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*Review*

# A review on golden species of Zingiberaceae family around the world: Genus *Curcuma*

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**Genus *Curcuma* has a long history of traditional uses, ranging from folk medicine to its culinary uses. More than 70 species of *Curcuma* are distributed throughout the world but extensively cultivate in Asian, Australian and Western African counties. Many phytochemical, pharmacological and molecular studies have been conducted on several *Curcuma* species worldwide. The interest on its medicinal properties have increased due to the discovery of novel bioactive compounds which possessing wide range of bioactivities such as antioxidant, antiviral, antimicrobial, and anti-inflammation activities. Furthermore, this valuable plant is used as natural dye, insecticide and as a repellent. This review focuses on gathering information regarding genus *Curcuma* including morphological characteristics, phytochemicals and their biological and pharmacological activities which provide information for further advance research studies.**

**Key words:** *Curcuma*, biological activity, morphology, pharmacology, phytochemicals.

## INTRODUCTION

The genus *Curcuma* belongs to the family Zingiberaceae comprises rhizomatous annual or perennial herbs. According to Xia et al. (2005), the genus *Curcuma* comprises of 70 species, which are distributed widely throughout tropical and subtropical regions of the world. Out of 70 species, about 40 species are reported from India (Pemba and Sharangi, 2017). However, the exact number of species is still controversial (Akarchariya et al., 2017). *Curcuma* naturally found in India to Thailand, Indochina, Malaysia, Indonesia, and finally spreads to northern Australia. *Curcuma* is extensively cultivated in tropical and subtropical regions of Asia, Australia, Western Africa and South America (Ravindran et al., 2007). The species are naturally found in tropical forests

and tropical broad-leaved evergreen forests.

*Curcuma* is an economically important genus having many different uses. It is used as spices, food preservatives, flavouring agent, medicines, dyes, cosmetics, starch and ornamentals (Xiang et al., 2011; Sahdeo and Bharat, 2011). The underground rhizome of *Curcuma* is an important source of a yellow dye (Srivilai, et al., 2018). The word "*Curcuma*" is derived from the Arabic word "Kurkum" which means yellow colour (Su et al., 2017). They have been used for the treatment of various diseases like enlarged liver, spleen, stomach ulcer, diabetes, cough, hepatic disorders, chest pain, skin diseases, boils, blood purifier, and rheumatism (Saikia and Borthakur 2010). Various parts of these plant species

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have been used either raw or cooked as vegetables in many Asian countries (Devi et al., 2014). They also considered as nutritionally rich foods because *Curcuma* plants are a rich source of starch, carbohydrates, proteins, fats, vitamins, and minerals (Roshan and Gaur, 2017).

*Curcuma* plants have been shown to contain various bioactive molecules, which possesses many pharmacological properties such as; anti-inflammatory (Sikha et al., 2015), antimicrobial (Jagtap, 2015), hypocholestraemic (Shafreen et al., 2018), antirheumatic (Abdel-Lateef et al., 2016), antiviral (Pant et al., 2013), antifibrotic (Jose et al., 2014); antihepatotoxic (Jagtap, 2015); antidiabetic (Nwozo et al., 2014); antinociceptive (Ramasree and Indira, 2006); anticancerous (Pawar et al., 2011); gastroprotective properties (Jeon et al., 2015) and beneficial effects on cardiovascular diseases (Nithya and Jayashree, 2017). Plants belonging to the genus *Curcuma* are gaining importance all over the world and subjected for many investigation and exploration in recent years due to its promising potentials and wide range of usage. Therefore, a proper morphological and physicochemical identification is necessary, but not systematically studied yet. This review intends to provide a comprehensive insight into the morphology, phytochemistry and pharmacology of the genus *Curcuma*.

## STUDIES ON GENUS *CURCUMA*

Several reports have been published concerning the phytoconstituents, essential oils, and pharmacological actions of *Curcuma* (Faiz et al., 2015; Abdel-Lateef et al., 2016). The significance of the genus *Curcuma* has been recognized since the discovery of the antioxidant properties. The dried rhizome of *Curcuma longa* L has been found to be a rich source of beneficial phenolic compounds known as the curcuminoids (Lechtenberg et al., 2004). The most important of *Curcuma* species, *C. longa*, is commercially known as turmeric plant. Since Vedic age turmeric has been used as spice, herbal medicines, dyeing agents and cosmetics (Shirgurkar et al., 2001). Phytochemical investigations have been reported three main curcuminoids called curcumin, demethoxycurcumin and bisdemethoxycurcumin, which are characteristically developing yellow pigmentation to turmeric rhizome (Lechtenberg et al., 2004).

Curcumin is the main active constituent, which is a curcuminoid present in genus *Curcuma*. Even though environmental factors influence its stability, curcumin is an important secondary metabolite whose biosynthesis involves genetic control (Anandaraj et al., 2014). The chemical composition of *Curcuma longa* has been studied extensively. A number of biologically active components have been identified with antioxidant, anti-tumour, germicidal, aromatic, carminative, anti-helmentic, cholesterol lowering and neuroprotective properties and turmeric has been also used for the treatment of

dyspepsia, peptic ulcers and gastric ulcers through pharmacological and clinical studies (Sikha et al., 2015, Shafreen et al., 2018; Jose et al., 2014; Jagtap, 2015). In addition, wound healing and detoxifying properties of curcumin have also reported (Jagtap, 2015).

Some *Curcuma* species such as *Curcuma aeruginosa*, *Curcuma amada*, *Curcuma angustifolia*, *Curcuma caesia*, *Curcuma elata*, *Curcuma petiolata*, *Curcuma rubescens*, *Curcuma zanthorrhiza* and *Curcuma zedoaria* produce beautiful inflorescences and foliages that have a commercial value in floriculture as ornamental crops (Maciel and Criley, 2003). Among them *Curcuma alismatifolia* is recognized and popular in international trade as cut flower (Paisooksantivatana and Thepsen, 2001). Even though Curcuminoids have been approved by the US Food and Drug Administration (FDA) as "Generally Recognized As Safe" (GRAS) with good tolerability and safety profiles, which is proven by clinical trials (Gupta et al., 2013). There is limited literature available for studies related to curcuminoids as food value, nutritional composition, and health benefits of the edible *Curcuma* species (Sanatombi and Sanatombi, 2017).

Many morphological and physiochemical studies have been reported on commonly used plant parts of the *Curcuma* such as rhizome (Satyendra et al., 2013), leaves (Cuellar et al., 1998), stem (Dung et al., 1997), roots (Dung et al., 1996), inflorescence/ flowers and buds (Dung et al., 1998) and Entire plant (Maikhuri and Gangwar, 1993). From all evidences, the leaf, flowers, fresh and dry rhizomes are important in obtaining different phytochemical effects as a medicine as well as for other uses.

## MORPHOLOGICAL CHARACTERISTICS OF GENUS *CURCUMA*

Many researchers have been studied the morphological characteristics of different species in genus *Curcuma*. When one consider the Morphology, the genus *Curcuma* is highly variable in taxonomically important traits. Four tribes in family Zingiberaceae were recognized namely, *Globbeae*, *Hedychieae*, *Alpinieae* and *Zingibereae* based on morphological features like number of locules and placentation in the ovary, development of staminodes, modifications of the fertile anther, and rhizome-shoot-leaf orientation (Kress et al., 2002) where *Curcuma* is belongs to Zingibereae.

Commonly the rhizomes of *Curcuma* are branched, fleshy and aromatic (Revathi and Malathy, 2013). Roots attached to the rhizome often bear conical or ellipsoid tubers (Dung et al., 1997). Basal leaf blades are normally broad, lanceolate or oblong or rarely linear in shape (Cuellar et al., 1998). Flowers contain a single versatile anther and spiral bract with large compound spike inflorescence is a prominent characteristic when

recognizing the genus *Curcuma* (Dung et al., 1998). The terminal bracts form a sterile cluster is very long and often brightly coloured (Dung et al., 1998). It has two distinct flowering times. Early flowering species develop flowers laterally from rhizomes before the development of leafy shoots and late flowering species usually developed terminally from the leafy shoots (Sirirugsa, 1998). The plants are normally 50 to 200 cm in height. *Curcuma* species are mostly triploid and reproduce asexually by rhizomes. They do not produce seeds (Malek et al., 2006). Morphology of the different early flowering *Curcumas* lead to identification problems because they exhibit large intra- and inter specific morphological variations.

*C. longa* rhizome is medium sized, aromatic and conical in shape. The internal colour of the rhizome is deep orange-yellow (Abdel-Lateef et al., 2016). They are native to Southeast Asia, southern China, the Indian Subcontinent, New Guinea and Northern Australia and naturally found in some warm regions of the world such as tropical Africa, Central America, Florida, and various islands of the Pacific, Indian and Atlantic Oceans. It has cylindrical and branched sessile tubers. Leaf lamina is oblong-lanceolate with wavy margins and short ligules. Inflorescence is in the middle. The peduncle concealed within the leaf sheaths Spike has a distinct white coma and bracts are pale green. Corolla tube of the large flowers are white in colour with unequal lobes. Labellum is light yellow in color with a median dark yellow band. Lateral staminodes are linear and anthers are spurred (Kress et al., 2002).

