. According to Gomez & Gomez (1984), this procedure makes it possible to estimate variation within row blocks and among column blocks and to remove them from experimental error. This means that the lattice design achieves homogeneity within blocks by grouping experimental plots based on known patterns of heterogeneity in the experimental area, and the group balanced block design achieves the same objective by grouping treatments based on known characteristics of the treatments (Gomez & Gomez, 1984).
  - There are four sources of variation, two more than that for the CRD and one more than that for the RCB design. These sources of variation are row, column, treatment, and experimental error.
- ***Split-Plot Design (SPD):*** The SPD is specifically suited for a two-factor experiment that has more treatments than can be accommodated by a CBD and one of the factors is assigned to the main plot, which is called the main-plot factor. According to Gomez & Gomez (1984), the main plot is divided into subplots to which the second factor, called the subplot factor, is assigned; thus, each main plot becomes a block for the subplot treatments. This means that with SPD, the precision of the measurement of the effects of the main-plot factor is sacrificed to improve that of the subplot factor, and the measurement of the main effect of the subplot factor and its interaction with the main-plot factor is more precise than that obtained with RCB.
  - The analysis of variance was divided into main-plot analysis and subplot analysis.

Statistical analysis

The results or data obtained from the research can be subjected to various analyses in FSR, including descriptive analysis, farm business analysis, financial analysis, cash flow analysis, and statistical analysis, including regression analysis. The application of statistics in agriculture has dominated most commonly used analyses in agriculture (Borrelli et al., 2021). Various statistical techniques are used in agricultural studies to ensure efficient planning of experiments and for interpreting experimental data (Bayo, 2014). Statistical techniques are also used for economic analyses and future predictions of different businesses of great value for human development (Lind et al., 2012).

These statistical analyses are considered in various agricultural sciences to respond quickly and efficiently to an existing problem for future solutions (Collinson, 1982), and this has been the result of the integration of various statistical tools and models into agricultural science. The FAO (2023) noted that the basic statistical tools commonly used for agricultural analyses with various statistical software include the sum, mean, standard deviation, coefficient of variance, confidence limit of measurement, and propagation of errors, while the statistical tests include two-sided vs. one-sided tests, F tests for precision, t tests for bias, linear correlation and regression, and analysis of variance (ANOVA). However, the common statistical software packages are Excel spreadsheet, SPSS (Statistical Package for Social Science) (Quintero et al., 2012), SAS (Statistical Analysis Software) (SAS Institute, 2023), GENSTAS (Warwick University, 2023), Stata (Eric et al., 2016), Minitab (Barbara et al., 1972), R, Epi-info (CDC, 2023), Epi-data (EpiData Association, 2023), NVivo (Lumivero, 2023) and ATLAS.ti (ATLAS-ti Scientific Software Development GmbH, 2023). These specialized programs are designed to perform complex statistical analyses, assist in the organization and interpretation of the results, and calculate and present the overall results for present and future use (Lind et al., 2012). With computer technology and its application in agriculture (FAO, 2011; Abbasi et al., 2014; Choudhary et al., 2022), these sets of software can be used to perform many statistical analyses and solve voluminous problems in agriculture (Bayo, 2014). In many instances, this statistical software requires minimal practice to operate and generate significant results for detailed interpretations.

CONCLUSION

Research and its methodologies are major components of science. They provide the complete structure and guidelines on how to start and complete agricultural research both in the field and in the laboratory. Research methodology is a science and technology that must be studied and examined before the initiation of any study under any of the agricultural components (animal science, agricultural extension, agronomy, soil science, among others). It is a major driving machine that can be used to achieve any objective and answer important research questions in relation to agricultural research objectives. It plays a key role in deciding how science and economic development are pictured in global academic and policy decision-making. This piece of knowledge compilation emphasizes the need for regular reading and examination of the overall concept of research, its methodologies, experimental designs and statistical hypotheses and analyses. There are many advances in the way research and research analysis should be performed in practical fields of study, such as agriculture, and this must be learned regularly in both universities and colleges. Similarly, theories and principles must be understood at all levels of research and studies in the fields of agriculture, sciences and social sciences.

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Efficacy of *Basella alba* L. Extract on the Masculinization of Nile Tilapia (*Oreochromis niloticus* Linnaeus, 1758) Using Immersion and Oral Administration Techniques

Lai Lanie A. CUNGIHAN[1*], Ventura C. CHINAMAN[2], Vincent K. CARIÑO[3], Haidee E. TORIO[3]

[1]*Department of Animal Science, College of Agriculture, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines*
[2]*Department of Fisheries, College of Agriculture, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines*
[3]*College of Veterinary Medicine Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines*

[*]*Corresponding Author: lacungihan@nvsu.edu.ph*

[*]*ORCID: 0009-0001-4493-4679*

Abstract

The study evaluated the efficacy of *Basella alba* L. extract in inducing masculinization in Nile tilapia (*Oreochromis niloticus*) fry and eggs using oral administration and immersion techniques. Tilapia seedstocks were randomly assigned to negative control (no hormonal treatment), positive control (17α – methyltestosterone or 17α-MT), and *B. alba* extracts. Each treatment was administered via egg immersion, fry immersion, and oral administration, with the setup replicated three times. Yellow eggs were immersed for 96 hours in aqueous *B. alba* extract and 17α-MT hormone, while fish fry was immersed two hours weekly over 28 days. Oral administration involved feeding fish fry with feeds added with *B. alba* ethanol extract and 17α-MT. The study employed the standard acetocarmine squash technique of gonads to analyze the sex reversal percentage. The findings demonstrated that immersion of eggs and fry in *Basella alba* extract resulted in higher sex reversal percentages compared to orally treated fish fry, suggesting the effectiveness of both egg and fry immersion as masculinization techniques. Moreover, there were no significant differences in the percentage of males between groups treated with 17α-MT and those treated with *B. alba* extract, regardless of whether the treatment was administered orally or through immersion. These findings highlight the potential of *Basella alba* extract as a viable alternative to synthetic steroid hormones for achieving masculinization in Nile tilapia. Furthermore, egg and fry immersion can be considered an alternative technique to the traditional sex reversal method of feeding the fry with hormone-treated feeds.

Keywords: Nile tilapia, *Basella alba*, Sex reversal, Immersion, 17α-MT

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INTRODUCTION

Although tilapia (*Oreochromis niloticus*) is an introduced species in the Philippines, it has become the second largest freshwater cultured species by volume, following milkfish (Guerrero, 2017). Globally, tilapia ranks as the third most widely farmed finfish, surpassed only by grass carp (*Ctenopharyngodon idellus*) and silver carp (*Hypophthalmichthys molitrix*) as reported by Radkhah and Eagderi (2021a) and the Food and Agriculture Organization (FAO) in 2022. This highlights the importance of Nile tilapia as a significant source of protein for human consumption worldwide (Arumugam et al., 2023).

The significant increase in tilapia production can be attributed to its rapid growth rate and short production cycle. In commercial aquaculture, monosex "all-male" tilapia populations are preferred due to their higher energy efficiency and faster growth than females (Megbowon and Mojekwu, 2014). Techniques to produce all-male populations include manual sex separation (Radkhah and Eagderi, 2021b) genetic manipulation or YY-male technology (Mair et al., 1997; Jordaan, 2004), and hormonal sex reversal (Desprez et al., 2003). Among these methods, synthetic hormones, particularly 17α-methyl testosterone (17α-MT), are the most common, achieving high masculinization success rates (Wassermann and Afonso, 2002). The efficacy of 17α-MT is linked to its ability to inhibit aromatase activity, thus preventing estrogen production and promoting androgenesis in developing gonads (Golan and Levavi-Sivan, 2014). However, synthetic hormones have raised health concerns for hatchery workers and environmental issues (Megbowon and Mojekwu, 2014; Abaho et al., 2021), prompting research into phytochemical alternatives.

Plant parts and extracts are increasingly utilized in aquaculture, although research has focused on their effects on fish growth and immunity. Reverter et al., (2014) and Van Hai (2015) indicated that plant extracts containing phytochemicals such as isoflavonoids, flavonoids, and saponins, which possess estrogenic and androgenic properties, could potentially replace synthetic steroid hormones for sex reversal in tilapia. Notable plants with phytochemicals capable of altering the sex ratio in favor of males include pine pollen (Abaho et al., 2022), aloe vera (Gabriel et al., 2016), *Glycine max* (Kefi, 2014), *Tribulus terrestris (*Amer et al., 2021; Ghosal and Chakraborty, 2014), ginseng (Mansour et al., 2018), *Basella alba* (Ghosal et al., 2016), *Quillaja saponaria*, and *Trigonella foenum-graecum* (Stadtlander et al., 2012).

Basella alba L. commonly known as Malabar spinach, is a succulent, branched, smooth, twining herbaceous vine. The leaves of *B. alba* contain phytochemicals such as flavonoids, tannins, steroids, and saponins (Ghosal et al., 2016). Previous studies have demonstrated the androgenic activities of *B. alba* in the masculinization of Nile tilapia (Asad et al. 2024; Radkhah and Eagderi, 2021b; Yusuf et al., 2019). Therefore, this study aimed to validate the effect of *B. alba* on the masculinization of *O. niloticus* through different techniques and determine the most effective method of administration for achieving the highest percentage of male tilapias.

MATERIALS and METHODS

Experimental Design and Treatment

The experiment was conducted in a Completely Randomized Design (CRD). Experimental fish seeds were randomly distributed to different treatments and replicated three (3) times with 60 fry/egg in each replicate. The experimental design encompassed three main treatments: negative control (no hormonal treatment), positive controls (17α -MT), and *B. alba* extracts, all administered in three different techniques, namely, egg immersion, fry immersion, and oral administration.

Conditioning and Pairing of Broodstock

Tilapias are capable of mating at an early age of at least 2-3 months from the start of culture. Female and male broodstock were conditioned separately in hapa nets for 10 days and were fed a commercial diet at 3% of their body weight.

The broodstock was paired by stocking three females for every single male in a hapa measuring 2m × 1m × 1m (L×W×H).

Egg Collection

Egg collection commenced 10 days after the first day of pairing. The female tilapia normally holds the fertilized eggs in their buccal cavity for incubation. Yellow and/or eyed eggs were collected and transferred to artificial incubation units for incubation and treatment.

Egg Incubation and Hatching

A simple tilapia egg incubation system was developed using inverted 1.5 L capacity empty plastic soda bottles. The bottoms of the bottles were cut off to make ideal downwelling incubators. A fixed pipe above the container provides water entry. Water flow was adjusted to gently circulate the eggs, simulating the movement of eggs in the buccal cavity of the female to enable hatching. The larvae were moved to several trays immediately after hatching and kept separately until they reached the yolk sac fry stage.

Leaf Extract Preparation

Matured leaves from *Basella alba* plant of at least 100 days old were procured from a Malabar spinach farmer. The leaves were washed with distilled water, air-dried, and pulverized. Aqueous leaf extract was prepared by heating 18 g of powdered leaves in 1500 ml distilled water at 100 ºC for 30 minutes then filtered with Whatman filter paper of 11µm pore size, twice (Ghosal and Chakraborty, 2014). On the other hand, ethanolic extract was prepared according to the method described by Mukherjee et al., *(2018).* Briefly, 250 g of powdered leaves was soaked in 500 ml ethanol for 5 hours. The ethanolic extract was evaporated using a rotary evaporator and stored at -20^{o}C.

Egg Immersion Technique

Sixty yellow eggs per replicate were immersed for 96 hours in one liter of *B. alba* extract (0.12g/L) and 17α-MT (800µg/L). Aeration was provided into plastic containers that measured 30cm × 20cm × 20cm (L×W×H) to facilitate the continuous movement of eggs and provide sufficient oxygen for the developing embryos. The solutions (*B. alba* extract and 17α-MT) were replaced regularly with freshly prepared solutions using a siphon hose (0.5cm ϴ). After immersion, hatched eggs were transferred to hapa nets measuring 1m × 2m × 1m (L×W×H). The Nile tilapia fry was reared and fed a commercial diet for 60 days for further development.

$$SGR = \frac{lnW_f - lnW_i}{t} \times 100$$

$$Hatching\ rate = \frac{no.of\ hatched\ larvae}{initial\ no.of eggs} \times 100$$

$$Survival\ Rate = \frac{final\ stock}{initial\ stock} \times 100$$

Fry Immersion Technique

Batches of sixty Nile tilapia yolk-sac fry (5 days old) were immersed in one liter of *B. alba* extract (0.12g/L) and 17α-MT (800µg/L) for two hours every seven days for 28 days. The solution/s was aerated and replaced regularly by siphoning or using a siphon hose (0.5cm Ө). The experimental fish were then reared in hapa nets and were fed with a commercial diet for further development.

Table 1. Composition of the commercial diet used in the experiment

Composition	Percentage
Crude Protein	42
Crude Fat	5
Crude Fiber	5
Ash or Mineral	16
Moisture	12

Oral Administration Technique

Ethanolic leaf extract of *B. alba* was sprayed evenly on one kilogram of fry booster feeds. Meanwhile, 0.06 g of 17α-MT was dissolved in 500 ml ethanol and evenly sprayed on one kilogram of fry booster feeds. The treated feeds were spread on a platform for air drying at room temperature. Fry with fully absorbed yolks were fed the treated air-dried feeds (10% BW) three times daily for 28 days. For continued development, the fish were nursed in hapa net cages.

Sex Identification

Ten (10) fish from each replicate were randomly selected and prepared for sex identification following the gonad squash technique by Guerrero and Shelton (1974). The experimental fish were dissected, and the gonads were placed on a glass slide. A few drops of acetocarmine were added, and the gonads were gently squashed with a cover slip. Subsequently, the mounts were observed under a microscope for sex identification.

$$\%\, male = \frac{no.\ of\ identified\ males}{total\ no.of\ fish\ samples} \times 100$$

Statistical analysis

The data collected were: the percentage of males, hatching rate, and survival rate. Statistical analyses were carried out using SPSS version 20. One-way analysis of variance (ANOVA) and analysis of covariance (ANCOVA) were used to determine the significant difference among treatments. The least significant difference (LSD) test was used to compare treatment means at a 5% level.

RESULTS and DISCUSSION

Table 2 presents the growth rates of Nile tilapia subjected to various sex reversal techniques. Findings showed that the gain in weight of fry hatched from eggs immersed in 17α-MT was significantly higher (9.32±0.32) compared to both the negative control (7.74±0.03) and those immersed in aqueous *B. alba* extract (8.32±0.41).

On the other hand, no significant differences were observed among treatment means in the oral administration and fry immersion techniques.

Table 2. Effect of *B. alba* extracts on the specific growth rate (mean±SD) of Nile Tilapia subjected to sex reversal using the egg/fry immersion and oral administration techniques

Treatment	**Specific Growth Rate (SGR)**		
	Egg Immersion Technique	**Fry Immersion Technique**	**Oral Administration Technique**
Negative Control	7.74±0.03[b]	7.74±0.03[b]	7.74±0.03[b]
Basella alba	8.32±0.41[b]	8.30±0.49[b]	7.76±0.19[b]
17 α-MT	9.32±0.32[a]	7.77±0.04[b]	8.29±0.03[b]

**Values with different superscripts are significant at the 5% level.*

Medicinal plants containing diverse groups of phytochemicals such as phenolics, flavonoids, alkaloids, polysaccharides, and volatile oils have been reported to act as antimicrobial agents and to stimulate both specific and non-specific immunity in fish by modulating the functions of the immune cells increasing antibody production (Ghosal et al., 2020b; Chakraborty and Hancz, 2011) and eliminating undesirable constituents in the intestine. These phytochemicals enhance the absorption and/or stability of essential nutrients (Holst and Williamson, 2008) and have been linked to increased fish growth (Makkar et al., 2007; Chakraborty et al., 2013).

However, the results of this study showed that eggs immersed in 17α-MT had better growth performance compared to those immersed in the aqueous leaf extract of *Basella alba* and those that received no hormone solution. It was initially suspected that the higher growth rate observed could be attributed to the lesser number of fry survivors in this treatment, which means that there is a lower degree of food, dissolved oxygen, and space competition between fishes. It was mentioned by Ahmadoon et al., (2023) that growth depends on the number of factors divided into exogenous and endogenous factors. Exogenous factors include environmental parameters such as dissolved oxygen, degree of competition, amount of the nutrient, salinity, and temperature. In addition, the difference in growth rate established by young fish is not indeterminate and may not persist throughout life. Initially, slow-growing fishes may surpass fast-growing fish and finally reach a greater length and size (Kefi, 2014). However, the results revealed that survival has no effect (p>0.05) on the differences in SGR.