*C. amada* Roxb. consists of a large rhizome which is light yellow in colour inside and white towards the periphery, with the smell of green mango being found in southern India (Policegoudra et al., 2010). It has branched sessile tubers, which are thick and cylindrical or ellipsoid in shape. Roots are fleshy and tubers are absent. Pseudostem is 30 to 35 cm tall. The leaf laminae are oblong or lanceolate with puberulous lower surface and glabrous upper surface. Inflorescence is lateral or central with a peduncle covered by sheaths. Spike is light violet with fused coma bracts at base. Bracts are obtuse and green in colour. Corolla tube of the large flowers are funnel shaped and pale yellow in colour with unequal white lobes (Rao et al., 1989). Labellum is elliptical and pale yellow with a median dark yellow band. Stamens are white thecae and the basal spur is convergent. Ovary has many ovules with dense hairs. Style is long and filiform. Stigma is closely appressed within the anther lobes (Faiz et al., 2015).

*C. zedoaria* has a large rhizome that is deep yellow in colour. The plant is native to India and Indonesia but now naturalized in other places including the US state of Florida. The sessile tubers are thick and branched (Newman et al., 2004). The roots are thick and fleshy with fusiform fleshy pearl white root tubers. Oblong-lanceolate leaf lamina is having purple coloured patches

on the upper side along the whole midrib, which fades in older leaves. Inflorescences are laterally placed with peduncle. Spike has a distinct coma that is fused at the base and dark pink in colour. Fertile bracts are ovate, green with pink margin. 4-5 flowers are in each bract. Funnel shaped corolla tube is white in colour. Labellum is pale yellow in colour with a deep yellow band (Chen et al., 2013).

*Curcuma aromatica* has an aromatic yellow rhizome with many sessile tubers. The plant is native to Kerala, Karnataka, Orissa and Bihar in India. Leaf lamina is broadly lanceolate, acuminate and lower surface has dense pubescents (Choudhury et al., 1996). Coma bracts in inflorescences are large, spreading and pink in colour (Singh et al., 2002). Fertile bracts pale greenish-white in colour with hairs on upper surface. Corolla tube is funnel-shaped, pinkish-white in colour with unequal lobes. The dorsal lobe is broadly ovate arching over the anther and hooded. The lateral lobes are oblong and narrow. Labellum is deep yellow in colour. Lateral staminodes are oblong, obtuse and long, filiform (Jeon et al., 2015).

*Curcuma caesia* Roxb has a large rhizome, which is strongly aromatic. It is native to North-East and Central India. Rhizome is blue in colour in the centre, varying towards grey depending on the nature of the soil and age. The roots are fleshy with many root tubers, which are sessile, and branched (Sarangthem and Haokip, 2010). Distichous leaves with petiole are oblong to lanceolate with acute tip and acuminate base. Glabrous purple or reddish-brown patch is present along the sides on the distal half of the mid rib on upper surface (Paliwal et al., 2011). Large coma bracts present within the inflorescence are pink to violet in colour. Flowers are slightly shorter than the bracts. Corolla tube is long, pink in colour with unequal lobes. Ovary is trilocular with many ovules (Vairappan et al., 2013).

*Curcuma haritha* has non-aromatic large yellowish grey colour rhizome. It is native to Kerala in India. There are many finger shaped, long and branched sessile tubers. Roots are numerous and fleshy. Ovate-elliptical shaped leaf sheaths with acuminate tip and acute base are green in colour with light pink dots. The leaf is thick, leathery, densely puberulent on the lower surface and sparsely hairy above. Inflorescence is lateral and coma is fused only at the base and bright pink in colour. The lower bracts are fully green in colour whereas the upper ones are green with pink tips. Flowers are slightly smaller than the bracts. Corolla tube white in colour (Kress et al., 2002).

*Curcuma ecalcarata* has small yellow colour rhizome without sessile tubers (Revathi and Malathy, 2013). It is native to Kerala in India. Leaf lamina is broadly ovate, acuminate and densely pubescent on the lower surface. Inflorescences are centrally located with a pubescent peduncle. Coma bracts are longer and bright pink or greenish-white. Flowers are yellow or orange-yellow in colour and longer than the bracts (Sirirugsa, 1998).

*Curcuma oligantha* has a small rhizome. It is non-aromatic and internal colour is yellow. Sessile tubers are absent. Leaves are distichous and the lamina is ovate-elliptic in shape with acuminate tip and oblique base. Inflorescence is lateral and there is no any distinct coma. Fertile bracts are green in colour with a pinkish tinge. Flowers are longer than the bracts. There are many seeds produced in this species (Lai et al., 2004).

*Curcuma raktakanta* rhizome is medium sized, whitish towards the periphery and aromatic. The plant is naturally distributed in Kerala, India. There are many fleshy roots. Leaves are distichous and petiolate. The green leaf lamina is oblong-lanceolate with acuminate base and tip. Reddish-purple sheaths and the spike long with a distinct coma cover inflorescence. Flowers are as long as the bracts. Style is long and filiform. Stigma is slightly exerted from the anther. Fruiting is unknown (Kim et al., 2007). Rhizome of *Curcuma aeruginosa* is large (Pandey and Chowdhury, 2003). It is yellowish green colour in the centre and strongly aromatic (Angel et al., 2014). The sessile tubers are branched and condensed. Leaves are distichous and oblong-lanceolate in shape. Leaf tip is acute and base is acuminate. A purple or reddish-brown patch is present along the sides of the distal half of the mid rib on upper side. Coma bracts are pink to violet in colour. Flowers are slightly shorter than the bracts. Ovary is trilocular with many ovules (Kamazeri et al., 2012).

*Curcuma angustifolia* has narrow, green, glabrous leaves. It is most commonly found growing wild in India, especially in the northeast and western coastal plains and hills. Such areas include the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, Himachal Pradesh, Orissa (Odisha), Chhattisgarh, Tamil Nadu, and Kerala. This species can also be found in Burma, Laos, Nepal, and Pakistan. Small inflorescences are bearing yellow flowers with pink coma bracts (Sharma, 2012). Flowers usually appear near to the ground in the beginning of the rainy (Jena et al., 2017). Species is endemic to northwestern, central, and south India. *Curcuma australasica*, commonly known as Cape York lily, is an endemic species and the only native representative of the genus from Australia (Sharma, 2012). The plant species is usually distributed along the coast of the Gulf of Carpentaria and New Guinea and shady rainforest margins of the Cape York Peninsula in northern Queensland (Sharma et al., 2011). *Curcuma caulina* is an herbaceous perennial plant producing unbranched, erect, leafy pseudostems. Underground rhizome is bearing inflorescence with prominent greenish white or pinkish white colored bracts and yellow or white colored flowers (Sharma, 2012). The plant is reported to be a native of India that grows in the wild in areas of high annual rainfall (Pukhrabam, 2002).

Rhizome of *Curcuma leucorrhiza* is a source of an edible starch (Huxley, 1992). According to the Grieve (1971), it is a stemless perennial plant growing up to 60 cm tall. *Curcuma manga* is commonly known as

“mango turmeric” because it has a mango-like smell of rhizome as in *Curcuma amada* (Sharma, 2012). It is an herbaceous, perennial plant producing clumps. Erect pseudostems are emerging from a branched underground rhizome. It grows commonly in Java and Thailand (Liu and Wu, 1999). *Curcuma phaeocaulis* is widely distributed in southern regions of China (Sharma, 2012). This plant has similar characteristics as *C. zedoaria*, *Curcuma caesia*, and *Curcuma aeruginosa* (Sharma, 2012). Inflorescences are arising from pale blue, green, yellowish green or yellow colour rhizomes on separate shoots (Sirirugsa et al., 2007).

*Curcuma pierreana* is a herbaceous perennial plant. It has originated in Cambodia and Thailand (Tyag, 2005). Rhizomatous rootstocks are producing clumps of leafy stems. Inflorescences are sessile and have white staminodes with large purple-blotched apices (Huxley, 1992). *Curcuma pseudomontana* is grown as a potential ornamental species in Karnataka, Maharashtra, and Andhra Pradesh and endemic to the Western and Eastern Ghats of peninsular India. It has beautiful well-developed coma, with deep yellow flowers and broadly ovate and prominently sulcate leaves with bright green color (Sharma, 2012). *Curcuma purpurascens* is a perennial herb with pseudostems arising from a branched rhizome and wide leaf blades. It is considered as a less known *Curcuma* species, due to limited phytochemical and biological investigations on this plant (Rajashekhara and Sharma, 2010). *Curcuma zanthorrhiza* is a deeply colored rhizome native to Indonesia and was used as a dye. Nowadays it is often used as a substitute for *Curcuma aromatica* in cosmetics. The plant bears a cluster of erect pseudostems an underground rhizome and each pseudostem is made up of about eight long leaves (Ravindran et al., 2007).