Table 3 demonstrates comparable sex inversion rates for Nile Tilapia using egg and fry immersion techniques in both *B. alba* and 17α-MT treated groups. However, 17α-MT resulted in a notably higher ($p<0.05$) sex inversion rate when using the oral administration technique. It is also evident from the results that, among the three techniques used, the egg immersion technique produced the highest percentage of males.

Table 3. Effect of *B. alba* extracts on the sex inversion (mean±SD) of Nile Tilapia using egg immersion, fry immersion, and oral administration techniques

Treatment	Percent Male (%)		
	Egg Immersion Technique	**Fry Immersion Technique**	**Oral Administration Technique**
Negative Control	46.71 ± 8.72^{bc}	46.71 ± 8.72^{bc}	46.71 ± 8.72^{c}
Basella alba	80.20 ± 7.86^{a}	75.00 ± 6.90^{a}	64.96 ± 13.14^{b}
17 α-MT	82.63 ± 8.24^{a}	70.00 ± 6.50^{ab}	74.76 ± 4.63^{ab}

**Values with different superscripts are significantly different at the 5% level.*

The efficacy of *B. alba* extract on sex inversion was investigated in this study using three modes of introduction: egg immersion, fry immersion, and in-feed administration. The findings of the study revealed that the use of *B. alba* extract for sex inversion is as effective as the use of the synthetic hormone 17α-methyltestosterone. The study also demonstrated, through egg immersion, the efficacy of masculinization treatment during embryonic development, supporting the report of Rougeot et al., (2008) that the development of primordial germ cells and/or future somatic cells of the presumptive gonads is influenced by hormones. The egg immersion technique is rarely used in the sex manipulation of Nile tilapia. The most used method is oral administration, which takes 21 to 28 days to complete. However, unlike fry immersion and oral administration, the egg immersion technique provides a short-term procedure for masculinization in about 96 hours. The studies of Ghosal and Chakraborty (2014) and Ghosal et al., (2016) on *B. alba* did not include the egg immersion technique. To the knowledge of the authors, this is the first report on the efficacy of *B. alba* extract using the egg immersion method.

In this study, egg immersion using *B. alba* extract attained sex inversion rates of 80.20% which is comparable to 17α-methyltestosterone (82.63%). Additionally, the inversion rate of 75.00% for *B. alba* using the fry immersion technique surpassed the 70.30% rate reported by Ghosal and Chakraborty (2014). This study used a higher concentration of 0.12 g/L, whereas Ghosal and Chakraborty (2014) used a lower concentration of 0.10 g/L.

Previous studies indicated that the extract of *B. alba* leaves was found to stimulate the production of testosterone in testicular fractions and Leydig cell cultures in healthy adult albino male rats (Moundipa et al., 2006; Nantia et al., 2011). The result shows that phytochemical extracts, such as *B. alba* extracts, are more effective when used during the early stages of embryonic development. As the stage of development progresses, the efficiency of *B. alba* extract in sex manipulation decreases. Results indicate that the highest percentage of males was obtained when eggs were used, and the sex inversion rate decreased when yolk-sac fry and fry of advanced age were used.

In the early stage of development, Nile tilapia is sexually undifferentiated. Sexually undifferentiated gonads are bipotent and can either develop into testes or ovaries depending on genetic or environmental factors (Nishimura and Tanaka, 2016). External conditions and exogenous endocrine-active substances play a determining role in the development of sex characteristics. In the natural environment, the endocrine system, especially during the embryonic development of aquatic animals, can be affected by chemical effluents from different industries (Hoy and Benson, 1998). Early exposure to endocrine-disrupting chemicals (EDCs) can have immediate effects on the development of the reproductive tract or the establishment of the various gonad cell types; subsequent effects may be seen on hormonal homeostasis, somatic cell differentiation, gamete production, and gamete quality (Marlatt et al., 2022).

Phytochemicals modulate the endocrine system of fishes; hence these are referred to as endocrine-disrupting compounds (EDCs). The phyto-compounds can disrupt the biosynthesis, distribution, and functions of steroid hormones subsequently interfering with the reproductive physiology of fish (Abajo et al., 2021; Zhou et al., 2019;). It could be that the primordial cells in fish are present in the endodermal layer of the yolk sac (as observed in humans), where the phytochemicals present in *B. alba* extract can easily penetrate. As embryonic development proceeds, the primordial cells migrate into the gonads where they are harder to reach by the phytochemicals. Thus, the time of introduction of an environmental or exogenous endocrine-active chemical stimulus to manipulate the sex of an organism is highly important to attain success. In the case of masculinization, missing the perfect timing could result in a lower number of males being produced (Capel, 2017; Marlatt et al., 2022).

The result of the oral administration in this study (64.96%) is slightly higher than the findings of Omar et al., (2014) on the sex reversal of Nile tilapia using *T. terrestris* (64.48%) and Date palm pollen (56.67%) but is lower than the results obtained by Ghosal *et al*. in 2015 for *B. alba* (83.2±0.7) and *Tribulus terrestris* (88.9±1.1). The immersion technique resulted to significantly higher masculinization percentage than oral treatment. This result could be attributed to the statement of Abaho et al., (2021), that variations in the amount of sex steroids available to the fish, due to the non-uniform distribution of the extracts in the diets during mixing, limit the efficiency of the in-feed technique.

The hatching and survival rates of Nile Tilapia are presented in Table 4. Findings indicate a significantly higher (p<0.05) hatching rate of tilapia eggs immersed in aqueous *B. alba* extract (88.33%±2.08) compared to the negative control (56.67%±8.02), and 17α-MT (53.33%±4.51). No significant variations (p>0.05) in survival rates were observed among treatment means in both fry immersion and oral administration techniques.

Table 4. Hatching and survival rate (mean±SD) of experimental eggs/fish after immersion and oral administration

Treatment	Hatching Rate (%)	Survival Rate (%)	
	Egg Immersion Technique	**Fry Immersion Technique**	**Oral Administration Technique**
Negative Control	$56.67±8.02^{b}$	$56.67±8.02^{b}$	$56.67±8.02^{b}$
Basella alba	$88.33±2.08^{a}$	$61.67±4.25^{b}$	$58.33±3.79^{b}$
17 α-MT	$53.33±4.51^{b}$	$58.33±6.51^{b}$	$53.33±7.02^{b}$

**Values with different superscripts are significantly different at the 5% level.*

The highest hatching rate was observed in eggs immersed in aqueous *B. alba* extract. Major biological activities exhibited by *Basella alba* show androgenic, anti-inflammatory, antimicrobial, antioxidant, antiviral, central nervous system depressant, hepato-protective, and wound-healing properties (Chakraborty and Hancz, 2011). These properties are believed to have contributed to the higher hatching rate and comparable survival rate of eggs immersed in *B. alba* extracts.

CONCLUSION

Basella alba extracts can be used with promising results as an alternative to steroid hormones for the masculinization of Nile Tilapia. Both immersion techniques and oral administration of *B. alba* extracts resulted in masculinization. Immersion technique particularly egg immersion resulted in higher sex inversion rates.

Thus, egg immersion can be regarded as an alternative technique to the traditional sex reversal method of feeding the fry with hormone-treated feeds. Further studies, however, are recommended to identify the concentration of the extract that will result in optimal masculinization in Nile Tilapia using the egg immersion technique.

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Effect of *Ficus nota* (Blanco) Merr on the Hematobiochemical Profile and Growth Performance in Broiler Chickens

Lai Lanie A. CUNGIHAN

Department of Animal Science, College of Agriculture, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines

Corresponding Author: lacungihan@nvsu.edu.ph

ORCID: 0009-0001-4493-4679

Abstract

Ficus nota Blanco Merr, known for its positive effects on human health in traditional medicine owing to its phytobiotics, has not been adequately studied for its impact on farm animals, particularly in poultry. This research sought to address this knowledge gap by investigating its influence on growth performance, hematological and serum biochemical profiles of broiler chickens. A total of 168 10-day-old commercial Cobb 500 broiler chicks, randomly assigned into four treatment groups each replicated three times, were subjected to a 31-day experimental period. *Ficus nota* fruits were subjected to fermentation, yielding a fermented juice, subsequently administered to the chicks via their drinking water. The treatments included a control group receiving plain water and three experimental groups with varying concentrations of fermented fruit juice (FFJ): 40 ml FFJ/L, 60 ml FFJ/L, and 80 ml FFJ/L. Substantial differences ($p<0.05$) were observed in red blood cell count, hemoglobin concentration, and hematocrit. Conversely, platelet and white blood cell counts did not show significant variations ($p>0.05$) among the treatment groups. Except for reduced cholesterol levels in treated groups, there were no significant changes ($p>0.05$) in other blood serum biochemical indices. Furthermore, the treated groups exhibited notable weight gain and enhanced feed conversion ratio, underscoring the potential impact of the treatments.

Keywords: Feed conversion ratio, Fermentation, *Ficus nota*, Phytobiotics, Hematological Indices, Serum biochemical profile

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INTRODUCTION

Poultry farming, an integral part of global food production, has witnessed a significant rise in the utilization of antibiotics. Antibiotics became routine additives in poultry feed as necessary tools for disease prevention and growth promotion. However, the persistent, widespread use of antibiotics in poultry farming creates a pressing concern with profound implications for public health, animal welfare, and the environment. One of the primary concerns is the development of antibiotic resistance in bacteria, a phenomenon intensified by the continuous exposure of pathogens to these drugs. Antibiotic-resistant strains can easily proliferate and pose a serious threat to both animal and human health (Hosain et al., 2021).

In response to the concerns surrounding antibiotic use and to the limitations imposed in numerous countries regarding the utilization of antibiotic growth promoters in the process of meat production, there is an increasing focus on exploring alternatives. Phytobiotics, sourced from plants and encompassing compounds such as polyphenols, flavonoids, alkaloids, and phytoestrogens, have emerged as potential alternatives to synthetic supplements and antibiotics in livestock health and nutrition (Hashemi and Davoodi, 2011; Ognik et al., 2016; Zaikina et al., 2022).

Phytobiotic feed additives (PFAs) have shown promising effects on poultry output, as indicated by studies conducted by Abudabos et al. (2018) and Gheisar et al. (2015a). These alternatives have demonstrated potential in improving growth performance, nutrient absorption (Abdelli et al., 2021), and improving the antioxidant and anti-inflammatory status of animals (Kiczorowska et al., 2019).

Ficus nota (Blanco) Merr is an indigenous plant in the Philippines known for its bioactive compounds. Phytochemical screening results revealed that both leaves and fruits contained secondary metabolites such as alkaloids, anthraquinones, tannins, flavonoids, steroids, and saponins (Mapatac, 2015). In vitro studies in mice indicated potential health benefits such as antioxidant, anti-inflammatory, and immune-boosting effects (*Ahmed et al.,* 2015). Furthermore, *Ficus nota* holds significance in traditional human medicine. Its uses include decoction of the roots and bark for treatment of urinary tract infections, hypertension, and diabetes and drinking three times per day of the water extracted from the standing tree for fever, and muscle pain relief (Lanting and Palaypayon, 2002).

Despite these promising advantages, there is a notable absence of specific studies on the impact of phytobiotics derived from *Ficus nota* on farm animals, particularly in poultry. This creates a significant knowledge gap concerning its potential health and growth benefits in livestock and poultry production. Hence, the study addressed this gap by assessing the broiler's growth response and hematological and biochemical parameters, providing valuable insights into its potential utilization as a natural feed additive.

MATERIAL and METHOD

Experimental Design and Treatment

The study was laid out in a Completely Randomized Design (CRD). A total of 168 10-day-old commercial Cobb broiler chicks were subjected to a 31-day experimental period. The chicks were randomly assigned into four treatment groups each replicated three times, with 14 chicks per replicate. The treatments included a control group receiving plain water and three experimental groups with varying concentrations of fermented fruit juice (FFJ): 40 ml FFJ/L, 60 ml FFJ/L, and 80 ml FFJ/L.

Phytochemical Analysis of *Ficus nota* Fruit

Fruit and leaf samples were taken to the Nueva Vizcaya provincial office of the Department of Environment and Natural Resources (DENR) for verification of botanical identity. Fresh fully matured *Ficus nota* fruits were subsequently collected, thoroughly washed, and subjected to phytochemical screening. The phytochemical screening process followed the procedures outlined by Guevarra (2005).

It involved utilizing thin-layer chromatography (TLC) plates and various reagents to identify secondary metabolites in plant extracts. TLC plates were developed in an Ethyl Acetate-Chloroform mixture, and spots were visualized using UV light and hot plate. Vanillin-sulfuric acid reagent was used to identify phenols, sterols, triterpenes, and essential oils. Methanolic potassium hydroxide was used for anthraquinones, coumarins, and anthrones, while potassium ferricyanide-ferric chloride reagent was used for phenolic compounds and tannins. Alkaloids were detected using Antimony (III) chloride.

Phytochemical analysis of *Ficus nota* has revealed the presence of various bioactive compounds including phenols, flavonoids, tannins, saponins, coumarins, and steroids, among others (Table 1).

Table 1. Compounds isolated from *Ficus nota* fruits

Plant constituents	*Ficus* fruit	Plant constituent	*Ficus* fruit
Essential oils	-	Coumarins	+
Triterpenes	-	Anthrones	+
Sterols	-	Tannins	+
Phenols	+	Flavonoids	+
Fatty acids	-	Alkaloids	-
Sugars	-	Steroids	+
Anthraquinones	+	Amino acids	-

(+) Abundant; (-) Absent

Fermented Fruit Juice Preparation

Fresh fully matured Ficus fruits were collected for fermentation. The preparation of the fermented *Ficus nota* fruit juice followed the procedures outlined by Huervana (2016). Thinly sliced fruits were mixed with molasses in a 1:1 ratio. The resulting mixture was anaerobically fermented in an earth jar and left undisturbed for 7 days at room temperature. Fermented juice extracts were stored in clean plastic containers and kept refrigerated for up to 3 days to slow down continuous fermentation and preserve the juice until used.

Dietary Treatment

While the experimental treatments were introduced at 10 days old, the chicks were fed a commercial chick booster diet until they reached 14 days of age. Subsequently, from days 15 to 41, they were fed *ad libitum* with formulated isocaloric and isonitrogenous diet.

Distilled water was used as drinking water for the experimental birds. The use of distilled water ensures a consistent and pure water supply, minimizing the potential impact of impurities or contaminants on the test material and the birds' health and performance. Except for variations in the drinking water treatments, all other aspects of management were standardized across experimental groups. This ensures that observed differences in study outcomes primarily result from treatment variations rather than disparities in overall management, enhancing the validity and reliability of results for an accurate assessment of treatment impact on bird growth and performance.

Hematological and Serum Biochemical Analysis

On the 42nd day of the experiment, representative samples were randomly selected for blood collection. Blood samples were collected through the wing vein into EDTA bottles for hematological evaluation of the red blood cells (RBC), hemoglobin (Hb), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), mean corpuscular volume (MCV), hematocrit (HCT) and white blood cells (WBC), neutrophil and lymphocytes, white blood cells (WBC), lymphocytes and granulocytes. The samples were analyzed using a hematology analyzer.

Whole blood samples were centrifuged (2500g for 10 minutes at 4 °C) and the resulting sera were stored at -20°C for serum biochemical analysis using a semi-automated biochemical analyzer. Blood parameters, indicative of renal function (BUN and creatinine), hepatic function (ALT and total protein) as well as cholesterol and triglyceride levels were determined.

Growth Performance Data

The initial weight of the chicks was taken during randomization on day 10, with subsequent weekly weight measurements throughout the experiment. Additionally, precise measurements of feed and water were systematically recorded to ensure uniform provision of feeds and water. Performance data collected included gain in weight, feed intake and feed conversion ratio.

Statistical Analysis

The collected data were subjected to statistical analysis using IBM SPSS 23 software with the analysis of variance (ANOVA) conducted in a Completely Randomized Design (CRD). Differences among treatment means were assessed at a significance level of 0.05. A post-hoc test, using Tukey's test was used to determine which treatments significantly differ from one another.