## PHYTOCHEMICALS OF GENUS *CURCUMA*

The rhizomes of the *Curcuma* species are the most commonly used part for chemical extractions. Non-volatile curcuminoids and volatile oils are the main active components of the rhizome. Curcumin, demethoxycurcumin and bisdemethoxycurcumin are the major curcuminoids. They are nontoxic polyphenolic derivatives of curcumin. Sesquiterpenoids and monoterpenoids are identified as the major components in *Curcuma* oil (Xiang et al., 2018).

*C. longa* is the major species subjected to many studies. It contains protein (6.3%), fat (5.1%), minerals (3.5%) and carbohydrates (69.4%) (Anjusha and Gangaprasad, 2014). The essential oil (5.8%) obtained by steam distillation of rhizomes contains  $\alpha$ -phellandrene, sabinene, cineol, borneol, zingiberene and sesquiterpenes (Zhang et al., 2017). Curcumin (diferuloylmethane) is the compound responsible for the yellow colour, and comprises curcumin I (94%), curcumin II (6%) and

curcumin III (0.3%) (Xiang et al., 2018). Chemotypes in the turmeric vary widely. There are hundreds of compounds identified from the turmeric essential oils such as; *ar*-turmerone,  $\alpha$ -turmerone, and  $\beta$ -turmerone, followed by notable amounts of  $\alpha$ -zingiberene, curlone, *ar*-curcumene,  $\alpha$ -santalene, santalene,  $\beta$ -sesquiphellandrene, (*Z*)- $\beta$ -ocimene,  $\beta$ -bisabolene,  $\beta$ -caryophyllene,  $\alpha$ -phellandrene, (*Z*)- $\beta$ -farnesene etc (Angel et al., 2014). There is a significant variation in between the essential oils obtained from fresh and dry rhizomes of *Curcuma longa* (Kutti and Lingamallu, 2012). Oil extracted from rhizome of *C. zedoaria* is mainly composed of sesquiterpenoids and monoterpenoids (Purkayastha et al., 2006). Essential oils in *Curcuma aeruginosa* is usually composed of relatively equal amounts of monoterpenes and sesquiterpenes such as; 8,9-dehydro-9-formyl-cycloisolongifolene (35.3%), dihydrocostunolide (22.5%) (Kamazeri et al., 2012), germacrone (23.5%), curzerenone (11.8%) (Theanphong et al., 2015), dehydrocurdione (27.6%), curcumenol (15.1%), 1,8-cineole (22.7%), germacrone (17.7%) (Srivilai et al., 2018). Generally, monoterpenes are predominated (80–88%) in rhizomes of *Curcuma zanthorrhiza* (Akarchariya et al., 2017). The major constituents in *Curcuma aromatica* rhizome consisted with 8,9-dehydro-9-formyl-cycloisolongifolene (2.7–36.8%), germacrone (4.3–16.5%), *ar*-turmerone (2.5–17.7%), turmerone (2.6–18.4%), curdione (50.6%), camphor (18.8–32.3%), xanthorrhizol (26.3%), *ar*-curcumene (19.5%), di-*epi*- $\alpha$ -cedrene (16.5%), curcumol (35.8%), and 1,8-cineole (12.2%) (Tsai et al., 2011). *Curcuma phaeocaulis* rhizome has 8,9-dehydro-9-formyl-cycloisolongifolene (15.6–46.2%), germacrone (8.9–21.2%), and curlone (0.8–20.2%) as the main constituents (Zhang et al., 2017). *Curcuma caesia* composed mainly of 1,8-cineole (30.1%) followed by camphor, *ar*-curcumene, and camphene (Angel et al., 2014).

However, different *Curcuma* species produce a wide variety of volatile sesquiterpenes, monoterpenes, and other aromatic compounds (Singh et al., 2010). There is a significant variation in composition of *Curcuma* essential oils. Genotype, variety, geographical location, climate, season, cultivation practices, fertilizer application, stress during growth or maturity, harvesting time, stage of maturity, storage, extraction, and analysis methods will greatly determine different oil chemical profiles (Sanghamitra et al., 2015; Srinivasan et al., 2016). However, some of the variation could be due to misidentification of the plant species or some of the components (Noura and William, 2018).

## PHARMACOLOGICAL ACTION OF GENUS CURCUMA

Phytochemicals of *Curcuma* species possesses a wide variety of pharmacological properties, including anti-inflammatory (Sikha et al., 2015), anticancerous (Li et al.,

2014), antiproliferative (Oon et al., 2015), hypocholesterolemic (Shafreen et al., 2018), antidiabetic (Nwozo et al., 2014), antihepatotoxic (Fagodia et al., 2017), anti-diarrheal (Fouad et al., 2017), antimicrobial (Jagtap, 2015) and insecticidal (Fouad et al., 2017) activities. *Curcuma* oils are also known to enhance immune function, promote blood circulation, accelerate toxin elimination, and stimulate digestion (Raut and Karuppaiyil, 2014). *C. longa* and *C. zedoaria* are the most widely studied species of genus *Curcuma* (Noura and William, 2018).

### Antioxidant activity

Curcumin has the ability to improve systemic markers of oxidative stress (Sahebkar et al., 2015). It can increase serum activities of antioxidants such as superoxide dismutase (Panahi et al., 2016a). Curcumins can scavenge different forms of free radicals, such as reactive oxygen (ROS) and nitrogen species (RNS) (Menon and Sudheer, 2007). Also, it can inhibit ROS-generating enzymes such as lipoxygenase/cyclooxygenase and xanthine hydrogenase/oxidase (Lin et al., 2007). In addition, curcumin is an efficient scavenger of peroxy radicals like vitamin E. Therefore, curcumin is also considered as a chain-breaking antioxidant (Priyadarsini et al., 2003). The antioxidant mechanism of curcumin is attributed to its unique conjugated structure, which includes two methoxylated phenols and an enol form of  $\beta$ -diketone (Fagodia et al., 2017).

### Anti-Inflammatory activity

Curcumin blocks nuclear factor activation increased by several different inflammatory stimuli. Curcumin is effective against carrageenin-induced oedema in rats and mice. In addition, curcumin stimulates stress-induced expression of stress proteins and may act in a way similar to indomethacin and salicylate. Moreover, curcumins enhance wound-healing in diabetic rats and mice and in H<sub>2</sub>O<sub>2</sub>-induced damage in human keratinocytes and fibroblasts (Panahi et al., 2016b).

### Anticarcinogenic effect

Induction of apoptosis of curcumins plays an important role in its anticarcinogenic effect. It inhibits cell-cycle progression and cancerous cell growth in rat aortic smooth muscle cells (Chen et al., 2013). Curcumin induces apoptotic cell death by DNA-damage in human cancer cell lines via acting as topoisomerase II poison (Martin-Cordero et al., 2003). Curcumin rapidly reduces the potential in mitochondrial membrane to release of

cytochrome *c* (Jana et al., 2004). Curcumin can induce apoptosis by enhancing tumour necrosis factor-related apoptosis-inducing ligand (Deeb et al., 2003). Curcumin delays apoptosis along with the arrest of cell cycle at G1 phase in colorectal carcinoma cell line (Chen et al., 2013). Furthermore, curcumin produces nonselective inhibition of proliferation in several leukaemia, nontransformed haematopoietic progenitor cells. Curcumin suppresses human breast carcinoma and cancer cells through multiple pathways (Li et al., 2014).

#### Antimutagenic activity

Curcumin has been shown to reduce the number of aberrant cells in cyclophosphamide-induced chromosomal aberration in Wistar rats at 100 and 200 mg/kg body weight doses (Shukla et al., 2002). *Curcuma longa* has the ability to prevent mutation in urethane models (Hamss et al., 1999).

#### Anti-tumour activity

Germacrone from *Curcuma aromatica* inhibits the proliferation of glioma cells by promoting apoptosis and inducing cell cycle arrest. It also concluded that germacrone might be a novel potent chemo preventive drug for gliomas via regulating the expression of proteins associated with apoptosis and G1 cell cycle arrest (Liu et al., 2014). Beta-elemene isolated from the rhizome of *C. aromatica* is associated with the growth of hepatoma in mice on cellular proliferative activity (Wu et al., 2000).

#### Anticoagulant activity and Anti-platelet activity

Curcumin inhibits collagen and adrenaline-induced platelet aggregation in *in vitro* as well as *in vivo* in rat thoracic aorta (Su et al., 2017). According to Jantan et al., 2008, Curcumin isolated from *Curcuma aromatica* was the most effective antiplatelet compound as it inhibited arachidonic acid (AA), collagen and ADP-induced platelet aggregation with IC<sub>(50)</sub> values of 37.5, 60.9 and 45.7 microM, respectively.