RESULTS and DISCUSSION

Hematological Indices

The findings presented in Table 2 demonstrate that incorporating fermented *Ficus nota* fruit juice into the drinking water of the broiler chickens resulted in significantly higher ($p<0.05$) erythrocyte counts (3.16±0.03 – 3.34±0.05 $x10^{12}$ L), hemoglobin levels (10.51±0.53 – 10.63±0.86 g/dL), mean corpuscular hemoglobin (46.70±0.60 – 48.10±0.70 pg), mean corpuscular hemoglobin concentration (43.07±2.22 - 43.43±1.98 g/dL), and hematocrit values (23.87±0.37 – 25.37±0.83%). However, no significant variations ($p>0.05$) were observed among treatment means for mean corpuscular volume, platelets, white blood cells, lymphocytes, and granulocytes.

The results of the current study demonstrate increased red blood cell counts, hemoglobin levels, mean corpuscular hemoglobin concentration (MCHC), hematocrit, and mean corpuscular hemoglobin (MCH) percentages in treatments involving fermented *Ficus nota* fruit juice. This indicates the potential beneficial effects of the juice on red blood cell production and maintenance.

These findings align with several studies that have shown significant increases in erythrocyte counts and hemoglobin levels with the incorporation of phytobiotics such as cinnamic aldehyde, thymol, and carvacrol (Reis et al., 2018), cinnamon oil (Krauze et al., 2020), as well as organic acids and flavonoids (Gilani *et al*., 2018) into the diets of broiler chickens. Similarly, broilers fed with pawpaw leaf and seed meal (Oloruntula, 2019), turmeric powder (*Curcuma longa*), and cayenne pepper (*Capsicum frutescens*) (Adegoke et al., 2018) exhibited elevated hemoglobin and erythrocyte values.

Table 2. Hematological indices (mean±SD) of broiler chickens supplemented with fermented *Ficus nota* fruit juice

Parameters	T1 (Control)	T2 (40 ml)	T3 (60 ml)	T4 (80 ml)	CV (%)
RBC (10^{12} L)	2.89±0.09^{c}	3.16±0.03^{b}	3.34±0.05^{a}	3.32±0.05^{a}	6.25
Hb (g/dL)	8.10±0.26^{b}	10.59±0.54^{a}	10.63±0.86^{a}	10.51±0.53^{a}	12.35
MCH (pg)	42.23±0.86^{b}	46.70±0.60^{a}	48.10±0.70^{a}	47.07±1.65^{a}	5.45
MCHC (g/dL)	38.03±6.63^{b}	43.10±1.13^{a}	43.07±2.22^{a}	43.43±1.98^{a}	8.89
HCT (%)	20.20±0.81^{b}	23.87±0.37^{a}	25.00±1.73^{a}	25.37±0.83^{a}	9.82
MCV (fl)	105.00±0.62	109.93±8.55	110.33±3.51	112.00±2.98	4.55
Platelet (10^{9}L)	18.00±3.00	18.33±2.08	21.33±4.50	25.33±3.21	20.14
WBC (10^{9} L)	142.83±3.75	139.73±5.03	143.80±6.92	143.40±4.37	3.31
Lymphocytes (10^{9} L)	103.50±3.31	102.53±4.59	102.83±3.20	102.57±0.93	2.75
Granulocytes (10^{9} L)	24.10±1.11	22.30±3.23	27.57±2.67	24.60±2.45	11.81

**Values with different superscripts differ significantly at the 5% level*

The mean corpuscular volume (MCV) did not show significant differences among treatment groups, consistent with the results reported by Basit *et al*. (2023); Oghenebrorhie, and Oghenesuvwe (2016), who also found no significant differences in MCV among broilers fed with *Persicaria odorata* leaf meal and *Moringa oleifera* leaf meal, respectively.

While platelets are primarily known for their role in hemostasis or clot formation, it is important to note that they also participate in several other physiological processes such as wound healing and remodeling, tissue repair, and antimicrobial host defense (Leslie, 2010). Moreover, as stated by Huang and Chang (2012) platelets contribute to immune responses. White blood cells, which include lymphocytes and granulocytes, are crucial components of the immune system and play vital roles in defending the body against infections and diseases. Typically, when an infection or foreign organism is present in the body, white blood cell counts tend to increase as a response to combat the infection.

The results of the present study, which show a lack of significant differences in platelet and white blood cell counts among the treatment groups, suggest that the experimental birds in all treatments did not exhibit any signs of infection and were generally healthy. The absence of significant variations in lymphocyte and granulocyte counts further supports the conclusion that the experimental birds were in a healthy state and did not display any abnormalities in their immune responses.

Serum Biochemical Indices

Table 3 presents the results of serum biochemical responses indicating liver and kidney functions, as well as lipid profiles in broilers following supplementation with fermented *Ficus nota* fruit juice.

Table 3. Serum biochemical indices (mean±SD) of broiler chickens supplemented with fermented *Ficus nota* fruit juice

Treatments	Cholesterol (mg/dL)	Triglyceride (mg/dL)	Creatinine (mg/dL)	BUN (mg/dL)	ALT (µL)	Total protein (g/L)
T1 (Control)	241.18±10.47^{b}	126.98±9.39	0.57±0.04	3.64±0.26	11.29±4.39	1.51±0.08
T2 (40 ml)	181.21±12.82^{a}	125.66±4.24	0.52±0.04	3.68±0.15	10.56±1.43	1.52±0.05
T3 (60 ml)	170.74±8.19^{a}	122.35±11.38	0.56±0.03	3.60±0.07	11.11±4.03	1.49±0.03
T4 (80 ml)	176.18±3.40^{a}	125.84±2.29	0.54±0.03	3.65±0.16	10.26±2.04	1.51±0.05
CV	15.99	6.52	3.12	6.56	15.81	3.33

**Values with different superscripts differ significantly at the 5% level*

Statistical analysis revealed a notable variation ($p<0.05$) in the cholesterol levels between the treated groups and the control group. Cholesterol levels ranged from 170.74±8.19 to 181.21±12.82 mg/dL in the *Ficus nota* treated groups, which were significantly lower compared to the cholesterol concentration of 241.18 mg/dL observed in the control group. No significant variations (p>0.05) were observed among treatment means for triglyceride, creatinine, BUN, ALT, and total protein.

Triglyceride values ranged from 122.35±11.38 to 126.98±9.39 mg/dL, falling within the normal range of 45.7 to 172 mg/dL (Meluzzi et al., 1991, as cited in Odunitan-Wayas et al., 2018). Similarly, alanine aminotransferase (ALT) levels ranged from 10.26±2.04 to 11.29±4.39 mg/dL, which is within the normal range of 9.50-37.2 mg/dL as reported by Roa et al., (2020).

Serum concentrations of cholesterol and triglycerides serve as indicators of lipid metabolism (He *et al*., 2015). The significant reduction in cholesterol concentration observed in the present study suggests that *Ficus nota* fruit juice may possess hypocholesterolemic properties attributed to its phytobiotic contents. The results are consistent with Zhou *et al.* (2015) and Yu et al., (2019), who reported that dietary supplementation of broilers with fermented Ginkgo biloba rations and fermented Ginkgo biloba leaves can significantly reduce the serum levels of cholesterol. Comparable results were noted by Gilani et al., (2018), who demonstrated that the use of phytobiotics, organic acids, and their combinations led to a significant reduction in serum levels of cholesterol and triglycerides in broiler chickens.

Phytobiotics have been shown to decrease circulating cholesterol levels and inhibit lipid oxidation (Crouse et al., 1999; Fki et al., 2005; Starčević et al., 2020; Zeni et al., 2020). Additionally, studies by Chen et al., (2013) and Laka et al., (2022) elucidate their role in modulating cholesterol metabolism and improving lipid profiles. Additionally, phytobiotics are known for their ability to reduce the absorption of dietary cholesterol (Ahmed et al., 2017; Sarika et al., 2009), enhance the excretion of cholesterol (Koochaksaraie et al., 2011), and inhibit enzymes involved in cholesterol synthesis (Lee et al., 2007), thereby effectively lowering cholesterol levels in the animal's body.

Furthermore, the absence of significant changes and variations among treatment groups in BUN, creatinine, ALT, and total protein in the present study implies normal kidney and liver functions. These results indicate that the bioactive compounds from *Ficus nota* fruit juice were well-tolerated by the birds, without inducing any adverse effects on kidney and liver functions.

Growth Performance

The impact of fermented *Ficus nota* fruit juice on the growth of broilers, as presented in Table 4, was assessed using key parameters such as final weight, weight gain, and feed conversion ratio (FCR). Additionally, feed and water consumption were meticulously recorded and evaluated to provide a comprehensive analysis of the treatment's effects on broiler performance.

Statistical analysis revealed no significant differences (p>0.05) among treatment means for initial weights, indicating a high level of uniformity among the experimental birds. This uniformity is crucial for completely randomized experiments, as it minimizes the influence of weight variations on the results. The incorporation of fermented *Ficus nota* fruit juice in the drinking water of broilers resulted in significantly higher (p<0.05) final weight, weight gain, and feed conversion ratio (FCR) compared to the control group, with concentrations of 60-80 ml demonstrating the highest impact. However, no significant variation (p>0.05) was observed in the feed and water intake of the birds, indicating similar patterns of consumption across all groups.

Table 4. Growth performance indices (mean±SD) of broiler chickens supplemented with fermented *Ficus nota* fruit juice.

Parameters	T1 (Control)	T2 (40 ml)	T3 (60 ml)	T4 (80 ml)	CV (%)
Initial weight (g)	324.67±8.96	325.00±2.64	324.33±6.02	324.33±4.04	3.45
Final weight (g)	1335.33±5.68^{c}	1696.00±17.78^{b}	1992.00±10.78^{a}	2030.00±73.07^{a}	3.46
Gain in weight (g)	1010.67±14.57^{c}	1371.33±18.90^{b}	1668.33±16.19^{a}	1706.33±76.79^{a}	3.46
Feed intake (g)	2813.33±67.14	2871.00±49.72	2843.67±10.96	2835.67±46.05	3.46
FCR	2.78±0.10^{c}	2.09±0.06^{b}	1.71±0.01^{a}	1.70±0.05^{a}	3.61
Water intake (ml)	13851±63.31	13896±32.14	13910±21.79	13939±53.67	3.46

**Values with different superscripts differ significantly at the 5% level*

The inclusion of fermented *Ficus nota* fruit juice as a source of phytobiotics has demonstrated a positive effect on body weight and feed efficiency in experimental broilers. This aligns with existing literature emphasizing the benefits of phytobiotics in broiler feeds. Numerous studies, including those by Abdel-Wareth et al., (2019), Al-Sagan et al., (2020), Devi et al., (2018), Gheisar et al., (2015a, 2015b), Starčević et al., (2020), Toghyani et al., (2011), and Yan et al., (2011), consistently demonstrate the significant and observable economic benefits of phytobiotic supplementation on body weight (BW) and feed conversion ratio (FCR) in broiler development.

The similar patterns of feed and water intake among the treatment groups are crucial, as they imply that the observed differences in weight gain and feed efficiency are more likely attributed to the introduction of the fermented fruit juice treatment rather than differences in consumption patterns among the groups. This consistency strengthens the validity of the findings, indicating that the enhanced growth performance can be directly linked to the effects of fruit juice supplementation.

CONCLUSION

Supplementing broiler drinking water with 60-80 ml of fermented *Ficus nota* fruit juice enhances hematological indices and promotes broiler growth without causing harmful changes in blood biochemical parameters. These findings highlight the plant's potential as a safe and effective alternative for promoting health and growth in broilers. Furthermore, the results emphasize the importance of conducting further studies across different animal species to fully explore the benefits and applications of *Ficus nota* fruit juice in animal nutrition and health.

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The Impact of Climate Change on Countries in World

Oluwatosin Abidemi OGUNKALU

Nigde Omer Halisdemir University, Faulty of Agricultural Sciences and Technologies, Nigde, Türkiye

Corresponding Author: ogunkaluoluwatosin1@gmail.com

ORCID: 0000-0002-9188-7473

Abstract

Climate change controls the activities of human life entirely. Climate change effects daily resulted in disaster in our world. Climate change causes erratic weather patterns, melting ice sheets, and rising sea levels, which are well-known both globally and domestically. Thereby, impacting the environment negatively through biodiversity loss, food insecurity, lack of water, and Consumption of fossil fuels contributes to climate change and has implications for energy security. Climate change and energy security are two interconnected but distinct concerns for many countries, with varied approaches to balancing energy security, access, and affordability with sustainability and elevated and dried environment is likely to have an impact on wildfire activity, not only by creating more favourable conditions for burning but also by altering the structure of the fuel to be burned. Several effects of climate change have been discussed that affect some different countries of the world. This review highlights the impacts of climate change in countries around the world, creating awareness of its impacts can help to overcome its effects and this can result in a sustainable environment for the world at large.

Keywords: Climate Change, Global Warming, World

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INTRODUCTION

The global perceived and predicted change in climatic conditions for the 21st century, the warming of the earth's surface is a remarkable alteration to the globe which is usually experienced in sixty-five years. Climate change is a compounded government-related situation across the globe and its impacts are seen on all the parameters of ecological, surrounding, socio-political, and socio-economic aspects (Abbass et al., 2022). There is variation in the effects of climatic conditions around nations as do the demographics, socioeconomics, infrastructure, institutional capacity, and resilience of health systems. Therefore, there are regional variations in the capacity and complexity related to the health effects of climate (Schnitter and Berry, 2019). The rise in temperatures leads to food shortage For example, there is already an increasing chance of countless “breadbasket failures” (causing a food price shock) Amongst the top four maize-producing divisions (resulting in about 87% of maize production), The certainty of maize production misplacement is higher than 10% bounced from 7% yearly under a 2 °C temperature increase to 86% under 4 °C.

Increasing the necessary studies and measures to minimize the emissions of carbon emissions should be taken all over the world and measures that will minimize the greenhouse gas effect will play an important role in reducing the effects of global warming (Bağdatlı and Arıkan, 2020). Changing climate conditions will be an important factor in the current situation and the problems that may arise in the coming years. For this reason, solutions are needed for global warming and reduction of greenhouse gases that cause climate change (Bağdatlı and Arslan, 2020). The decrease over time of the changes in the surface of the water is noticeable. This also shows itself as the effect of disorder in the vaporization and current precipitation regime in the water sources dependent on climate change (Albut at al., 2018). Climate change has become the focus of constant attention of living things and civilizations take into account the climatic parameters determined their lifestyles. Climate increasing or decreasing in changes affect living things negatively. Decrease in productivity, especially in agricultural production causes (İstanbulluoğlu et al., 2013). Soil temperature decreases, plants that are not suitable for climatic conditions and resistant to cold will be affected by root and cause drying. As a result, a constantly increasing soil temperature will adversely affect plant life. It will decrease the efficiency (Bağdatlı and Ballı, 2020).

World effects of global warming caused by changes in the climate system of the highest peaks, ocean depths, is felt throughout much of the world from the equator to the poles. The polar ice caps are melting, sea level is rising and soil losses are experienced in coastal areas. Sea level due to melting of glaciers Increasing the temperature rose from 10 to 20 centimeters (Bağdatlı and Bellitürk, 2016a). Global climate change affects the world negatively day by day and reveals negative results in agricultural product yield. In particular, it is inevitable to evaluate the regional temperatures and to review the product pattern in parallel with the increasing global climate change (Bağdatlı et al., 2014)

The report from IPCC, in its 6th evaluation details, that the world populace of about fifty to seventy-five percent 50 to 75% of the global rendered vulnerable to life-threatening climatic conditions towards the end of the century as a result of excessive heat and humidity due which threatened the life of the populace. Production and outputs of important cereals crops can be unfavourably impacted as a result of high temperature with the combination of excess humidity. South and Southwest Asia can potentially be altered by this dangerous heat situation (Kemp et al., 2022). This review highlights the impacts of climate change on the countries of the world.

Climate change and Food Security in some country

Population growth rate along with the climate change phenomenon will cause lots of problems for worldwide food supply and we will face numerous nutritional problems in the near future. By gradually reaching to the 8 billion population on the earth, the mankind is really in challenge to provide the growing population food needs (Bağdatlı et al., 2015). Food production is a major concern that might be affected by climatic fluctuations (Bağdatlı et al., 2023; Elsheikh et al., 2023). For example, rising sea levels due to climate change can devastate forests, which are essential sources of food in many locations (Afreen et al., 2022). There is a direct impact of climate conditions on food security and the source of income for people who are involved in food products including their value chains. Currently, the total number of populaces impacted by starvation around the globe hit its high point in 2014.The channel of food distribution is affected by climate conditions which prevent physical access to markets through many means. The infrastructure is affected by heavy floods and snow and storms, road vandalization, bridges, and overpowering transportation channel transportation (Raj et al., 2022).

The variation in climatic conditions and their results such as floods, drought, heat, stress, cold waves, and storms yield unfavourable effects on agricultural production, specifically during cropping. The season is so important in food security and essential in food security, Hence, resulting in problems and complications in Asia. There was a challenge in the production of rice-wheat production, and this resulted in fifty percent of the food required to sustain Asia. The impacts of climate change are also felt in the quantity and quality of rice and wheat. For example, there was a reduction in protein composition and grain productivity as a result of the deadly impacts of increased temperatures (Habib-ur-Rahman et al.,2022). There are predictions that China's agriculture will have certain problems in upcoming years, majorly because of the increase in the pressure of food needs and, due to restricted land and water assets. China's challenges with food security will increase in the future as the populace, income, and resources become scarcer, there is likelihood of a reduction in the China food self-owned 94.5% in 2015 to approximately 91% by 2025 (Xie et al.,2020). The global and domestic food structure could be impacted by climate conditions and the repercussions can be direct and indirect. In the world at large, It has been reported that climate conditions could yield a remarkable impact on malnutrition, a dangerous health risk in this century. Thirty endangered nations to climate change impacts were evaluated for malnutrition, it was seen that there was six percent from 398 million people in 1990 to 422 million populaces in 2016. Seventy-five million additional undersized children by 2030 and 10.1 million by 2050.Moreover, projection of malnutrition in children that are below age 5 by 2050. The world at large recently experienced an increase in climate-associated shocks related have aggravated the movement. The case of climate change impacts in Canada, majorly on food security, specifically in the northern and the local populace. The impacts of climate such as reduction in time, thickness, sea and lake ice, and thawing permafrost. More especially in uncertain weather -like freezing rain, wildfires, shorter winter duration, food safety, and preservation and security (Schnitter and Berry, 2019).

Impacts of Climate change on water

Climate change and global warming are reducing the available water resources almost everywhere in the world (Uçak and Bağdatlı, 2017). The increase in the impact of global climate change will cause global water crises between countries. Necessary measures and measures should be taken in advance to reduce the impact of global climate change (Bağdatlı and Arslan, 2019).

According to Research by Lange (2019); The Middle East and North African region is anticipated to face future climatic changes that exceed worldwide averages. As a result, the region has been designated as one of the Earth's climate change "hot spots". Extreme weather conditions will have substantial implications for water and energy security in at least sections of the Middle East and North African area. Climate change has a significant impact on water availability and security in the Middle East and North African region, including a longer dry season for most countries, a 30-70% reduction in aquifer recharge on the Mediterranean Coast, affecting groundwater quantity and quality and significant reductions in surface and subsurface water availability, affecting river flow, instream flow, and soil water reservoirs (with negative consequences). Jordan's accessible water resources are predicted to fall below the 50 m3 per capita/year barrier, which has been designated as the minimum amount needed for social and economic development. According to Chen et al., (2023) stated that coastal floods caused by tropical storms, as well as the lack of sustainable water resources in many other locations, are even more concerning consequences of climate change. Climate change modifies precipitation patterns, which may significantly exacerbate the water scarcity issue.

Impacts of Climate Change on Energy

Warming has had a long-term influence on annual economic growth, resulting in significant decreases in output in hotter, poorer countries. In contrast to coastal flooding caused by tropical storms, the availability of reliable water resources in many other locations is more concerning issue related to climate change. Climate change modifies precipitation patterns, potentially exacerbating the water scarcity problem. Energy is necessary for socioeconomic operations, overall development, and quality of life. Infrastructure, price, and service disruptions caused by disasters and extreme weather occurrences, which are frequently linked to climate change, all impede adequate energy access. However, energy usage and climate change have a complex relationship. Consumption of fossil fuels contributes to climate change and has implications for energy security. Climate change and energy security are two interconnected but distinct concerns for many countries, with varied approaches to balancing energy security, access, and affordability with sustainability. Hurricanes are predicted to be responsible for nine out of ten significant outages in the United States, and long-term outage risk is proportional to climate change-induced storm frequency and intensity (Chen et al., 2023).

Impacts of Climate on Economics

Global investment from fossil fuels increased significantly in 2022. Despite an overall downward trend, direct fossil fuel subsidies rose to US $440 billion in 2021, a concerning increase from levels below US $200 billion. The fraction of greenhouse gas emissions covered by carbon pricing remained generally stable between 2021 and 2022, as did the global emissions-weighted average price per ton of CO_2 (about US$14.20 as of 2022). To effectively reduce global fossil fuel consumption, both the fraction of emissions covered, and the price of carbon must significantly increase.

Climate change on Natural disasters (Flooding)

According to the research of Ripple et al., (2022) The complex interrelated mechanisms of climate conditions resulted in excess weather conditions in the world. Climate change effects increased sea level change in rainfall form and change in jet streams. Heating of the surface of rapid artic could elevate the possibility of the Northern Hemisphere’s summer jet stream causing obstruction, which led to heat waves, flooding, droughts, and other natural calamities. The populace in low-income areas is affected by undernutrition and they are among the categories that contribute to greenhouse gas emissions. Flooding displaced thirty-three people and sixteen million children were affected in Pakistan during summer in the year twenty-twenty two. Eastern Australia, river drying in China and Europe, and the South-eastern United States experienced serious hurricanes, and Bangladesh and India experienced storms and flooding.

Climate change and Natural disasters (Wildfire)

Excessive increase and decrease of temperatures negatively affect the life of living things. It will be difficult to find clean water in the future as the increase of temperatures will increase the evaporation level. Increasing or falling temperatures will cause climate change (Bağdatlı and Can, 2020). The impacts of climate change on land occurs in several channels and its effects result in unpredictable weather styles. The dangerous elements of weather such as continuous heat waves, increased cold storms, droughts, widespread wildfires, dangerous inland floods, landslides, mudflows, urban heat islands, and air pollution, all result from high temperatures and unpredictable rainfall patterns.

Three variables are needed for wildfire to occur which are ignition, fuel, oxygen, and the root cause of ignition. The temperature between land and sea is projected to increase because of climate change and this variance in temperature of land and sea leads to land-sea constraints variation that later cause coarseness of wind power in the tropical and southern subtropical regions. As the wind becomes stronger, there is an increase in the supply of oxygen to the wildfires and this increases their spread to cover larger space which usually results in an uncontrollable fire incident for the firefighters departments (Xu, et al., 2020; Ripple et al., 2022). Lately, an unparalleled magnitude of wildfires occurred globally. Canadian government stated an uninterrupted record-breaking wildfire in the year 2023 should be a concern for the world. Australia reported wildfire occurrence between 2019 to 2020, Brazil in 2019 and 2020 and the United States of America reported wildfire between 2018 and 2020 in the western part of their country. British Columbia, Canada reported in 2017, 2018 and Southern Europe in 2017 (Chen et al., 2023).

Wildfire could also occur in an environment that is generally warm and dried, this does not occur just because the warm and dried favours the burning but also because of the alteration of the structures of the fuel that is expected to burn. This implies that the connection between climate and fire is likely to be altered in the future, and this irregularity in the climatic conditions may result in oscillatory effects in wildfire effects as a result of production changes (Turco et al., 2018). Climate warming is projected to result in a quick increase in burning areas over the Mediterranean region, increasing from ~40% to ~100% depending on the scenario (Chen et al., 2023).

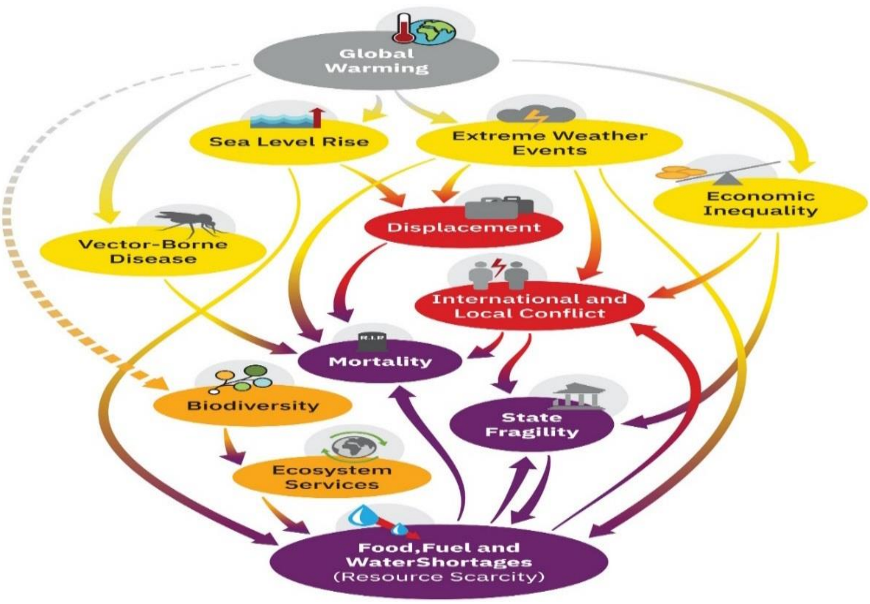

Figure 1. Diagram showing different aspects climate change affect the world. (Kemp et al., 2022).

Impacts of climate change on crop and animal diseases

Ayeri et al., (2012) reported changes in rainfall volume and pattern in Kenya, this occurrence alters soil erosion rates and moisture levels, both of which have a considerable impact on crop yields. Furthermore, rising temperatures make it harder for crops to thrive despite minimal rain, while increased wind puts crops at risk of being blown away or damaged.

The farmers at Muhonia, Kenya have a 76% perception of a high prevalence of animal diseases, compared to Umande's 54%. Heartwater, east coast fever (ngai), anaplasmosis (ndigana), and pneumonia (mahuri) were examples of diseases connected with climate change. Other diseases and pests listed were blindness, babesiosis, worms (njoka), and lumpy disease. Similarly, smallholders in Umande and Muhonia observe an increase in crop disease incidence of approximately 90% and 95%, respectively. Crop diseases addressed include blight and leaf rust. Crop pests described include spider mites, aphids, millipedes, and muthingiriri (little black ants).

Climate change impacts on Biodiversity

Gradually decreasing rainfalls due to climate changes endanger the living habitat. As a precaution, precise solutions are needed to reduce carbon dioxide in the air and slow down global warming and eventually end it. In this way, greenhouse effect and global warming can be prevented (Bağdatlı and Can, 2019).

International trade can put additional strain on habitats with a high potential for land conversion, such as tropical forests, which have serious implications for biodiversity. For example from 2000 to 2011, the cultivation of beef, soybeans, palm oil, and wood products in seven countries (Argentina, Bolivia, Brazil, Paraguay, Indonesia, Malaysia, and Papua New Guinea) accounted for 40% of total tropical deforestation and carbon losses. It is estimated that around 20% of the total global farmland area was used to grow crops for export in 2008 and that between 1969 and 2009, land for export production increased quickly (by about 100 Mha).

Several international trade trends hurt biodiversity because they facilitate connections to reach growing global food demand through the expansion of agricultural land areas in highly biodiverse regions, as well as the displacement of local biodiversity by invasive species (Ortiz et al., 2021).

CONCLUSION

Global climate change, the industrial revolution of the then mankind atmosphere to release the carbon dioxide, methane, ozone and nitrogen oxides as gases are very quickly heat the earth by the greenhouse effect that occurred as a result of the increase is a result of an increase above normal (Bağdatlı and Bellitürk, 2016a). Increasing world population, changing climate conditions and economic activities are growing with each passing day makes it more important than water (Bağdatlı and Bellitürk, 2016b). Climate change impacts include excessive weather such as dramatic changes in temperature, precipitation, and wind speed, productivity, food provision shortages and insecurity, disturbance of terrestrial and marine ecosystems, infrastructure and resource damage, as well as general economic and social instability,physical and mental diseases, and persistent socioeconomic and ecological stresses. The food system is interrelated and requires efforts from multiple sectors to function well. The impacts of climate change on different countries of the world cannot be overemphasized as it is obvious that the predicted changes in climatic conditions and their repercussions would heighten demands for basic needs and increase the risks to water and energy security in the world. Natural disasters such as flooding and wildfire which occurred as a result of elevated temperatures have caused a lot of families to be displaced while billions of people have lost their lives as a result of climate change globally. There is a need for policymakers to come up with policies to overcome the effects of climate change in the world.

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Assessing Wheat Yield Responses and Growing Stages Alterations to Diverse Climate Change Scenarios

Ahmet Fatih AKANSU[1], Tefide KIZILDENİZ[2*]

[1]*Department of Plant Production and Technologies, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Türkiye.*

[2]*Department of Biosystem Engineering, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Türkiye.*

[*]*Corresponding Author: tefidekizildeniz@gmail.com*

ORCID: 0000-0002-5254-1082[1], 0000-0002-5627-1307[2]

Abstract

Climate change is now acknowledged as being one of the globe's most significant environmental challenges of today's World. One of the most frequently utilized agricultural crops in the world and is cultivated a wide range of staple foods and energy sources for its crucial economic significance in the Anatolia. Wheat is adapted to the local ecological circumstances in the Central Anatolian province of Konya. Therefore, it is essential to predict its response to changing climate. This work aimed to assess the potential influence of climate change on wheat yield and phenology alteration in Konya by applying the LINTUL-MULTICROP Model. Four distinct scenarios were contrasted to limit the impact of climate change on wheat production in the Konya province. The scenarios are as a) current condition, b) current condition +2°C, c) current condition +4°C, and d) current condition +200 ppm. Results indicate that a 2°C temperature increase leads to the yield from 5.5 to 6.9 t ha^{-1}, while a 4°C increase further boosts the yield from 5.5 to 8.0 t ha^{-1}. Additionally, an increase of 200 ppm in CO_2 levels results in a yield of 7.1 t ha^{-1} with a corresponding change in Radiation Use Efficiency (RUE) to 1.56 g MJ^{-1}. Changing the planting date can lessen the detrimental impacts of climate change on cereal production. It highlights the significance of irrigation to increase agricultural output and efficiently manage water resources.

Keywords: Crop modelling, Climate change, Wheat, LINTUL, Yield Estimation

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INTRODUCTION

Climate change is now acknowledged as being one of the globe's most significant environmental challenges of today's world (Raihan, 2023) with extensive consequences such as rising temperatures being the principal source of concern (Lee et al., 2023), along with drought and other climate-change related factors across the world (IPCC, 2018). Consequently, increased food demand, especially regarding to wheat that is considered as the world's second largest consumed cereals commodity (Asseng et al., 2015), and its yield is estimated to reduce by 0.2-0.8 t ha^{-1} during 2080–2100 (Alsafadi et al., 2023) ought to remain at pace with the projected population expansion. Climate change has made this goal more difficult to attain (Ahmad et al., 2023).

Emerging worldwide affluence imposes an additional strain on agricultural production by raising the need for premium agricultural products, livestock forage, and fiber. Whilst increased CO_2 levels may boost wheat yield and growth in certain wheat-producing territories in the coming years, this is only if there is an abundant accommodate with water and nitrogen (Hernandez-Ochoa et al., 2018). Moreover, wheat yields are anticipated to fall in the majority of wheat-producing countries (Osman et al., 2022) when global temperatures rise by 1-4 °C by 2100 (IPCC, 2018).