#### Antifertility activity

The 100% antifertility effect has been reported in rats with petroleum ether and aqueous extracts of turmeric rhizomes when fed orally (Garg, 1974). Curcumin inhibits 5 $\alpha$ -reductase, which converts testosterone to 5 $\alpha$ -dihydrotestosterone, thereby inhibits the growth of flank organs in hamsters (Liao et al., 2001). Curcumin also inhibits human sperm motility (Rithaporn et al., 2003).

#### Antitussive activity

Antitussive effect on Sulfur dioxide induced cough model in mice suggested that the *Curcuma aomatica* extract exhibited significant antitussive activity in a dose dependent manner (Marina et al., 2008).

#### Antimelanogenic activity

Antimelanogenic effects of *C. aromatica* extracts were investigated with Ultraviolet A (UVA) irradiation, leading to melanogenesis, which is associated with melanoma skin cancer and hyperpigmentation by assessing tyrosinase activity, tyrosinase mRNA levels, and melanin content in human melanoma cells. This study demonstrated that UVA mediated melanin productions were suppressed by *C. aromatica* extracts at non-cytotoxic concentrations (Panich et al., 2010).

#### Anti-nephrotoxic activity

*C. aromatica* leaf extract were studied on nephrotoxicity induced by arsenic trioxide in rats and the results revealed that leaf extract has a potential to modulate the renal dysfunction caused by arsenic trioxide (Saxena et al., 2009).

#### Antidiabetic activity

Galactose-induced cataract formation can be prevented by very low doses of curcumin (Suryanarayana et al., 2003). Blood sugar level in alloxan-induced diabetes in rat is decreased by curcumin (Arun and Nalini, 2002). Advanced glycation products induced complications in diabetes mellitus also can be reduced by curcumin (Nwozo et al., 2014). Ethanolic extract containing both curcuminoids and sesquiterpenoids is more powerfully hypoglycemic than either curcuminoids or sesquiterpenoids (Nishiyama et al., 2005).

#### Antifungal activity

Prevention of fungal growth may depend on concentration of curcumin. Dried powder of *Curcuma* rhizome addition in plant tissue culture at the 0.8 and 1.0g/L had considerable inhibitory activity against fungal infections (Ungphaiboon et al., 2005). The methanolic extract of *C. longa* showed antifungal activity against *Cryptococcus neoformans* and *Candida albicans* with values of 128 and 256  $\mu$ g/mL respectively (Kim et al., 2003). Hexane extract of *C. longa* has antifungal effect against *Rhizoctonia solani*, *Phytophthora infestans*, and *Erysiphe graminis* (Chowdhury et al., 2008). Curcumin oil

showed antifungal effect against *Fusarium solani* and *Helmintho sporium* (Prucksunand et al., 2001). It was reported that 18 months old and freshly distilled oil isolated from rhizome of *Curcuma longa* exhibited the most potent antifungal effect against 29 clinical isolates of dermatophytes with values of 7.2 and 7.8 mg/mL, respectively. Curcumin showed more potent significant effect against *Paracoccidioides brasiliensis* than fluconazole and it did not affect the growth of *Aspergillus* species (Martins et al., 2009).

### Antibacterial activity

Curcumin and the oil fractions extracted from *Curcuma* species can suppress the growth of several bacteria like *Streptococcus*, *Staphylococcus*, *Lactobacillus*, etc (Bhavani and Sreenivasa, 1979). The aqueous extract of *Curcuma longa* rhizomes has shown antibacterial effects (Kumar et al., 2001). Curcumin also prevents growth of *Helicobacter pylori* CagA+ strains *in vitro* (Mahady et al., 2002).

### Antiviral activity

Curcumin acts as an inhibitor of Epstein–Barr virus key activator BamH fragment Z left frame 1 (BZLF1) protein transcription in Raji DR-LUC cells (Taher et al., 2003). Curcumin in the course of inhibitory activity against the enzyme called inosine monophosphate dehydrogenase (IMPDH) is flexible as a potent antiviral compound (Dairaku et al., 2010). According to the Li et al., 1993, curcumin to be an effective compound to inhibit the HIV-1 LTR-directed gene expression without any major effects on cell viability. Moreover, curcumin reserved the acetylation of Tat protein of HIV significantly by p300 related with invasion of HIV-1 multiplication (Balasubramanyam et al., 2004).

### Antiprotozoan activity

It has been reported that the ethanol extract of the rhizomes has anti-*Entamoeba histolytica* activity and anti-*Leishmania* activity *in vitro* (Koide et al., 2002). Several synthetic derivatives of curcumin showed Anti-*Plasmodium falciparum* effects, anti-*L. major* effects (Rasmussen et al., 2000) and anti-*L. amazonensis* effects (Gomes et al., 2002).

### Antidepressant properties and effect on nervous system

A study has been reported that rats suffering from the chronic mild stress (CMS) have a considerably lower consumption of sucrose, increased interleukin (IL-6), tumour necrosis factor alpha (TNF- $\alpha$ ) levels, Corticotropin releasing factor (CRF), and cortisol levels. Ethanolic

extract of turmeric causes to increase the sucrose intake to normal control levels, increase in serum IL-6 and TNF- $\alpha$  level and reduced the CRF levels (Yu et al., 2002). Ethanolic extracts of *C. longa* causes to reverse the decrease in some neurotransmitters concentrations as well as the increase in serotonin turnover, cortisol levels and serum corticotrophin-releasing factor (Xia et al., 2007). According to Xu et al., 2006, curcumin exhibited antidepressant activity on behavior in a long-lasting stress rats instead of imipramine, which was the control in the study. A study on Alzheimer's disease (AD) has been shown a direct effect of curcumin in decreasing the amyloid pathology (Ringman et al., 2005).

### Anti-asthmatic activity and smooth muscle relaxant activity

The hydroalcoholic extract of *C. caesia* showed relaxant effect in Guinea pig trachea and study revealed that the extract has receptor antagonists and enzyme inhibitors (Arulmozhi et al., 2006). The *Curcuma caesia* extract concentration dependently relaxed the carbachol (1  $\mu$ M)-induced pre-contractions. Methanolic *C. caesia* extract was studied on the histamine aerosol induced bronchospasm and pre-convulsion dyspnoea in guinea pigs showed significant protection against histamine-induced bronchospasm (Paliwal et al., 2011).

### Analgesic activity

Analgesic and antipyretic activity of extracts obtained from *C. caesia* and *C. amada* rhizomes were evaluated by chemical model of acute pain and brewer's yeast induced hyperthermia in rats. Both plants exerted analgesic and antipyretic activity while *C. amada* showed better response than *Curcuma caesia* (Baghel et al., 2013).

### Anthelmintic activity

Rhizomes of *C. amada* and *C. caesia* with four extracts viz; Petroleum ether, Dichloromethane, ethanol and aqueous extract were investigated for anthelmintic activity at three different concentrations (50 mg/ml, 100 mg/ml and 150 mg/ml). The results suggested that ethanol extract (150 mg/ml) of *C. caesia* was most effective in causing paralysis of earthworms, while the ethanol extract (150 mg/ml) and Dichloromethane extract (150 mg/ml) of both *Curcuma* species were very effective in causing death of earthworms (Gill et al., 2011).

### Effect on gastrointestinal system

Turmeric powder act as gastroprotectant against irritants



while increasing mucin secretion in rabbits (Lee et al., 2003). Anti-ulcer (Uemura et al., 2001), ulcerogenic activities and antifatulent activity in *in vivo* and *in vitro* experiments in rats also has been reported. Curcumin increases the intestinal lipase, sucrose, and maltase activity (Su et al., 2017). Curcumin also suppresses the intestinal fibrosis (Lin et al., 2006). Moreover, it has been reported that curcumin has significant effect on dyspepsia and gastric Ulcer and a study showed defensive effects of male Sprague–Dawley (pylorus-ligated) rats treated with curcumin (Kim et al., 2005). Ethanolic extracts of *Curcuma* are believed to inhibit gastric acid, gastric juice secretion, and ulcer formation (Rafatullah et al., 1990). Curcumin shows protective activity in cultured rat hepatocytes against carbon tetrachloride, D-galactosamine, peroxide and ionophore-induced toxicity (Kang et al., 2002). Both curcumin and essential oil of *C. longa* showed increased bile production in dogs (Jentzsch et al., 1959) and increases the activity of pancreatic lipase, amylase, trypsin and chymotrypsin (Platel et al., 2000). 1-phenyl-1-hydroxy-*n*-pentane of *C. longa* increases plasma secretion and bicarbonate levels (Chey et al., 1983).