Wheat is an essential crop for the world's food stability, but boosting wheat production on present cultivating areas is unlikely to meet the larger portion of projected worldwide demand for food predictions (Kettlewell et al., 2023). Wheat holds the distinction of being the most extensively cultivated crop and produced cereal crop in the world for human consumption. This is due to the broad adaptability of the wheat plant. In addition, the wheat grain is the staple food of approximately 50 countries due to its favorable nutritional value, ease of storage and processing. Wheat provides about 20% of the total calories derived from plant-based foods to the world population and it is 53% for Türkiye (TÜİK, 2022). According to TÜİK (2022), wheat yield reached to 335 kg da^{-1} in Konya. Wheat is used in many food and industrial sectors, including baked goods (Republic of Turkey Ministry of Agriculture and Forestry, 2023). However, climate change is allowing wheat to be produced on formerly uncultivated ground at upper northern latitudes. There are various issues with producing wheat in these areas, the most serious of which being its emission of greenhouse gasses (Kettlewell et al., 2023). Konya, located in the Türkiye's Central Anatolian Plateau, plays a pivotal role in the nation's wheat production (Özensel, 2023). Ranked second only to Şanlıurfa in terms of cultivation area, the region boasts fertile soil and a temperate climate – seemingly ideal conditions for nurturing this vital crop. However, the challenges and opportunities presented by Konya's unique ecological environment must be carefully evaluated, as maximizing both wheat yield and quality has become crucial (Akman & Topal, 2011).

Wheat is a high yield-drought sensitive (Zahra et al., 2023) that drought including other abiotic factors can reduce wheat yield by up to 71%, particularly in rainfed areas (Rana et al., 2013). Drought stress impacts wheat at different stages of growth, including jointing, tillering, and anthesis (Thapa et al., 2020). These critical stages are particularly vulnerable to water deficits (Dhakal, 2021). Drought stress causes a number of biochemical and physiological changes in wheat plants. These changes include decreased water content, reduced stomatal closure, stunted growth, and leaf water potential (Jaleel et al., 2009). Drought stress also disrupts nutrient and water relations, throws phenological timing off kilter, and stifles respiration and photosynthesis (Farooq et al., 2009). To mitigate the impacts of drought stress on wheat, it is important to understand the complex nature of this stress. Various management practices, such as drought-resistant cultivars, developed irrigation techniques, and techniques of soil conservation, can help wheat to withstand drought stress (Dhakal, 2021).

As evidenced by the IPCC report, the ever-increasing threat of climate change poses significant challenges to global wheat production (Pachauri et al., 2014). The years 1980 to 2012 has been identified as the warmest in the past 1400 years, leading to adverse effects on crop yields, particularly for vital fundamental foods like wheat (Dettori et al., 2017). The effects of climate change on wheat development and yield is location-dependent, influenced by temperature thresholds and variations in heat and drought stress (Porter & Gawith, 1999).

Studies in different regions, such as France and Italy, indicate accelerated flowering dates and reduced yields due to climate-induced changes (Gouache et al., 2012; Dettori et al., 2017). Nevertheless, the complex relationship between temperature and wheat development offers opportunities for mitigation through agronomic management strategies. One such strategy involves leveraging crop models to predict and adapt to climate change influences (Lobell & Burke, 2010). The use of crop models, like the one employed by Wang et al. (2015) in Australia, allows for the simulation of various scenarios, enabling farmers to adjust critical developmental stages by manipulating sowing dates that is altered resulted in a viable strategy to counteract yield decline and adapt to changing climatic conditions. Similarly, Nouri et al. (2017) proposed the postponement of rainfed wheat cultivation's sowing dates in Northwest Iran to align with favorable precipitation periods. As an adaptive alternative, this approach enhances precipitation during crucial growth phases, thus mitigating the adverse impacts of climate change on wheat production. These studies demonstrate that employing crop models in wheat cultivation offers a proactive approach to anticipate and manage the impacts of climate change. By strategically adjusting sowing dates based on model predictions, farmers can optimize developmental stages, ensuring suitable phenology for the changing climate (Ahmad et al., 2023; Wang et al., 2015; Nouri et al., 2017).

The Lintul Model, inspired by studies in Middle Asia (Sommer et al., 2013), provides a comprehensive assessment of the influences of climate change on wheat developmental stages and yield. Notably, the model indicates an overall favorable influence on wheat yield in Middle Asia, attributed to a reduction in the risk of late spring cold stress and a rise in thermal stress (Sommer et al., 2013). The Light INTerception and UtiLization (LINTUL) models (Spitters & Schapendonk, 1990) or in other named "Lintul Model"'s strength lies in its ability to simulate various climate scenarios, offering insights into the dynamic relationship between temperature changes and wheat development (Ahmed et al., 2013). The initial adaptation of the model (LINTUL 1) was established to estimate potato crop development using daily collected photosynthetically active radiation (PAR) and light utilization efficiency within optimum development circumstances. LINTUL 2 was evolved further to model crop growth in water-stressed environments (Spitters & Schapendonk, 1990). Winter oilseed rape (Habekotté, 1997), banana (Nyombi, 2010; Taulya, 2015), corn (Farré et al., 2000), and rice (Shibu et al., 2010) have all advantageous crops that were simulated by this model. Adopting Monteith (1977), the model anticipates that biomass rate of development is directly related to the quantity of light intercepted with a fixed light or radiation consumption effectiveness. The LINTUL model is a beneficial instrument for understanding the impact of climate change and other factors on wheat production. It can be used to develop strategies for adapting to these changes and guaranteeing food security in the future. Therefore, this work aimed to assess climate change's possible effects on the cultivation of wheat and wheat phenology alteration in Konya by applying the LINTUL-MULTICROP Model.

MATERIAL and METHOD

Model Explanation

The LINTUL-MULTICROP model, originally developed in Fortran and converted to MS-Excel by Linus Franke of the University of Bloemfontein, South Africa, was used for crop simulations. The model was first employed in scientific studies by Haverkort et al. (2013) and Franke et al. (2013).

Three key data types are required for model simulations: climate, crop, and soil. Climate data includes average minimum and maximum temperatures (°C), precipitation (mm), solar radiation (MJ m^{-2} day^{-1}), and monthly evapotranspiration values (mm). These data form the first input set. Crop data, the second input set, includes planting and harvesting dates (days), planting and effective rooting depth (cm), dry matter concentration (%), harvest index (%), sprout growth rate (mm degree day^{-1}), effective temperature sum between emergence and 100% ground cover (GC) (0-100% GC, degree day), radiation use efficiency (RUE, g MJ^{-1}), minimum and maximum photosynthesis temperatures, and optimal photosynthetic temperatures. Soil data, the final input set, allows users to choose from a pre-defined list of nine soil types with varying bulk densities, water capacities, wilting points, and accessible water contents. The LINTUL-MULTICROP model generates various outputs. By calculating the growing time (days), days between planting and emergence, days between emergence and 100% GC, and days between 100% GC and harvest, the model suggests potential adaptation strategies for climate change. Additionally, the model uses precipitation and ETP data to determine irrigation water requirements. Finally, the model predicts yield (t ha^{-1}) under both irrigated and dry conditions.

Study Site

The research was carried out in the Konya Province, located in Central Anatolia, Turkey (37°41' 29" N, 33°14' 39" E; altitude 1016 m) because of Konya Province (Figure 1) is a part of the Konya Plain that as the second-largest plain and is accounting for 17% of all agricultural areas in Türkiye. A semi-arid climate prevails in the region and the average climate data from 1929 to 2022 and the monthly crop evapotranspiration data (ETP) are given in Figure 2 (TSMS, 2022).

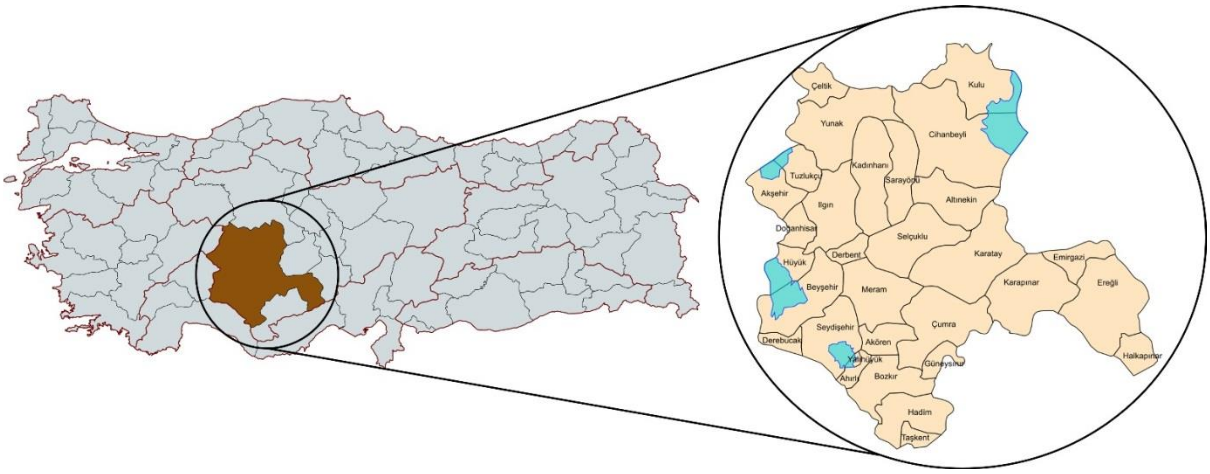

Figure 1. Study Site (Konya)

Plant Material

Wheat, perfectly adapted to the region's ecological landscape and holding significant economic importance, was chosen as the plant material for this research due to its major production and consumption cereal in Türkiye. The LINTUL-MULTICROP model was apply to model the impacts of climate change on the cultivation of wheat, utilizing input crop data meticulously collected from diverse, and reliable sources, as presented in Table 1.

Climate Change Scenarios

To comprehensively examine the impacts of climate change on wheat cultivation in the semi-arid Konya Region, four scenarios were devised; Scenario (a): Current climate conditions, simulated for the Konya Province to serve as a reference point; scenario (b): Current conditions, augmented by a 2°C temperature raise; scenario (c): Current conditions, augmented by a 4°C temperature raise; scenario (d): Current conditions, augmented by a 200 ppm increase in atmospheric CO_2. By varying the temperature and atmospheric CO_2 levels, these scenarios enable us to evaluate the most likely effects of climate change on wheat farming in the Konya Region.

Table 1. Factors for the model input

Parameter	Value	Reference
Month of planting	10	Ministry of Agriculture and Forestry, 2017
Day of planting	15	Purucker, 2020
Planting depth (cm)	4	
Month of harvest	6	Balaghi et al., 2008
Day of harvest	7	
Rooting depth (cm)	90	Fan et al., 2016
DM concentration (%)	87	Fang et al., 2010, Papakosta & Gagianas, 1991, Zhang et al., 2008
Harvest index (%)	33	Tari, 2016
The days between emergence and 100 GC	177	Hoogendoorn, 1985
RUE (g MJ^{-1})	1.2	Sandaña et. al., 2012
Min. photosynthesis temp. (°C)	0	Khan et al., 2020
Min. photosynthesis temp. (optimal) (°C)	14	
Max. photosynthesis temp. (optimal) (°C)	25	
Max. photosynthesis temp. (°C)	30	
Actual yield (kg da^{-1})	335	TÜIK, 2022

RESULTS and DISCUSSION

The current wheat yield is 5.5 t ha^{-1} while actual yield is 3.35 t ha^{-1} (Turkish Data Portal for Statistics, 2022) due to may not reflect real-world variability such as unexpected weather events, localized pest and disease outbreaks, or differences in soil quality and/or more accurate or generalized input data, assume advanced technologies and practices not fully adopted by all farmers, and not account for the variability in actual farming techniques and if the temperature increases by 2°C, the yield increases to 6.9 t ha^{-1}. If the temperature increases by 4°C, the yield further increases to 8.0 t ha^{-1}. With an increase of 200 ppm in atmospheric CO_2 levels (RUE 1.56), the yield reaches 7.1 t ha^{-1}. The growth season length was simulated by the LINTUL- MULTICROP for different scenarios.

In scenario (d), if 200 ppm is added to the existing atmospheric CO_2 amount, the new RUE value is determined as 1.56 g MJ^{-1}. Tang et al., 2018 examined the potential yield and water requirements of winter wheat in the Huang-Huai-Hai Plain under the RCP4.5 and RCP8.5 scenarios. The results showed that potential yield increased from the northwest inland to the southeast coast under both scenarios, while evapotranspiration (ETc) decreased from the Shandong Peninsula to the surrounding areas. Under the RCP4.5 scenario, potential yield, ETc, and effective precipitation increased, leading to a decrease in irrigation water requirements. In contrast, under the RCP8.5 scenario, potential yield, ETC, and irrigation water requirements first increased and then decreased. These findings provide valuable insights for mitigating the impacts of climate change on agricultural production and water use.

On the other hand, Yeşilköy and Şaylan (2020) ‘s study assessing the future impacts of climate change on winter wheat in the Thrace region of Turkey, results indicated that increasing temperatures and atmospheric CO_2 concentrations could significantly boost wheat yields by up to 46.8% by the late 21st century under the RCP 8.5 scenario. Consequently, the water footprint (WF) of winter wheat is projected to decrease by as much as 82.5% due to increased yields and changing precipitation patterns.

Since harvesting dates were input of the model, the total growing period was not changed for all scenarios (Table 2). Days between emergence and 100% GC scenarios a and d remained the same in this evaluation criterion and were determined as 177 days. However, although there is a difference in scenarios b and c, there was a 38-day decrease in scenario b. For scenario c, there was a decrease of 84 days. Thus, the germination times of the plants decreased in scenarios b and c. Considering the climate data of Konya, 600-700 mm of precipitation, distributed in accordance with the growing period of wheat, is sufficient for maximum yield in wheat cultivation (Dündar & Topak., 2021). Irrigation water requirements were determined as 25.19 mm for scenario a, and these values were calculated as 20.66 mm and 16.90 mm for scenario b and c, respectively. It is calculated as 19.38 mm for scenario d where +200 ppm increase is added. Alexandrov & Hoogenboom (2000) reported that modification of the sowing date can decrease the adverse influence of climate change on wheat cultivation. The cultivation period of wheat in the semi-arid environment of Konya has been established as 235 days and it does not change under any scenarios.

Table 2. Growing stages of wheat grown in different scenarios

Growing stages	Climate Change Scenario			
	a	**b**	**c**	**d**
Days between planting and emergence	4	3	3	4
Days between emergence and 100% GC	177	140	93	177
Days between 100% GC and harvest	54	92	139	54
Growing period (days)	235	235	235	235

In scenario a, the potential yield is 5.5 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement is 25.19 mm. In scenario b, the potential yield increases to 6.9 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement decreases to 20.66 mm. In scenario c, the potential yield further increases to 8.0 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement decreases to 16.90 mm. In scenario d, the potential yield is 7.1 t ha^{-1} for potential yield and yield irrigated.

The irrigation water requirement is 19.38 mm. These values demonstrate the variations in potential yields and irrigation water requirements across different scenarios, highlighting the importance of irrigation for achieving higher yields and managing water resources effectively in agricultural practices (Table 3).

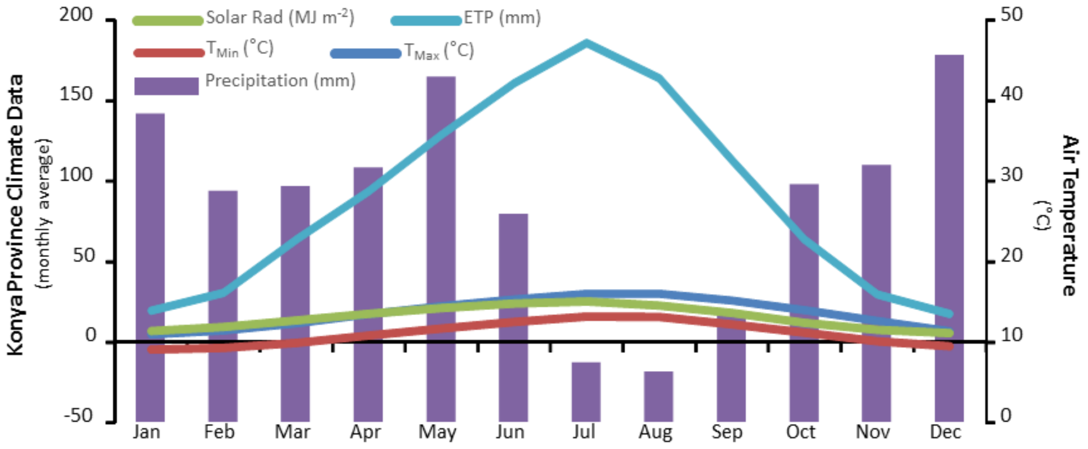

Figure 2. Temperature data according to climate change scenarios for current condition in Konya.