### Effect on cardiovascular system

Curcumin increases the possibility of pharmacological interventions to correct the defective  $Ca^{2+}$  homeostasis in the cardiac muscle by  $Ca^{2+}$  transport and its slippage from the cardiac muscle sarcoplasmic reticulum (Sumbilla et al., 2002). Curcumin also has been reported a significant hypocholesteremic effect in hypercholesteremic rats (Shafreen et al., 2018).

### Effect on nervous system

Curcumins and manganese complexes of curcumin extracted from *Curcuma* plants offer protective action against vascular dementia (Thiyagarajan and Sharma, 2004).

### Effect on lipid metabolism

*In vivo* interaction between curcumin and  $\alpha$ -tocopherol that may increase the bioavailability of vitamin E and decrease cholesterol levels by significantly reducing low density lipoprotein and very low-density lipoprotein in plasma and total cholesterol level in liver along with an increment of  $\alpha$ -tocopherol level in rat plasma (Kamal-Eldin et al., 2000). Treatments with curcumin also leads to decrease the ethanol-induced liver damage of humans (Akrishnan et al., 2001).

### Wound healing activity

Powdered rhizome, topical application of rhizome extracts

and cream formulations of *Curcuma aromatica* exhibited wound healing activity in excision wound models of rabbits (Kumar et al., 2009).

### Other uses of genus *Curcuma*

Curcumin has been recognized and used worldwide in many different forms due to its other multiple potential benefits except pharmacological actions. For example, in India and Sri Lanka, turmeric is used in curries; in Japan, it is served in tea; in Thailand, it is used in cosmetics; in China, it is used as a colorant. In addition, in Korea, it is served in drinks; in Malaysia, it is used as an antiseptic; and in the United States, it is used in mustard sauce, cheese, butter, and chips, as a preservative and a coloring agent (Gupta et al., 2013).

### *Curcuma* as a natural dye

People used *Curcuma* species as natural dyes in cosmetics, food (Padhi, 2012), textile materials leather and in medicine (Nattadon et al., 2012). Curcumin, the only natural pigment extracted from the fresh or dried rhizomes of turmeric is historic one of the most famous and the brightest of naturally occurring yellow dyes. It is capable of directly dyeing silk, wool and cotton. Turmeric variety and maturity determine the curcuminoid content, which responsible for color. Harvesting at the correct maturity is an important factor for optimum colour (Aisha et al., 2018). The dye is found to have good saturation and rubbing fastness on cotton (Reazuddin et al., 2017).

### Insecticidal effect

It has been found that the compound *ar*-turmerone of *Curcuma* could be used as a low-cost botanical insecticide for integrated management of cabbage looper in vegetable production (Abbott, 1925). The rhizome extract of *Curcuma longa* was found stronger on dose mortality action against *Tribolium castaneum* adults than the aerial part extract (Talukder and Howse, 1993). Termite (*Reticulitermes flavipes*) (Kollar) was exposed to different solvent extracts of turmeric to investigate potential termiticidal properties showed that termiticidal components of turmeric are extractable as a blend containing mainly *ar*-turmerone, turmerone, and curlone (Alshehry et al., 2014). Turmeric is toxic to the maize weevil (*Sitophilus zeamais*) and the fall armyworm (*Spodoptera frugiperda*) and essential oil extracts from turmeric leaf are toxic against *Sitophilus oryzae* L., *Rhyzopertha dominica* and *Tribolium castaneum* (Tavaresa et al., 2013).

### Repellent activity

*C. aromatica* extracts showed repellence against *Aedes*

*togoi* and provided biting protection for 3.5 h when applied at a concentration of 25%. Further studies on *Curcuma* extracts have reported protective effects against *Armigeres subalbatus*, *Culex quinquefasciatus*, and *Cx. Tritaeniorhynchus* (Pitasawat et al., 2003). Crude rhizome extracts and volatile oils of *C. aromatica* were evaluated for anti-mosquito potential, including larvicidal, adulticidal, and repellent activities against the *Aedes aegypti* mosquito proved that volatile oils of *Curcuma* possessed a significantly higher larvicidal activity against the 4th instar larvae of *Aedes aegypti* (Kojima et al., 1998).

## CONCLUSION

According to the review, genus *Curcuma* is an important medicinal plant with several lead molecules, which are responsible for numerous bioactivities as well as other uses. Hence, isolation and identification of those important molecules are needed for opening of new window in therapeutics. Although there are many *Curcuma* species, chemical constituents and bioactivities and other uses have been investigated only for few commonly used species. In addition, there is limited literature available for studies related to food value, nutritional composition, and health benefits of the edible *Curcuma* species. Further research on nutritional values along with pharmacological studies of uninvestigated and novel compounds is desirable. This will provide immense opportunities for the development of new plant-based food and pharmaceutical products. Moreover, there is no systematic method to differentiate the species within the genera. Even though many species have been identified in India, other countries have not paid much attention to identify *Curcuma* species within their countries and phytochemical or pharmacological investigations. Therefore, researchers have vast field of research to be discovered than what exists presently on medicinally important *Curcuma* species, which will be more useful in therapeutic alternatives to treat many diseases as well as other ecological remedies.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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## REFERENCES

Abbott WS (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology* 18:265-267. <https://doi.org/10.1093/jee/18.2.265a>

- Abdel-Lateef E, Mahmoud F, Hammam O, El-Ahwany E, El-Wakil E, Kandil S, Taleb HA, El-Sayed M, Hassenein H (2016). Bioactive Chemical Constituents of *Curcuma longa* L. Rhizomes Extract Inhibit the Growth of Human Hepatoma Cell Line (Hepg2). *Acta Pharmaceutica* 66:387-398. <http://dx.doi.org/10.1515/acph-2016-0028>
- Aisha R, Abdur R, Waleed K, Faiza S, Abdul B, Hafiz SM, Kashif I, Munir A (2018). Simultaneous dyeing and anti-bacterial finishing on 100% cotton fabric: process establishment and characterization. *Cellulose* 25(9):5405-5414. <http://dx.doi.org/10.1007/s10570-018-1934-9>
- Akarchariya N, Sirilun S, Julsrigival J, Chansakaowa S (2017). Chemical profiling and antimicrobial activity of essential oil from *Curcuma aeruginosa* Roxb., *Curcuma glans* K. Larsen & J. Mood and *Curcuma xanthorrhiza* Roxb. collected in Thailand. *Asian Pacific Journal of Tropical Biomedicine* 7:881-885. <http://dx.doi.org/10.1016/j.apjtb.2017.09.009>
- Akrishnan VR, Menon VP (2001). Potential role of antioxidants during ethanol-induced changes in the fatty acid composition and arachidonic acid metabolites in male Wistar rats. *Cell Biology and Toxicology* 17:11-22.
- Alshehry AZ, Zaitoun AA, Abo-Hassan RA (2014). Insecticidal activities of some plant extracts against subterranean termites, *Psammotermes hybostoma* (Desneux) (Isoptera: Rhinotermitidae) *International Journal of Agricultural Science* 4:257-260.
- Anandaraj M, Prasath D, Kandianan, John ZKT, Srinivasan V, Jha AK, Singh BK, Singh AK, Pandey VP, Singh SP, Shoba N, Jana JC, Ravindra KK, Uma MK (2014). Genotype by environmental interaction effects on yield and curcumin. *Industrial Crops and Products* 53:358-364. <http://dx.doi.org/10.1016/j.indcrop.2014.01.005>
- Angel GR, Menon N, Vimala B, Nambisan B (2014). Essential Oil Composition of Eight Starchy *Curcuma* Species. *Industrial Crops and Products* 60:233-238. <https://dx.doi.org/10.1016/j.indcrop.2014.06.028>
- Anjusha S, Gangaprasad A (2014). Phytochemical and Antibacterial Analysis of Two Important *Curcuma* Species, *Curcuma aromatica* Salisb. And *Curcuma Xanthorrhiza* Roxb. (Zingiberaceae). *Journal of Pharmacognosy and Phytochemistry* 3(3):50-53.
- Arulmozhi DK, Sridhar N, Veeranjanyulu A, Arora SK (2006). Preliminary mechanistic studies on the smooth muscle relaxant effect of hydroalcoholic extract of *Curcuma caesia*. *Journal of Herbal Pharmacotherapy* 6:117-124.
- Arun N, Nalini N (2002). Efficacy of turmeric on blood sugar and polyol pathway in diabetic albino rats. *Plant Foods for Human Nutrition*. 57:41-52.
- Baghel SS, Baghel RS, Sharma K, Sikarwar I (2013). Pharmacological activities of *Curcuma caesia*. *International Journal of Green Pharmacy* 7:1-5. <http://dx.doi.org/10.4103/0973-8258.111590>
- Balasubramanyam K, Varier RA, Altaf M, Swaminathan V, Siddappa NB, Ranga U, Tapas KK (2004). Curcumin, a novel p300/CREB-binding protein specific inhibitor of acetyltransferase, represses the acetylation of histone/nonhistone proteins and histone acetyltransferase-dependent chromatin transcription. *Journal of Biological Chemistry* 279:51163-51171. <http://dx.doi.org/10.1074/jbc.M409024200>
- Bhavani STN, Sreenivasa MV (1979). Effect of turmeric (*Curcuma longa*) fractions on the growth of some intestinal and pathogenic bacteria *in vitro*. *Indian Journal of Experimental Biology* 17:1363-1366.
- Chen CC, Chen Y, His YT, Chang CS, Huang LF, Ho CT, Way TD, Kao JY (2013). Chemical constituents and anticancer activity of *Curcuma zedoaria* Roscoe essential oil against non-small cell lung carcinoma cells *in vitro* and *in vivo*. *Journal of Agricultural and Food Chemistry* 61(47):11418-11427.
- Chey WY, Millikan L, Lee KY, Watanabe S, Shiratori K, Takeuchi T (1983). Effect of 1-phenylpentanol on release of secretin and exocrine pancreatic secretion in dogs and humans. *Gastroenterology* 84:1578-1584.
- Choudhury SN, Ghosh AC, Saika M, Choudhury M, Leclercq PA (1996). Volatile oil constituents of the aerial and underground parts of *Curcuma aromatica* Salisb. from India. *Journal of Essential Oil Research* 8:635-638.

- Chowdhury H, Banerjee T, Walia S (2008). *In vitro* screening of *Curcuma longa* L and its derivatives as antifungal agents against *Helmintho sporumoryzae* and *Fusarium solani*. Journal of Pesticide Science 20:6-9.
- Cuellar MJ, Giner RM, Recio MC, Just MJ, Manez S, Cerda S, Rios JL (1998). Screening of anti-inflammatory medicinal plants used in traditional medicine against skin diseases. Phytotherapy Research 12:18-23.
- Dairaku I, Han YN, Yanaka N, Kato N (2010). Inhibitory effect of curcumin on IMP dehydrogenase, the target for anticancer and antiviral chemotherapy agents. Bioscience, Biotechnology and Biochemistry 74:185-187.
- Da Silva JKR, Maia JGS, Dosoky NS, Setzer WN (2016). Antioxidant, antimicrobial, and cytotoxic properties of *Aniba parviflora* essential oils from the Amazon. Natural Product Communications 11:1025-1028.
- Deeb D, Xu YX, Jiang H, Gao X, Janakiram N, Chapman RA, Gautam SC (2003). Curcumin (diferuloyl-methane) enhances tumor necrosis factor-related apoptosis-inducing ligand-induced apoptosis in LNCaP prostate cancer cells. Molecular Cancer Therapeutics 2:95-103.
- Devi NB, Singh PK, Das AK (2014). Ethnomedicinal Utilization of Zingiberaceae in the Valley Districts of Manipur. IOSR Journal of Environmental Science, Toxicology and Food Technology 8(2):21-23.
- Dung NX, Truong PX, Ky PT, Leclercq PA (1996). Chemical composition of the essential oils of *Curcuma cochinchinensis* Gagnep. From Vietnam. ACGC Chemical Research Communications 5:11-16.
- Dung NX, Truong PX, Ky PT, Leclercq PA (1997). Volatile Constituents of the Leaf, Stem, Rhizome, Root and Flower Oils of *Curcuma harmandii* Gagnep. from Vietnam. Journal of Essential Oil Research 9:677-681.
- Dung NX, Tuyet NTB, Van Khien P, Barthel, Leclercq PA (1998). Characterization of the Leaf Oil of *Curcuma aureginosa* Roxb. from Vietnam. Journal of Essential Oil Research 10:527-528.
- Fagodia SK, Singh HP, Batish DR, Kohli RK (2017). Phytotoxicity and cytotoxicity of *Citrus aurantiifolia* essential oil and its major constituents: Limonene and citral. Industrial Crops and Products 108:708-715.
- Faiz HC, Al-Amin M, Rahman KM, Sarker A, Alam MM, Chowdhury MH, Khan SN, Sultana GN (2015). Analgesic Principle from *Curcuma Amada*. Journal of Ethnopharmacology 163:273-277.
- Fouad HA, Da Camara CAG (2017). Chemical composition and bioactivity of peel oils from *Citrus aurantiifolia* and *Citrus reticulata* and enantiomers of their major constituent against *Sitophilus zeamais* (Coleoptera: Curculionidae). Journal of Stored Products Research. 73:30-36.
- Garg SK (1974). Effect of *Curcuma longa* (rhizomes) on fertility in experimental animals. Planta Medica. 26:225-227.
- Gill R, Kalsi V, Singh A (2011). Phytochemical investigation and evaluation of anthelmintic activity of *Curcuma amada* and *Curcuma caesia* - a comparative study. Inventi Impact: Ethnopharmacology. Article ID -Inventi: ep/412/11, Available from: <http://www.inventi.in/Article/ep/412/11.aspx>.
- Gomes DC, Alegrio LV, De Lima ME, Leon LL, Araujo CA (2002). Synthetic derivatives of curcumin and their activity against *Leishmania amazonensis*. Arzneimittel-Forschung 52:120-124.
- Grieve M (1971). A Modern Herbal: The Medicinal, Culinary, Cosmetic and Economic Properties, Cultivation and Folk-lore of Herbs, Grasses, Fungi, Shrubs, and Trees with All Their Modern Scientific Uses (Volume 2 of Modern Herbal), Courier Corporation. ISBN 0486227995, 9780486227993.
- Gupta SC, Patchva S, Aggarwal BB (2013). Therapeutic Roles of Curcumin: Lessons Learned from Clinical Trials. The AAPS Journal 15:195-218. <http://dx.doi.org/10.1208/s12248-012-9432-8>.
- Hamss R, Analla M, Campos-Sanchez J, Alonso-Moraga A, Munoz-Serrano A, Idaomar MA (1999). Dose dependent anti-genotoxic effect of turmeric. Mutation Research 446:135-39.
- Huxley A (1992). The New RHS Dictionary of Gardening; MacMillan Press: Great Britain.
- Jagtap S (2015). Phytochemical Screening, Anti-Oxidant Activity, Multi-Elemental Analysis by ICP- Spectroscopy and Antimicrobial Activity of Rhizome Extracts of *Curcuma pseudomontana* J. Graham. European Journal of Biomedical and Pharmaceutical Sciences 2(4):1152-1169.
- Jana NR, Dikshit P, Goswami A, Nukina N (2004). Inhibition of proteasomal function by curcumin induces apoptosis through mitochondrial pathway. Journal of Biological Chemistry 279:11680-1685.
- Jantan I, Raweh SM, Sirat HM, Jamil S, Mohd Yasin YH, Jalil J Jamia Azdina (2008). Inhibitory effect of compounds from Zingiberaceae species on human platelet aggregation. Phytomedicine 15(4):306-309.
- Jena S, Ray A, Banerjee A, Sahoo A, Nasim N, Sahoo S, Kar B, Patnaik J, Panda JC, Nayak S (2017). Chemical Composition and Antioxidant Activity of Essential Oil from Leaves and Rhizomes of *Curcuma angustifolia* Roxb. Natural Product Research 9:1-4.
- Jentzsch K, Gonda T, Holler H (1959). Paper chromatographic and pharmacological investigations on *Curcuma* pigments. Pharm. Helvetica Chimica Acta 34:181-188.
- Jeon WY, Lee MY, Shin IS, Jin SE, Ha H (2015). *Curcuma aromatica* Water Extract Attenuates Ethanol- Induced Gastritis via Enhancement of Antioxidant Status. Evidence-Based Complementary and Alternative Medicine 582496.<http://dx.doi.org/10.1155/2015/582496>
- Jose S, Thomas TD (2014). Comparative Phytochemical and Anti-Bacterial Studies of Two Indigenous Medicinal Plants *Curcuma caesia* Roxb. And *Curcuma aeruginosa* Roxb. International Journal of Green Pharmacy 8:65-71.
- Kamal-Eldin A, Frank J, Razdan A, Tengblad S, Basu S, Vessby B (2000). Effects of dietary phenolic compounds on tocopherol, cholesterol, and fatty acids in rats. Lipids 35:427-435.
- Kamazeri TSAT, Samah OA, Taher M, Susanti D, Qaralleh H (2012). Antimicrobial Activity and Essential Oils of *Curcuma aeruginosa*, *Curcuma mangga* and *Zingiber cassumunar* from Malaysia. Asian Pacific Journal of Tropical Medicine 5(3):202-209.
- Kang HC, Ji-Xing N, Pil-Hoon P, Ji-Young K, Sung HL, Sun WW, Yu-Zhe Z, Eun-Jeon P, Dong HS (2002). Curcumin inhibits collagen synthesis and hepatic stellate cell activation *in vivo* and *in vitro*. Journal of pharmacy and pharmacology 54(1):119-126.
- Kim DC, Kim SH, Choi BH, Baek NI, Daeho Kim, Kim MJ, Kim KT (2005). *Curcuma longa* extract protects against gastric ulcers by blocking H2 histamine receptors. Biological and Pharmaceutical Bulletin 28:2220-2224.
- Kim DSHL, Kim JY, Han YS (2007). Alzheimer's Disease Drug Discovery from Herbs: Neuroprotectivity from Beta-Amyloid (1-42) Insult. The Journal of Alternative and Complementary Medicine 13(3):333-340.
- Kim MK, Choi GJ, Lee HS (2003). Fungicidal property of *Curcuma longa* L. Rhizome-derived curcumin against phytopathogenic fungi in a greenhouse. Journal of Agricultural and Food Chemistry 51:1578-81.
- Koide T, Nose M, Ogihara Y, Yabu Y, Ohta N (2002). Leishmanicidal effect of curcumin *in vitro*. Biological and Pharmaceutical Bulletin 25:131-133.
- Kojima H, Yanai T, Toyota A (1998). Essential oil constituents from Japanese and Indian *Curcuma aromatica* rhizomes. Planta Medica 64(4):380-381.
- Kress WJ, Prince LM, Williams KJ (2002). The phylogeny and a new classification of the gingers (Zingiberaceae): evidence from molecular data. American Journal of Botany 89:1982-1996.
- Kumar A, Chomwal R, Kumar P, Renu S (2009). Antiinflammatory and wound healing activity of *Curcuma aromatica* salisb extract and its formulation. Journal of Chemical and Pharmaceutical Research 1(1):304-10.
- Kumar S, Narain U, Tripathi S, Misra K (2001). Synthesis of curcumin bioconjugates and study of their antibacterial activities against beta-lactamase-producing microorganisms. Bioconjugate Chemistry 12:464-469.
- Kutti GD, Lingamallu J (2012). Comparison of chemical composition and antioxidant potential of volatile oil from fresh, dried and cured turmeric (*Curcuma longa*) rhizomes. Industrial Crops and Products 38:124-131.
- Lai EYC, Chyau CC, Mau JL, Chen CC (2004). Antimicrobial Activity and Cytotoxicity of the Essential Oil of *Curcuma zedoaria*. The