Table 3. Yield and irrigation simulations of different scenarios for wheat

Yield and irrigation requirement	Climate Change Scenario			
	a	b	c	d
Potential yield (t ha^{-1})	5.5	6.9	8.0	7.1
Yield irrigated (t ha^{-1})	4.9	6.1	7.2	6.3
Yield not irrigated (t ha^{-1})	3.6	4.4	5.3	4.6
Irrigation water requirements (mm)	25.19	20.66	16.90	19.38

CONCLUSION

The key findings indicate that a 2°C temperature increase (scenario b) significantly modifies the alfalfa growing period, requiring adjustments to seeding and harvesting schedules, while a 4°C temperature increase (scenario c) exacerbates challenges for wheat growers, potentially making current practices unsustainable. Additionally, increased CO_2 levels (scenario d) change sowing and harvesting dates, resulting in longer intervals between 100% Ground Cover (GC) and harvest. These findings highlight the urgency of developing and implementing effective adaptation strategies to mitigate the negative effects of climate change on wheat and alfalfa production in the Konya Region. Precision planting and harvesting can mitigate some adverse effects, but long-term solutions are necessary for sustainable production. The susceptibility of wheat to fluctuating climatic conditions requires a holistic approach to ensure its long-term sustainability.

This involves advancements in agricultural practices, technological innovations, and robust policy frameworks. Future research should focus on developing comprehensive long-term adaptation solutions that integrate the insights from this study, advancing agricultural practices, enhancing technological innovations, and establishing strong policy frameworks to ensure the long-term sustainability and resilience of wheat production amidst a changing climate. By elucidating the intricate relationship between climate change and wheat growth, this study lays bare the vulnerability of this essential crop. This knowledge paves the way for informed decision-making, effective policy formulation, and equitable resource allocation, all crucial for fostering proactive adaptation and sustainable agricultural practices. Ultimately, the development of robust and sustainable wheat production systems is imperative for safeguarding food security, economic stability, and environmental preservation in the face of climate change. Taking decisive action and implementing the solutions outlined in this study will ensure that wheat continues to thrive, providing sustenance and prosperity for generations to come.

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Family Labour Utilization among Small Scale Arable Crop Farmers: Evidence from Akoko South West Local Government Area of Ondo State, Nigeria

Gbenga F. KOLEDOYE

Department of Agricultural Extension and Rural Development, Faculty of Agriculture, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria.

Corresponding Author: festus.koledoye@aaua.edu.ng

ORCID: 0000-0001-6514-3123

Abstract

This study focused on the use of family labor by arable crop farmers in Ondo State, aiming to understand their involvement in farming and its implications for income and employment generation, particularly for the youth. The research specifically assessed the availability of family labor and its utilization level among farmers. A two-stage sampling procedure was employed to select 120 arable crop farmers across the Local Government Area of the State. Data were gathered using structured questionnaire and interviews for quantitative analysis, and Focus Group Discussions (FGD) for qualitative insights. The data were analyzed using Ordinary Least Squares (OLS) at a 0.05 significance level, and qualitative data were transcribed following standard transcription guidelines. The findings revealed that only 31.9% of the respondents utilized family labor, with 21.0% of this labour comprising the farmers' direct children. Family labor was primarily employed for activities like planting ($\bar{x}$ = 3.31), weeding ($\bar{x}$ = 2.72), processing ($\bar{x}$ = 2.13), and fertilizer application ($\bar{x}$ = 2.01). The OLS results indicated that age (t = -4.28; $p < 0.000$), years of experience (t = -5.96; $p < 0.000$), and farm size (t = 4.16; $p < 0.000$) significantly and positively influenced the use of family labor. The study concluded that arable crop farmers predominantly relied on hired labor, with family labor being employed for less physically demanding tasks, excluding land clearing and tree felling. It is recommended that the government should design a programme that could encourage youth to stay in the farming communities with the primary aim of making them available for family labour.

Keywords: Arable crops, Evidence, Family labour, Farmers, Small scale, Utilization

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INTRODUCTION

Agriculture employs over 60% of the Nigeria population and most of the farmers engage in the production of arable crops such as rice, yam, cassava, sorghum, maize, and soybean among other annual crops (Adebayo and Olagunju, 2015 and Ogaji et al., 2023). It is therefore a strategic crop category to combat poverty and hidden hunger (FAO, 2010).

Furthermore, it boosts the economy by turning out labour for industries, increases food production and booms domestic market for industrial goods. Apart from food production, it is a precondition for economic growth and development (Ujah and Okoro, 2009), especially in Nigeria where it engages more that 60% of the population (Onubuogu et al., 2014) as labour force either directly or indirectly. Thus, production of arable crop plays dominant role in job creation and livelihood for a major part of the society, and essentially, it creates values and wealth for the teaming population (NEPAD, 2013).

Agriculture entails essentially the production of crops and rearing of animals and among the common crops grown, arable crops are grown by almost all households in Nigeria (Onubuogu et al., 2014). These crops contribute to the share of agriculture in the country's GDP and possess a great potential comparative advantage to compete in the liberalized economy (Mohammed and Isgin, 2016). Similarly, either one arable crop or the other is grown by almost every household in Nigeria (Onubuogu et al., 2014). According to Marjanovic (2017), arable crops encompass a number of crops grown and reach gestation period within a year and these include grains, pulse, oil, forage, fiber, and tuber crops. Most common among these crops in Nigeria are, maize, rice, wheat, millet, lentil, soybean, cowpea, cotton, jute, potato, cassava and yam. Also, most arable crops, apart from being a food crop have equally become a commercial crop on which many agro-based industries depend on for raw materials (Oluwatayo et al., 2008). In crop and annual production, several resources are needed and among the resources, labour is very essential. The labour could be either hired or family. The family labour in most cases is underutilized and the cost are not usually accounted for. In recent time, in Nigeria, labour use has been an issue of concern and this may be responsible for decline in crop production. This is because Amaza and Maurice (2005) reported a sharp deterioration in the productivity of Nigeria’s agriculture and investigation revealed that lack of labour in rural areas contributed to this decline.

The role of family labor in Nigeria, particularly within its rural sectors, is a significant aspect of the country's socio-economic fabric. In these communities, family labor not only constitutes a primary source of employment but also plays a pivotal role in sustaining agricultural operations and other family-run businesses (Mohammed and Isgin, 2016). This form of labor, deeply ingrained in cultural traditions, ensures the transmission of skills and knowledge across generations, promoting a sense of ownership and responsibility among family members.

Technological advancements have emerged as a dynamic force influencing various aspects of the Nigerian economy, particularly in rural areas. These changes are pivotal in reshaping employment patterns, enhancing productivity, and altering the functional income distribution within these communities. The adoption of new technologies in agriculture and small-scale industries can significantly boost output, improve efficiencies, and pave the way for the diversification of rural economies. However, this transition also presents challenges, particularly in terms of workforce adaptation and the potential displacement of traditional labor practices (Ujah and Okoro, 2009).

The significance of labor in any economy cannot be overstated. As Schneider (2005) points out, labor is not just an economic factor; it holds profound social implications as well. Engaging the labor force effectively can mitigate various social issues, including poverty, unemployment, and crime. Labor's multifaceted role extends beyond its economic contributions; it fosters social cohesion, enhances the quality of life, and promotes societal stability.

Moreover, labor's interplay with other factors of production—land, capital, and entrepreneurship—is crucial for economic development. As a critical factor of production, labor influences the efficiency of other resources and drives innovation and growth. In the global context, labor dynamics are evolving, influenced by factors such as globalization, technological innovation, and demographic changes. These trends underscore the importance of adapting labor policies and practices to meet contemporary challenges and harness opportunities for sustainable development.

Therefore, the nexus of family labor, technological change, and economic and social roles of labor underscores the complex interdependencies shaping Nigeria's rural economy and its broader socio-economic landscape. Addressing these dimensions holistically can contribute to more inclusive and sustainable development, leveraging labor's potential to catalyze progress across multiple domains.

Some studies of labor use patterns among farmers in Nigeria, highlights the critical reliance on human labor in agricultural production, especially for smallholder arable crop farmers who constitute a significant portion of the agricultural output in Nigeria, ranging from 50 to 60% (Olayide, 2002; Ogaji et al., 2023). The findings indicate that contract labor is predominantly used for various farming activities, with male labor being the primary workforce. There is a suggestion for increased financial support for farmers to afford contract labor and an advocacy for the adoption of machinery to reduce labor intensity. This research underlines the importance of understanding labor patterns to enhance agricultural productivity and development

In Nigeria, agriculture is commonly practiced in the rural areas and currently, the rural areas are deprived of basic amenities, which makes young people who are potential labour force for agriculture to migrate at alarming rate to urban centres where there are relatively better social amenities. This makes labour very scarce and it is a major constraint to food production in Nigeria (Anyiro et al., 2021). The scarcity of labour in agriculture in Nigeria would have resulted to the use of family labour in a situation where they available. The availability of labour has been found to have impact on planting precision, better weed control, timely harvesting and crop processing (Oluyole et al., 2007). According to Tanko et al. (2006), Nigeria's food deficient situation has been worsened by declining farm productivity owing to inefficient production techniques, poor resource base and insufficient farm labour supply among others. Labour has been found to constitute a large proportion of cost in the food crop production process in Nigeria and inadequate supply of labour coupled with the use of crude implements which impedes farmers' ability to increase production have been attributed to poor productivity of food crops. Therefore, a study of the utilization of family labour would be very apt in determining the availability and level of utilization in food production in Nigeria.

Based on the identified research gap, the study was designed to assess the level of utilization of family labour among arable crop farmers in Akoko South Local Government Area, with a view to unraveling issue associated with family labour usage. Specifically, the study profiled the demographic characteristics of arable crop farmers, examined level of utilization of family labour and identified the variables that influence the use of family labour among respondents

MATERIALS and METHODS

The study was conducted in Akoko South West Local Government Area of Ondo State Nigeria. Akoko South-west Local Government Area is a Local Government Area with her headquarters in Oke-Oka, consisting about 15 communities with an approximately area of 226km and a population of 229,486 at the 2006 census (National population commission, 2006). Farmers in the LGA grow food crops and other cash crops for both domestic consumption and export. The common food crops common to the LGA are cassava, yam, groundnut, cocoyam, maize, tomator, pepper and many other annual crops while cash crops like cocoa, cashew, citrus, plantain, are also being cultivated alongside with these arable crops.

Farmers who produce arable crop and that cultivated less than two (2) hectares of farm land formed the population of this study. Simple random sampling techniques were used for this study. The appropriateness of this techniques was due to the fact that there is no prior information about the target population as no proper registered was found at the LG secretariat for arable crop farmers. Therefore, six out of the fifteen communities within the local government area were randomly selected. Secondly, twenty arable crop farmers were randomly selected in each of the selected six communities to form a total of one twenty (120) farmers used as the total sample size for this study. However, one (1) of the questionnaire used was expunged as it was not properly filled. This makes the total sample size used to be 119 arable crop farmers. Primary data were used for this study and they were collected with the use of questionnaire and interview schedule while Focus Group Discussion was used to collect qualitative data. Data collected were analyzed using descriptive and inferential statistics. Descriptive statistics such as frequencies, percentages and mean while inferential statistics such as multiple regression analysis was used to make inferences.

RESULTS and DISCUSSION

Socio-economic profile of farmers

Evidence in Table 1 shows that 58.0% and 42.0% of the sampled farmers were male and female respectively. This shows that both male and female arable crop farmers in the study area were involved in the cultivation of arable crops in the study area. It is observed that almost equal proportion of both sexes participated in the production of arable crops. The implication of this finding is that arable crop production may not have any gender barrier in the study area. This finding is against the finding of Bassey and Okon (2008) who established that females were more involved in the arable crop production in the study area. The result shows that most of the farmers were found between 40 and 49 years while reasonable proportion (22.7%) of them were found as 50 years and above. The means age of 49.63 years shows that most of the sampled farmers are still within their productive ages.

The implication of this finding is that farmers sampled for this study seem to be at their productive and active ages, which are useful as farmers' productive ages. This contradicts the study of Alao et al. (2013) that says most of the respondents are 58 years.

Furthermore**,** results show that 86.6% of the respondents were married and 13.4% were single. This means that majority of the respondents were married. The implication of this study is that respondents who were married work together with their spouse to support optimal production of their arable crops and to promote their livelihood. It also means that they contribute more to farming in terms of labor. This could reduce the need for hired labour. It was also shown that 27.7% of the respondents has no formal education, 24.4% has primary school education, 39.5% has secondary school education while 8.4% has tertiary school education. The finding shows that most of the respondents were found having secondary school education. This study rejects the notion by Alao et al. (2013) that an average proportion of the respondents had no formal education.

In addition, results show that the mean number of years spent in school was approximately 14 years with a standard deviation of approximately 4 years. The implication of this finding is that on average, sampled respondent had primary education. At the same time, the difference between the respondents' educational status does not differ significantly with the low standard deviation, which is the interpretation of the deviation from the mean. The finding is in consonant with the study of Alao et al. (2013) that states that majority of the farmers were illiterate without any form of schooling experience in terms of the numbers of years spent in formal education. Also, it was revealed that respondents were experienced with average experience of 23 years approximately with a standard deviation of approximately 9 years. The implication of this finding is that on average, respondents had much arable arable farming experience. This is likely to impact positively on arable crop production as experienced have been found to enhance the use of improved technology. Experienced people are believed to have learned through several years of trials and errors. This is in line with the study of Bassey and Okon (2008)

Similarly, results show that the mean size of sampled farmers' farm was 1.3 hectares of land with a standard deviation of 0.13 hectares. The implication of this finding is that farmer's farm size are small which also makes the standard deviation low. Small farm size of the respondents influenced the choice of family labour. This is in line with an expectation of farmers opting for family labour to meet their small-scale farm requirements. This study is against the study of Alao et al. (2013) that states that farm size of the respondents is 9.12 hectares.

Family labour utilization and level of use

This finding shows where farmers make use of family labour the more, which are; planting, weeding, and fertilizer application. Specifically, labour was mostly used for planting ($\bar{x}$=3.31), weeding ($\bar{x}$=2.72), food processing ($\bar{x}$- 2.13) and fertilizer application ($\bar{x}$=2.01) based on the results in Table 2. The implication of the result is that, to get maximum yield in arable crop production, there will have to be maximum labour in land clearing, weeding and food processing. This study is in support of the study of Albert et al. (2020) which states that farmers use family labour more in weeding, planting, application of fertilizer, unity in task execution, safe guard for food security and traditional practices in agriculture.

This study elucidates the predominant utilization of family labor in agricultural activities such as planting, weeding, and fertilizer application. It highlights that the intensity of labor usage varies across different tasks, with planting receiving the highest labor input, followed by weeding and fertilizer application. The results underscore the critical role of labor in enhancing productivity in arable crop farming. Echoing Albert et al. (2020), the findings reaffirm that strategic employment of family labor in these key activities not only promotes efficiency and yield but also aligns with traditional agricultural practices and contributes to food security. This comprehensive understanding underscores the importance of optimized labor allocation in farming operations to ensure sustainable agricultural outcomes.

Availability of family labour for farm work

The finding in Table 3 shows that the farmers' children, extended family are not really available for farm work than their husband/wife. The implication of the study is that children may not have any interest in farm work, some may not have the ability to be involved in such tedious work and they leave their parents alone doing the work. It also implied that extended family does not really have any contribution to farmers' farm because some may also have their own farm to work on and having no or limited time to work on another person's farm. The findings reveal the unavailability of family labour for farm work. This conforms to the findings of Yusuf (2018), which supported the unavailability of family labour for most farm practices in Nigeria. The non-availability of family labour for farm work was attributed to lack of social amenities based on the excerpt from the FGD conducted in Supare Akoko as transcribed thus: …many of our children leave the community for urban cities because of lack of social amenities such as school, roads, electricity, portable water and even health centre. Many of them are in the state capital using motorcycle to work as transporters. They hardly come home as they believe that leaving in the cities make them better…Excerpt from FGD at Supare in Akoko South West Local Government Area.

The above analysis that indicates limited availability of children and extended family members for farm work suggests a potential shift in family labor dynamics within agricultural practices. This shift may reflect broader socio-economic trends, such as the lack of interest among younger family members in farming, possibly due to the arduous nature of farm work or more attractive opportunities elsewhere. The limited involvement of extended family could be attributed to their own agricultural commitments or the allure of better infrastructural facilities in urban areas, leading to rural-urban migration, especially among the youth. These patterns support Yusuf's (2018) findings and highlight a pressing challenge in sustaining family labor within the agricultural sector, underscoring the need for strategies to engage younger family members or compensate for this labor shift to maintain farm productivity.

Determinants of family labour utilization

Result in Table 3 shows the relationship between selected socio-economics characteristics and utilization of family labour. It was observed that age ($t=4.28$; $p<0.000$), years of experience ($t=5.96$; $p<0.000$) and farm size ($t=4.16$; $p<0.000$) were the significant variable that had positive influence on the utilization of family labour in arable crop production in the study area. The implication of this finding may be connected to the fact that farmers who are still economically active, having large farm size with long time experience in farming would probably use family labour more than those farmers who are aged. The findings underscore the significant correlation between certain socio-economic factors—namely, age, years of experience, and farm size—and the utilization of family labor in arable crop production. The data suggests that younger, more experienced farmers with larger farm holdings are more inclined to employ family labor. This could be interpreted as a reflection of more extensive operational needs and a greater capacity for mentorship and task delegation within larger family-run farms. Additionally, experienced farmers likely have a deeper understanding of the efficiencies family labor can bring, optimizing the blend of tradition and expertise to enhance productivity and sustainability in their farming practices (Yusuf, 2018). Such insights offer valuable implications for agricultural policy and family labor management strategies, emphasizing the need to consider demographic and experiential dynamics in agricultural development planning.

Table 1. Socio-economic characteristics of arable crop farmers

Sex	**Freq. n = 119**	**%**	**Mean**	**Std. Dev.**
Male	69	58.0		
Female	50	42.0		
Age (in years)				
<30	13	10.9		
30 – 39	24	20.2		
40-49	55	46.2	49.63	
50 and above	27	22.7		
Marital Status				
Married	103	86.6		
Single	16	13.4		
Level of education				
No formal education	33	27.7		
Primary school education	29	24.4		
Secondary school education	47	39.5		
Tertiary school education	10	8.4		
Number of years spent in school			13.76	3.69
Years of farming experience			22.11	8.45
Farm size (hectares)			1.25	0.13
Members of Co-operative/association	41	34.5		
Access to subsidy from government	11	9.2		
Major sources of capital for farming				
Personal savings	66	55.5		
Credit borrowed	13	10.9		
Family	40	33.6		
Access to credit	9	7.6		
If yes, number of times in last one year			1.41	0.09
Visited by an extension agent	5	4.2		
If yes, no of times in the last one year?			1.98	0.18

Source: Computed from field survey, 2022.

Table 2. Family labour utilization and level of use among arable crop farmers

	Utilize family labour		Level of utilization	
Farming activities	**Freq.**	**%**	**Mean**	**Std. Dev.**
Land clearing	31	26.1	101	0.04
Tree felling	12	10.1	0.61	0.12
Burning	29	24.4	1.16	0.19
Making of ridges	12	10.1	1.12	0.35
Planting	67	56.3	3.31*	0.14
Weeding	75	63.0	2.72*	0.27
Mulching	55	46.2	1.81	0.21
Staking of crops	31	26.1	1.18	0.12
Application of herbicides	27	22.7	1.13	0.08
Application of fertilizers	72	60.5	2.01*	0.88
Planting of crops	47	39.5	1.27	0.32
Application of fertilizers	43	36.1	1.27	0.71
Harvesting	59	49.6	1.87	0.24
Food processing	72	60.5	2.13	0.24

Source: Computed from field survey, 2022 **Mean > 2.00 = High level of use*

Table 3. Availability of family labour for farm work

Major sources of your labour	**Freq.**	**%**	**Mean**	**Std. Dev.**
Is family member the major labour used?	38	31.9		
Is hired the major labour used?	111	93.3		
Are your children available for farm work?	25	21.0		
Do you have extended family available for farme work?	16	13.4		
Is your wife /husband available for farm work?	39	32.8		
Do you live in the farm house within the farm?	14	11.8		
Are you happy living in the farm house?	14	11.8		
How many hours do you work per day?			6.19	1.36

Source: Computed from field survey, 2022.

Table 4. Determinants of utilization of family labour

Variables	**B. coeff.**	**Std. Err.**	**t-stat**	**Sig.**
Age	2.78	0.65	4.28**	0.000
Number of years spent in school	0.29	0.19	1.53	0.671
Years of experience	1.55	0.26	5.96**	0.000
Farm size	3.16	0.76	4.16**	0.000

Source: Computed from field survey, 2022. *R- Squared value = 0.691, Adjusted R-squared value = -0.163*
***Significant at 0.01 level of significance*

CONCLUSION and RECOMMENDATIONS

Labour is one of the most limiting resources in crop production. Given that the dominant structures for agricultural production are family farms, this paper investigates the use of family labour in Akoko South West Local Government Area of Ondo State, Nigeria as a case study. The study shows that family labour was not seriously used for most agricultural practices and the non-use of family labour would imply that cost of production would be high among the respondents, although the findings establish that family labour was not also available but the available ones were used for the none tedious agricultural practices like planting, wedding and fertilizer application. The findings recommend that farmers should make use of the available family labour in order to reduce cost of production. Also, government should provide basic amenities to the rural communities in order to encourage the stability of labour with a view to enhancing their utilization.

Labor scarcity is a critical constraint in crop production, particularly in settings where family farms predominate, such as in Akoko South West Local Government Area of Ondo State, Nigeria. This study highlights a paradox: while family labor is a vital resource, it is underutilized for intensive agricultural activities. The tendency to employ family labor for less demanding tasks like planting, weeding, and fertilizer application suggests an opportunity to optimize this resource for greater economic efficiency. To address labor underutilization and high production costs, the study advocates for strategic engagement of available family labor.

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Impacts of Climate Change on Animal Production and Product Quality

Ayesha ANWAR[1], Sema YAMAN FIRINCIOĞLU[2*]

[1]Niğde Ömer Halisdemir University, Department of Animal Production and Technologies, Graduate School of Natural and Applied Sciences, Niğde/Turkey

[2]Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Animal Production and Technologies Department, Niğde/Turkey*

[*]Corresponding Author: semayaman60@yahoo.com

ORCID: 0009-0005-3343-2859[1], 0000-0001-9575-9981[2]

Abstract

Climate change is very challenging for global livestock production because it effects both production efficiency of animals and product quality. The complex impacts of climate change on animal production cover several aspects including effects on animal health, reproduction imparity, alteration of product composition, and concerns about global food security. Frequent heat waves, changing season and precipitation patterns, changes in atmospheric temperature and humidity, and altering disease dynamics affecting livestock productivity either in a direct or indirect way. Reproduction imparity such as poor fertility rate is occurring more frequently among animals due to high ambient temperatures. In addition, climate-induced vegetation changes affecting forage quality that is causing scarcity of feed resources. Water quality is also being affected due to rises in sea level and salination. Among environmental stressor, heat stress is causing the most distress to animals by compromising their health and welfare. Therefore, declining overall profitability for farmers. Apart from this, climate change has a huge impact on animal product quality and composition. Heat stress along with altered forage quality is a potential factor responsible for reduced milk yield, protein, and fat composition in dairy cattle. Meat texture and flavor can also be affected by higher ambient temperatures. High temperature-humidity index (THI) is believed to be negatively affecting most quality parameters in eggs. There is an urgent need to address these challenges by implementing comprehensive mitigation and adaptation strategies such as improved management practice in hot regions, genetic selection of more resilient breeds, and introduction of smart agricultural practices and technologies. Moreover, collaboration among organizations, farmers, and researchers is essential to mitigate the adverse effects of climate change on livestock production and ensure global food security in a sustainable way.

Keywords: Climate, Heat stress, Animal health, Production systems, Milk quality

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INTRODUCTION

Global climate change is currently a hot topic all over the world. It is a complicated challenge with significant influence on the environment, agriculture, livestock, and other social disciplines (Feliciano et al., 2022). Climate change is any prominent change in the natural weather pattern of a region in a specific period (Mahato, 2014).

It is a natural phenomenon, but anthropogenic involvement is influencing the rate of global warming significantly and causing irreversible changes. Earth's temperature rose approximately 1ºC in 100 years (Mikhaylov et al., 2020), resulting in frequent temperature and precipitation changes. Consequences of climate change are now more visible such as the melting of glaciers, rising of sea level, causing reduction of arable land, frequent drought waves, and rising temperature, and projections are that the frequency of natural disasters will increase more and more (Adedeji et al., 2014). Intergovernmental Panel on Climate Change (IPCC, 2021) reported a projected scenario that by 2050 the average temperature rise could be 2ºC per decade if there is no immediate reduction in the current greenhouse gas emissions. Agriculture is among the most susceptible sectors to climate change with implications for livestock and crop production (Mendelsohn, 2008).

Among the agricultural sectors climate change has an adverse impact on livestock production not only related to animal health and productivity, but also associated with their feed resources and processing activities of their products (Godde et al., 2021). Livestock products are very crucial to support the nutritional demands of growing population. According to (FAO, 2020) livestock contributes to 31% and 15% of global protein and energy supply per capita respectively. It has also been reported that the demand for animal products which are high in protein such as red meat will tend to be double in the coming years due to the fact that animals provide high quality products to meet the nutritional requirements of consumers (Michalk et al., 2019; Reynolds et al., 2015). Furthermore, animal products are enriched in micronutrients such as zinc, iron and several essential vitamins which assist in overcoming malnutrition (Randolph et al., 2007). In addition, livestock contributes to several other services such as financial support and resilience of communities, as a fertilizer for poor soils, and transportation services in many countries (Tourrand et al., 2015). Therefore, livestock sector plays a crucial role in sustaining global food security and economy.

The purpose of this review is to address the currents challenges livestock sector is facing due to increased climate change, how animal product quality is affecting as a result of those challenges and what could be the possible mitigation or adaptive strategies towards a sustainable livestock production for the global food security.

IMPACTS OF CLIMATE CHANGE ON ANIMAL

Livestock and climate change have a distinctive relationship as livestock are accountable for climate change at the same time affected by it. The extremities of climate are held responsible for the impairment of livestock potential. Livestock are very susceptible to climatic components such as air humidity, temperature, intense solar radiations, and wind velocity (Sejian et al., 2022).

Temperature changes affect the animal both directly and indirectly. Direct impact comprises ambient temperature-related disease or death in case of extreme weather, while indirect impact is related to problems such as poor adaptation, feed and water scarcity, increased frequency of occurrence of infectious diseases mainly due to the influence of climatic conditions on causative agents, and distribution of food and vector-borne diseases (Nardone et al., 2010).

Direct impacts

Animal health

Livestock being warm blooded animals have ability to sustain their body temperature but prolonged exposure to high temperature negatively affects the animal potential (Sejian et al., 2022). Impact of climate change on animal health stays under the shadow of economical and production losses and often neglected (Godde et al., 2021; Sejian et al., 2022). Among the environmental stressors, livestock are extremely affected by heat stress, which is a great concern of today and future owing to global warming. Animals encounter several physiological and metabolic changes reported in Table 1, under heat stress which adversely affect their overall health (Gonzalez-Rivas et al., 2020).

During the high ambient temperatures animals reduce the feed intake as an adaptive strategy to lower the production of internal heat (Sejian et al., 2022). Exposure to prolonged high temperatures and feed reduction cause negative energy balance (NEB) in animals which is driving force for several metabolic disorders (Nardone et al., 2010). Apart from NEB, animals encounter metabolic and hormonal disruption in heat stress (Li et al., 2020). Cortisol, a well-known stress hormone, is released when hypothalamus-pituitary axis is triggered as a result of heat stress. Furthermore, abnormal secretions of triiodothyronine (T_3) and thyroxine (T_4) occurs which disrupts metabolic activities (Sejian et al., 2022). Non-esterified fatty acids (NEFA), β-hydroxybutyric acid (BHBA) and several other toxic compounds are produced in animal's body as a result of heat stress-induced metabolic disruption. Liver dysfunction, lower plasma cholesterol and albumin content are observed after animals were exposed to higher temperatures (Ronchi et al., 1999). In addition, production of glucocorticoids which severely affects the cytokines by inhibiting their synthesis and causing immune suppression in heat stressed animals has also been reported (Inbaraj et al., 2016). There are several studies present, exposing the negative impacts of heat stress in animals (Bernabucci et al., 2010; Joo et al., 2021; Li et al., 2020; Xia et al., 2022).

Table 1. Physiological and metabolic changes occurring in ruminants and non-ruminants as a result of heat stress. Adapted from (Gonzalez-Rivas et al., 2020).

Physiological changes	*Metabolic changes*
↑Respiration	↑Body fat
↑Heart rate	↑Protein catabolism
↓Feed intake	↓Thyroid hormone
↑Water intake	↑Glycolytic potential
↑Body temperature	↓GIT barrier
↓Carcass weight	↑Intracellular Ca ion
↓Live weight	↑Heat shock proteins
↓Muscle glycogen	↑Acidosis
↓Muscle dry matter	

Animal fertility

High ambient temperature has adverse effects on the reproductive performance of livestock species. Both genders are affected by heat stress (Bernabucci et al., 2010). In females, heat stress causes hormonal impairment which affects the ovulation cycle. Females failed to ovulate because heat stress alter the normal cycles of their reproductive hormones including progesterone, follicle stimulating hormone and luteinizing hormone (Ronchi et al., 2001). Furthermore, females show reduced estrus cycles (Cheng et al., 2022). A study reported that in cattle summer fertility rates reduces significantly due to hormonal suppression and silent heats are more common (Amundson et al., 2006). Sows experience late estrus after parturition and higher mortality rate during birth (Nardone et al., 2010). Research reported that in buffalos, progesterone and prolactin profiles during summer and winter seasons were significantly different. It was stated that during the summer season the plasma prolactin was higher, and progesterone was lower and consequently, infertility rates were higher (Roy and Prakash, 2007). In poultry, heat stress causes delay in ovulation, impaired ovulation process and poor egg hatchability (Ayo et al., 2011; Nawab et al., 2018).

It has been reported that male birds tend to affect more from higher ambient temperatures than females (Cheng et al., 2022). In males, heat stress causes impaired spermatogenesis. Lower quality sperms, poor testicular development, and reduction in fertile sperm production are some defects seen in males (Bernabucci et al., 2010). Major sperm defects are reported in summer bulls as compared to winter bulls and a decline in spermatozoa is observed (Mathevon et al., 1998; Nichi et al., 2006). Poor embryonic development can also occur when animal expose to heat stress during gestation period (Nardone et al., 2010; Naqvi et al., 2012).

Animal production

Climate change directly affects animal production by declining production rates. Lower feed intakes and health related issues in stressed animals are major forces influencing production rates and performance potential (West, 2003).

Milk production

Milk production of ruminants greatly suffers under high temperature and temperature-humidity index (THI) above 72 (Gorniak et al., 2014; Ravagnolo et al., 2000). Studies stated that milk yield decline due to nutrient intake is 35% while heat-induced milk decline during early and mid-lactations are 14% and 35% respectively (Bernabucci et al., 2010; Rhoads et al., 2009; Lacetera et al., 1996). A significant relation between the THI and milk yield of cow is reported that for every unit increase in THI above 69, daily milk yield decreases by 0.41kg (Bouraoui et al., 2002). Thresh hold temperature for dairy cattle is reported to be 26ºC (West, 2003). Sensitivity of cow to heat stress depends on both the stage of lactation and production capacity. In mid-lactation, milk yield losses are higher than early lactation. This is because of nutritional-metabolic condition, as cow becomes more heat sensitive in mid phase as compared to early lactation phase where milk production is also supported by body tissues when feed intake reduces. It has been stated that the production of metabolic heat during early lactation is comparatively lower than in the mid-phase of lactation because metabolic utilization of fat tissue is more efficient as compared to metabolic utilization of feedstuff (Bernabucci et al., 2010).

Furthermore, metabolic heat production in high yielding cows is more than low yielding cows that is why high yielding cows are more likely to be affected by higher ambient temperatures (Abdurehman and Ameha, 2018). Increased metabolic heat production in high producing cows is correlated with milk losses (Purwanto et al., 1990).