- American Journal of Chinese Medicine 32:281.
- Lechtenberg M, Quandt B, Nahrstedt A (2004). Quantitative determination of curcuminoids in *Curcuma* rhizomes and rapid differentiation of *Curcuma domestica* Val. and *Curcuma zanthorrhiza* Roxb. by capillary electrophoresis. *Phytochemical Analysis* 15:152-158.
- Lee CJ, Lee JH, Seok JH, Hur GM, Park YC, Seol IC, et al. (2003). Effects of baicalein, berberine, curcumin and hesperidin on mucin release from airway goblet cells. *Planta Medica* 69:523-526.
- Liao S, Lin J, Dang MT, Zhang H, Kao YH, Fukuchi J, Hiipakka RA (2001). Growth suppression of hamster flank organs by topical application of catechins, alizarin, curcumin, and myristoleic acid. *Archives of Dermatological Research* 293:200-205.
- Li CJ, Zhang LJ, Dezube BJ, Crumpacker CS, Pardee AB (1993). Three inhibitors of Type 1 human immunodeficiency virus long terminal repeat-directed gene expression and virus replication. *Proceedings of the National Academy of Sciences of the United States of America* 90:1839-1842.
- Li J, Bian WH, Wan J, Zhou J, Lin Y, Wang JR, Wang ZX, Shen Q, Wang KM (2014). Curdione inhibits proliferation of MCF-7 cells by inducing apoptosis. *Asian Pacific Journal of Cancer Prevention* 15:9997-10001.
- Lin X, Xue L, Zhang H, Zhu C (2006). Determination of curcumins in turmeric by micellarelectro kinetic capillary chromatography. *Canadian Journal of Analytical Sciences and Spectroscopy* 51:35-42.
- Lin YG, Kunnumakkara AB, Nair A, Merritt WM, Han LY, Armaiz-Pena GN, Kamat AA, Spannuth WA, Gershenson DM, Lutgendorf SK, Aggarwal BB, Sood AK (2007). Curcumin inhibits tumor growth and angiogenesis in ovarian carcinoma by targeting the nuclear factor- $\kappa$ B pathway. *Clinical Cancer Research* 13:3423-3430.
- Liu B, Gao YQ, Wang XM, Wang YC, Fu LQ (2014). Germacrone inhibits the proliferation of glioma cells by promoting apoptosis and inducing cell cycle arrest. *Mol Med Rep* 10(2): 1046-1050.
- Liu N, Wu TL (1999). Notes on *Curcuma* in China. *Journal of Tropical and Subtropical Botany* 7:146-150.
- Maciel N, Criley RA (2003). Morphology, growth and flowering behavior of *Curcuma zedoaria*. *Acta Horticulturae (ISHS)* 624:111-116.
- Mahady GB, Pendland SL, Yun G, Lu ZZ (2002). Turmeric (*Curcuma longa*) and curcumin inhibit the growth of *Helicobacter pylori*, of group 1 carcinogen. *Anticancer Research* 22:4179-4181.
- Maikhuri RK, Gangwar AK (1993). Ethnobiological notes on the Khasi and Garo tribes of Meghalaya, Northeast India. *Economic Botany* 47:345-357.
- Malek SN, Seng CK, Zakaria Z, Ali NA, Ibrahim H, Jalil MN (2006). The Essential Oil of *Curcuma inodora* aff. *Blatter* from Malaysia. *Journal of Essential Oil Research* 18(1):281-283.
- Marina GD, Kekuda PTR, Sudarshan SJ (2008). Antitussive activity of ethanolic extract of *Curcuma aromatica* rhizomes on sulfur dioxide induced cough in mice. *Ancient Science of Life* 27(3):36-40.
- Martin-Cordero C, Lopez-Lazaro M, Galvez M, Ayuso MJ (2003). Curcumin as a DNA topoisomerase II poison. *Journal of Enzyme Inhibition and Medicinal Chemistry* 18:505-509.
- Martins CV, Da Silva DL, Neres AT, Magalhães TF, Watanabe GA, Modolo LV, Sabino AA, De Fátima A, De Resende MA (2009). Curcumin as a promising antifungal of clinical interest. *Journal of Antimicrobial Chemotherapy* 63:337-339.
- Menon VP, Sudheer AR (2007). Antioxidant and anti-inflammatory properties of curcumin. *Advances in Experimental Medicine and Biology* 595:105-125.
- Nattadon R, Ungruangkitkrai R, Attanaphol M, Ongkholrattanasit (2012). Eco-Friendly of Textiles Dyeing and Printing with Natural Dyes. *International Conference, Textiles & Fashion, July 34, 2012, Bangkok Thailand.*
- Newman MF, Lhuillier A, Poulsen ADA (2004). Checklist of the Zingiberaceae of Malaysia. *Blume* 16:63. ISBN 90-71236-XX-X
- Nishiyama T, Mae T, Kishida H, Tsukagawa M, Mimaki Y, Kuroda M, Kuroda M, Sashida Y, Takahashi K, Kawada T, Nakagawa K, Kitahara M (2005). Curcuminoids and sesquiterpenoids in turmeric (*Curcuma longa* L.) suppress an increase in blood glucose level in Type 2 diabetic KK-Ay mice. *Journal of Agricultural and Food Chemistry* 53:959-963.
- Nithya R, Jayshree N (2017). A review on herbs of the Zingiberaceae family with beneficial effects on cardiovascular diseases. *World Journal of Pharmacy and Pharmaceutical Sciences* 6(6):635-643.
- Noura SD, William NS (2018). Chemical Composition and Biological Activities of Essential Oils of *Curcuma* Species, *Nutrients* 10:1196.
- Nwozo SO, Osunmadewa DA, Oyinloye BE (2014). Anti-fatty liver effects of oils from *Zingiber officinale* and *Curcuma longa* on ethanol-induced fatty liver in rats. *Journal of Integrative Medicine* 12:59-65.
- Oon SF, Nallappan M, Tee TT, Shohaimi S, Kassim NK, Sa'ariwijaya MSF, Cheah YH (2015). Xanthorrhizol: A review of its pharmacological activities and anticancer properties. *Cancer Cell International* 15:100.
- Paisooksantivatana Y, Thepsen O (2001). Phenetic relationships of some Thai *Curcuma* species (Zingiberaceae) based on morphological, palynological and cytological evidences. *Thai Journal of Agricultural Science* 34:47-57.
- Paliwal P, Pancholi SS, Patel RK (2011). Pharmacognostic Parameters for Evaluation of the Rhizomes of *Curcuma caesia*. *Journal of Advanced Pharmaceutical Technology and Research* 2:56-61.
- Panahi Y, Alishiri GH, Parvin S, Sahebkar A (2016a). Mitigation of systemic oxidative stress by curcuminoids in osteoarthritis: Results of a randomized controlled trial. *Journal of Dietary Supplements* 13:209-220.
- Panahi Y, Hosseini MS, Khalili N, Naimi E, Simental-Mendia LE, Majeed M, Sahebkar A (2016b). Effects of curcumin on serum cytokine concentrations in subjects with metabolic syndrome: A post-hoc analysis of a randomized controlled trial. *Biomedicine & Pharmacotherapy* 82:578-582.
- Pandey AK, Chowdhury AR (2003). Volatile Constituents of the Rhizome Oil of *Curcuma caesia* Roxb. From Central India. *Flavour and Fragrance Journal* 18:463-468. <https://doi.org/10.1002/ffj.1255>
- Panich U, Kongtaphan K, Onkoksoong T, Jaesak K, Phadungrakwittaya R, Thaworn A, Pravit A, Adisak W (2010). Modulation of antioxidant defense by *Alpinia galanga* and *Curcuma aromatica* extracts correlates with their inhibition of UVA-induced melanogenesis. *Cell Biology and Toxicology* 26(2):103-116.
- Pant M, Misra H, Jain DC (2013). Phytochemical Investigation of Ethyl Acetate Extract from *Curcuma aromatica* Salisb. Rhizomes. *Arabian Journal of Chemistry* 6:279-283.
- Pawar RK, Sharma S, Singh KC, Sharma Rajeev KR (2011). Development and validation of HPTLC method for the determination of andrographolide in kalmegh navayas lohaan ayurvedic formulation. *International Journal of Pharmacy and Pharmaceutical Sciences* 3:975-1491.
- Pemba HB, Sharangi AB (2017). Promising curcuma species suitable for Hill regions towards maintaining biodiversity. *Journal of Pharmacognosy and Phytochemistry* 6(6):726-731.
- Pitasawat B, Choochote W, Tuetun B, Tippawangkosol P, Kanjanapothi D, Jitpakdi A, Duangrat R (2003). Repellency of aromatic turmeric *Curcuma aromatica* under laboratory and field conditions. *Journal of Vector Ecology* 28(2):234-240.
- Platel K, Srinivasan K (2000). Influence of dietary spices and their active principles on pancreatic digestive enzymes in albino rats. *Nahrung* 44:42-46.
- Policegoudra RS, Rehna K, Rao LJ, Aradhya SM (2010). Antimicrobial, Antioxidant, Cytotoxicity and Platelet Aggregation Inhibitory Activity of a Novel Molecule Isolated and Characterized from Mango Ginger (*Curcuma amada* Roxb.) Rhizome. *Journal of Biosciences* 35(2):231-240.
- Priyadarsini KI, Maity DK, Naik GH, Kumar MS, Unnikrishnan MK, Satav JG, Mohan H (2003). Role of phenolic O-H and methylene hydrogen on the free radical reactions and antioxidant activity of curcumin. *Free Radical Biology and Medicine* 35:475-484.
- Prucksunand C, Indrasukhsri B, Leethochawalit M, Hungspreugs K (2001). Phase II clinical trial on effect of the long turmeric (*Curcuma longa* Linn) on healing of peptic ulcer. *The Southeast Asian Journal of Tropical Medicine and Public Health* 32:208-215.
- Pukhrabam C (2002). Evaluation of Antioxidant Properties in Some Members of Zingiberales and Micropropagation of Elites. Ph.D Thesis, Manipur University, Imphal, 2002.
- Purkayastha J, Nath SC, Klinkby N (2006). Essential oil of the rhizome of *Curcuma zedoaria* (Christm.) Rosc. native to northeast India. *Journal of Essential Oil Research* 18:154-155.