Meat and eggs production

Thermal stress affects meat production significantly which make it another critical economic trait (Sejian et al., 2022). All the commercial livestock species are vulnerable to heat stress and relative humidity changes (Gonzalez-Rivas et al., 2020). Reportedly, decline growth rates, body weights, carcass weight, and feed conversion ratio have been observed in animals (Sejian et al., 2022). A study reported that steers exposed to high temperatures showed significant reduction in dry matter intake, daily average gain, carcass weight, and more surveillance of diseases among the herd (Mitlöhner et al., 2001). The outdoor production systems for beef cattle make them particularly sensitive to heat stress and sudden temperature changes (Nardone et al., 2010). Fat and darker hair coat cattle appear to be extremely sensitive to high temperatures (Bernabucci et al., 2010). The threshold temperature above which growth, feed efficiency and dry matter intake in beef cattle are affected is 30ºC if relative humidity is below 80% and 27ºC if relative humidity is above 80% (Hahn, 1999). Pig production is also negatively affected by thermal stress. When encounter higher ambient temperature, fatter pigs produced leaner carcass at slaughter (Nardone et al., 2010). Reduction in meat quality and carcass weight and a decline in average daily gain up to 9.8% is reported in pigs (da Fonseca de Oliveira et al., 2019; Pearce et al., 2013).

In poultry, poor growth performances are observed in hot regions (Zaboli et al., 2019). Broilers show higher mortality rates when the temperature rises above 30ºC (De Basilio and Picard, 2002). Higher susceptibility of broilers to thermal stress is associated with the selection and development of rapidly growing breeds (Berrong and Washburn, 1998). Heat stress significantly reduced feed efficiency, growth rates, carcass weight, daily weight gain, protein concentration in meat, and breast muscle weight (Song and King, 2015).

Deleterious effects of heat stress on layers and egg production are seen (Sejian et al., 2022). In layers, the decline in egg production as a result of heat stress is assisted by reduced feed intake and hormonal disruption (Novero et al., 1991). Problems related to eggshell resistance, egg mass, egg production, daily feed intake and in addition poor eggshell quality are more frequent (Mignon-Grasteau et al., 2014).

Indirect impacts

Feed and water availability

Impacts of climate change on livestock's feed and water resources are also a point of concern. Apart from direct effect on livestock, climate change associated feed and water scarcity issues are becoming frequent. Droughts and precipitation changes have a huge impact on feed and water supply. Livestock feed is mainly composed of forage and some cereal grains. Forages can be further classified into two large groups grasses and legumes (Cheng et al., 2022). Legumes can be divided into two categories; warm season crops (C_4) and cold season crops(C_3) (Pearcy and Ehleringer, 1984).

It has been observed that C_3 crops (wheat, cotton, soybean) can be influenced by elevated levels of atmospheric CO_2 while C_4 (sorghum and corn) category crops are not influenced by CO_2 (Hatfield et al., 2011). Additionally, high atmospheric CO_2 hugely impacts the herbage growth in C_3 species while having little impact on their grain yields (Chapman et al., 2012). However, temperature increases above 30ºC favors the growth of C_4 species as they benefit from temperature rises strictly depending on production system, area, and species (Hadi et al., 2020). Moreover, corn and soybean production is affected by precipitation (Cho and McCarl, 2017).

Drought causes a significant reduction in the production of most forages (Ray et al., 2018). Not only production rates but also the quality of feed is affected by climate change. Water soluble carbohydrates and nitrogen content of forage decline when the crop is exposed to higher temperatures and water scarcity (Hopkins and Del Prado, 2007). On the other hand, higher temperatures are associated with the lignin content of plants and significantly increase it which has negative impact on digestibility (Polley et al., 2013). Climate changes are also influencing the length of the growing season which is linked to the quality of feedstuff (Abdurehman and Ameha, 2018). These feed changes have a negative impact on livestock when they are being fed. Poor quality forage reduces the feed efficiency rate and lowers the utilization, as a result, livestock produce more methane (Benchaar et al., 2001).

Water demand is increasing all over the world as temperature rises. Animals and humans both are competitive for water as they both need water to ensure optimum body function. According to the estimation of (The World Bank, 2022) agricultural sector alone is responsible for using 70% of freshwater. Animals in tropical regions are drinking 2-3 times more water as they encounter longer hot temperatures (Abdurehman and Ameha, 2018). Rising water demand for livestock production is a point of concern as climate change is adversely affecting the water supply and this scenario is likely to get worse in future. It has been stated that global warming could force the livestock breeders to develop genetically modified animals that require lesser amounts of water (Abdurehman and Ameha, 2018). As a result of temperature rising, water usage per unit is increasing (Gerten et al., 2011). Furthermore, water quality is also declining as a result of salination and rise in sea level (Tully et al., 2019; Juniad and Gokce, 2024). Animals suffer greatly when they drink poor quality water.

Vector-borne diseases

Vector and feed-borne diseases increase as a result of fluctuating climate. Increased temperature and high relative humidity of air provide an ideal scenario for the vectors and pathogens to thrive and cause diseases in animals (Abdurehman and Ameha, 2018). Temperature variations are associated with ability of some insect vectors like ticks, midges, and flies to carry the pathogens (Wittmann and Baylis, 2000). It has been reported that as a result of global warming, an advancement of midges from Africa to northwards has been observed which carries a specific type of virus called bluetongue infecting various livestock species like cattle, sheep, and goats (Maggiore et al., 2020).

IMPACTS OF CLIMATE CHANGE ON ANIMAL PRODUCTION SYSTEMS

Animal production units are suffering from adverse effects as a result of climate change. Livestock species are different in terms of their production systems. Production of animal products from different production systems is reported in Table 2. Mainly, three types of production systems are common; mixed-crop livestock system, grazing or pastoral system and industrial livestock system (Abdurehman and Ameha, 2018). Mixed-crop livestock production system utilizes about 2.5 million hectares and is suitable for rearing all kinds of livestock species (Nardone et al., 2010). Two sub-categories of this system are; rain-fed and irrigated systems. Rain-fed systems are mainly located in Central Africa, Central and Eastern Europe, on the border between Canada and the United States, and India while irrigated systems cover Central America, Central Europe, Eastern and Southern parts of Asia. Grazing or pastoral systems use more than 3 billion hectares of land and cover the areas of Australia, Asia, America, Africa, and Europe. Lastly, the industrial systems are located in Europe, Central and Southern America, and wide parts of Eastern Asia (Nardone et al., 2010).

Table 2. Production of different livestock species from the different production systems (Nardone et al., 2010).

Production Systems	Milk	Ruminant Meat	Non-Ruminant meat	Egg
Mixed-crop livestock system	90%	70%	25%	40%
Grazing or pastoral system	-	20% (cattle) 30% (sheep, goats)	-	-
Industrial livestock system	-	6%	70% (poultry) 55% (swine)	60%

Mixed-crop livestock system

Mixed-crop livestock systems comprise beef, dairy cattle, dairy sheep, and dairy goat farming. Climate change affects these systems by influencing animal health, performance, feed availability, and feed quality (Abdurehman and Ameha, 2018). Extreme heat stress is a potential factor affecting these kinds of production systems. Moreover, rain-fed systems are comparatively more vulnerable than irrigated systems (Nienaber and Hahn, 2007). Animal performance is adversely affected by higher temperatures. Furthermore, the effects of heat waves and drought on forage quality and availability are deleterious. Drought-tolerant forage crops could be an answer for future productions while low producing and better thermo-tolerant animals in mixed systems can be foreseen.

Grazing or pastoral system

Grazing systems are mainly for rearing ruminants. In many parts of the world, ruminants are raised extensively in open areas, depending on grasslands and paddocks. Grazing systems are strongly influenced by changes in climate conditions. During summer, animals experience prolonged heat stress, and as a result their production declines. Moreover, extended heat waves are responsible for the surveillance of many vector-borne diseases among those extensively produced herds. Water availability in tropical and sub-tropical regions is also a point of concern due to the reduction in rainfall (Nardone et al., 2010). Technological adaptation and production of heat-tolerant species of both plants and animal can have the potential to sustain these kinds of systems.

Industrial livestock systems

Industrial livestock systems as compared to mixed-crop and grazing system have less influence from climatic changes because of controlled environmental and feeding conditions (Nardone et al., 2010). But they are not completely out of the picture. Industrial systems are dependent on market-feed resources. Projected climate change scenarios describe that there could be reduction in the production of some crops due to water scarcity and alteration in growing parameters which, consequently, decreases industrial livestock production. Cost variation and availability of some grains can significantly disrupt the sustainability of these systems (Nardone et al., 2010).

IMPACTS OF CLIMATE CHANGE ON ANIMAL PRODUCT QUALITY

Climate-induced changes in the livestock sector eventually affect the food products obtained from them. Alterations in production rates and product compositions occur when animals suffer as a consequence of climate change. Temperature changes, especially heat stress, play a major part in this context causing both direct and indirect effects on livestock production. Prolonged exposure to heat causes a decline in feed intake and production of several thermo-regulator components by animals which induce changes in the composition of animal products. Lower- quality products decrease consumer demand as they are unable to fulfill the nutrient requirements of consumers and sometimes adversely affect the consumer's health. Poor-quality products are thus responsible for economic loss of the industry (Warner et al., 2022). The impacts of climate change on milk quality, meat quality, and egg quality are discussed below.

Milk quality

Climate-induced changes such as higher temperatures along with higher humidity levels severely affect milk production, milk quality, and cow's health (West, 2003). Higher temperatures are associated with altering the fat and protein content of milk (Sevi and Caroprese, 2012). An experiment conducted on Friesian Holstein cows showed a decline in the protein content of milk up to 1.3% when cows were exposed to higher THI for an additional hour. A decline of 1.3% in protein content reflects 0.455 mg/liter where the average protein content was 35 mg/liter (Vroege et al., 2023). Heat stress causes alterations in the rumen metabolism especially fermentation of volatile fatty acids (VFAs). Acetic acid and propionic acid are produced as a result of fermentation which are utilized by animal and responsible for milk fat and protein content (Babinszky et al., 2011). A study reported a significant decline in rumen acetic acid content when cows were exposed to 30ºC instead of 20ºC (Bandaranayaka and Holmes, 1976). Reduced feed intake limits the sulfur intake which adversely affects the protein metabolism by microbes and is responsible for lowering the essential amino acids, especially methionine in cow which eventually leads to a decline in milk protein content (Babinszky et al., 2011). It can be said that additional sulfur supplements can somehow reverse the impacts of heat stress on milk protein content.

Meat quality

Meat from animals is a rich source of protein and that's why consumer demand for good quality meat is increasing. Increasing climate changes adversely affect meat-producing animals and as a result, animals undergo stressful conditions.

When a productive animal encounters such events the impact on its product is deleterious. When beef cattle are exposed to higher temperatures, several metabolic and physiological changes occurs in them and their meat color darkens as a result (Adzitey and Nurul, 2011). The dark color of meat is associated with depletion of muscle glycogen reserves which causes an increase in pH. Furthermore, the predominance of purple deoxymyoglobin is also responsible for darker meat (Warner et al., 2022; Suman and Joseph, 2013). Beef cattle produce darker meat in summer as compared to winter months (Hughes et al., 2018). In sheep, exposure to higher temperatures and transportation stress resulted in low glycogen level in muscles (Pighin et al., 2013). Moreover, feedlot beef cattle are at higher risk of heat stress because of continuous exposure to the sun and high energy feed composition (Renaudeau et al., 2012). Meat from feedlot cattle is more vulnerable to show poor quality (Gonzalez-Rivas et al., 2020). A study showed that beef cattle slaughtered in hot weather had significantly higher marbling scores and smaller ribeye areas in comparison with those slaughtered in other seasons (Kang et al., 2009).

Similarly, poultry products are also under the negative influence of climate change. The more improved varieties are more susceptible to elevated temperatures because of faster growth rates and increased metabolic heat production (Gonzalez-Rivas et al., 2020). Heat stress encounters trigger the defensive mechanism in birds, and it has been seen that the plasma thyroid hormone concentrations elevate as a response (Bowen and Washburn, 1985). This response can result in increased incidences of pale soft exudative (PSE) meat. Broilers kept under high ambient temperatures (34-36ºC) from 4 to 6 weeks of age until slaughter, showed higher rates of glycolysis in their thigh and breast muscles demonstrated a reduction in meat pH, higher lactate production, more light-colored meat, cooking loss, and Warner-Bratzler shear force (WBSF) as compared to those kept under thermoregulated conditions (23ºC) (Zhang et al., 2012). Furthermore, oxidative modification of proteins and lipids has been reported in chickens exposed to heat stress (Lu et al., 2017).

Egg quality

The quality of eggs is also compromised as a result of climate change. Heat stress negatively affects egg production and quality in layers. Several studies have shown that higher ambient temperatures can cause feed intake reduction, lower body weights, reduced fertility rates, and egg masses. A study reported that birds raised in hot environments had significantly lower-quality eggs in terms of egg weight, shell thickness, shell weight, and specific gravity (Mashaly et al., 2004). Poor shell quality eggs are generally not prioritized by consumers. Another study found that egg yolk color and Haugh unit of eggs from layers kept under 85 THI were significantly reduced as compared to 68, 72, and 78 THI groups (Kim et al., 2024). Higher relative humidity affects the eggshell weights, eggshell thickness, Haugh unit, yolk weight, and albumen weight (Kim et al., 2022). Furthermore, (Allahverdi et al., 2013) stated that as the temperature rises from 22ºC to 36ºC for laying hens, their egg weights and specific gravity tend to decrease.

MITIGATION AND ADAPTATION STRATEGIES

The threat of climate change to the food production systems, especially livestock production systems is a prevalent motivational factor for livestock producers to take voluntary actions against climate change. Climate change is a serious threat and many organizations worldwide are working to reduce or mitigate the impacts of climate change.

The livestock sector needs a better understanding of the threat, and more exploration should be done to cope with the existing challenges. However, several models are being implemented in the livestock sector to mitigate the risks related to climate change that have proved to be effective. Heat stress is a great threat to animals, and it causes detrimental effects on animal health and production. It is crucial to alleviate the impact of heat stress to sustain animal production. Providing cooling and shading areas for cows is a common practice in farms to reduce the heat impact. This strategy resulted in a significant improvement in cattle performance and yield (West, 2003). Breed selection is also important in this context. It has been reported that indigenous, adaptive, or high thermo-tolerant breeds perform much better than imported breeds in hot regions (Osei-Amponsah et al., 2019). Furthermore, there should be genetic modifications of breeds to tolerate higher temperatures. Similarly, genetic modifications of forage crops against drought and hot conditions should be done. Apart from genetic selection, nutritional management plays a vital role. Animals should be provided with a high-energy and nutritive diet in hot environmental conditions as they reduce their feed intake. Rotational grazing systems can be used to minimize damage to pasture and lands (Gomez-Zavaglia et al., 2020). Additionally, training livestock farmers about climate challenges and mitigation strategies is of utmost importance.

CONCLUSION

Climate change poses a great risk to all food production systems including livestock. The vulnerability of the livestock sector increases as it is greatly affected by several climate variables. From heat stress to surveillance of vector-borne diseases and scarcity of water and feed resources for animals, all are great points of concern for the world. Livestock contributes to global food security and provides a wide range of essential nutrients to consumers. Furthermore, the economic status of this sector is also huge and is a source of income and sustainability for many households around the world.

Climate-induced changes are adversely affecting animal productivity, growth, welfare, reproduction, composition of animal products, forage quality, feed, and water supply. Stressful thermal conditions can catastrophe the production rates of most livestock species. The extended impacts on livestock production systems are convoluting the sustainability of the sector. In addition, climate change is responsible for altering the composition of animal-origin food. Reduction in protein and fat content of milk and certain nutrients in meat and eggs are consequences of poor animal performance as a result of temperature changes.

There is a need to do more intensified research on various environmental stressors other than heat stress which is predominantly known in depth. Furthermore, detailed information about the consequences of climate variables on product quality is still limited and needs to be explored more. The development of more effective mitigation and adaptation strategies considering sustainability of the sector should be proposed more often. It is recommended to establish digital agriculture frameworks in the livestock sector to reduce emissions and hence, to eventually lower the impact of climate change.

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