- Rafatullah S, Tariq M, Al-Yahya MA, Mossa JS, Ageel AM (1990). Evaluation of turmeric (*Curcuma longa*) for gastric and duodenal antiulcer activity in rats. *Journal of Ethnopharmacology* 29:25-34.
- Rajashekhar N, Sharma PP (2010). A Comparative Study of Efficacy of Tugaksheeree (*Curcuma angustifolia* Roxb. and *Maranta Arundinacea* Linn. In Management of Amlapitta, Ayurveda 31(4):482-486.
- Ramasree AB, Indira B (2006). Anatomical and histochemical studies on four species of *Curcuma*. *Phytomorphology* 56:1-8.
- Rao AS, Bandaru R, Ramachandran S (1989). Volatile Aroma Components of *Curcuma amada* Roxb. *Journal of Agricultural and Food Chemistry* 37:740-743.
- Rasmussen HB, Christensen SB, Kuist LP, Karazmi A (2000). A simple and effective separation of the curcumins, the antiprotozoal constituents of *Curcuma longa*. *Planta Medica* 66:396-398.
- Padhi BS (2012). Pollution due to synthetic dyes toxicity and carcinogenicity studies and remediation. *International Journal of Environmental Sciences* 3:940.
- Raut JS, Karuppaiyl SM (2014). A status review on the medicinal properties of essential oils. *Industrial Crops and Products* 62:250-264.
- Ravindran PN, Babu KN, Shiva KN (2007). Botany and crop improvement of tumeric. In *Turmeric the Genus Curcuma*; CRC Press: Boca Raton, FL, USA pp. 15-70.
- Reazuddin R, Tauhidul IM, Abdullah AM (2017). Ecological risk assessment and health safety speculation during color fastness properties enhancement of natural dyed cotton through metallic mordants. *Fashion and Textiles* 4:1.
- Ringman JM, Frautschy SA, Cole GM, Masterman DL, Cummings JL (2005). A potential role of the curry spice curcumin in Alzheimer's disease. *Current Alzheimer Research* 2:131-136.
- Rithaporn T., Monga M, Rajasekharan M (2003). Curcumin: a potential vaginal contraceptive. *Contraception* 68:219-223.
- Roshan PY, Gaur T (2017). Versatility of turmeric: A review the golden spice of life. *Journal of Pharmacognosy and Phytochemistry* 6(1):41-46.
- Sahdeo P, Bharat BA (2011). Turmeric, the golden spice: from traditional medicine to modern medicine. In: *Herbal Medicine: Biomolecular and Clinical Aspects*. Benzie IFF, Wachtel-Galor S, editors. Boca Raton FL., CRC Press Taylor and Francis 2011 Chapter 13.
- Sahebkar A, Serbanc MC, Ursoniuc S, Banach M (2015). Effect of curcuminoids on oxidative stress: A systematic review and meta-analysis of randomized controlled trials. *Journal of Functional Foods* 18:898-909.
- Saikia B, Borthakur SK (2010). Use of Medicinal Plants in Animal Healthcare- A Case Study from Gohpur, Assam, *Indian Journal of Traditional Knowledge* 9(1):49-51.
- Sanatombi R, Sanatombi K (2017). Nutritional value, phytochemical composition and biological activities of edible *Curcuma* species: A review, *International Journal of Food Properties* 20(sup3):S2668-S2687. <http://dx.doi.org/10.1080/10942912.2017.1387556>
- Sanghamitra N, Sujata M, Nagar K (2015). Differential effect of soil and environment on metabolic expression of turmeric (*Curcuma longa* cv. Roma). *Indian Journal of Experimental Biology* 53:406-411.
- Sarangthem K, Haokip MJ (2010). Bioactive Components in *Curcuma caesia* Roxb. Grown in Manipur. *Bioscan* 5:113-115.
- Satyendra SB, Rajendra SB, Kshamashil S, Indu S (2013). Pharmacological activities of *Curcuma caesia*. *International Journal of Green Pharmacy* 7:1-5.
- Saxena PN, Anand S, Saxena N, Bajaj P (2009). Effect of arsenic trioxide on renal functions and its modulation by *Curcuma aromatica* leaf extract in albino rat. *Journal of Environmental Biology* 30(4):527-31.
- Shaffreen RB, Lubinska M, Ró'za' nska A, Dymerski T, Namie'snik J, Katrich E, Gorinstein S (2018). Human serum interactions with phenolic and aroma substances of Kaffir (*Citrus hystrix*) and Key lime (*Citrus aurantifolia*) juices. *J. Lumin.* <https://doi.org/10.1016/j.jlumin.2018.04.010>
- Sharma A (2012). Traditional Processing of Shotti (*Curcuma angustifolia* Roxb.)- A Rhizome Based Ethnic Weaning Food. *Indian Journal of Traditional Knowledge* 11(1):154-155.
- Sharma GJ, Chirangini P, Kishor R (2011). Gingers of Manipur: Diversity and Potentials as Bioresources. *Genetic Resources and Crop Evolution* 58:753-767.
- Shirgurkar MV, John CK, Nadguada RS (2001). Factors effecting *in vitro* microrhizome production in turmeric. *Plant Cell, Tissue and Organ Culture* 64:5-11.
- Shukla Y, Arora A, Taneja P (2002). Antimutagenic potential of curcumin on chromosomal aberrations in Wistar rats. *Mutation Research* 515:197-202.
- Sikha A, Harini A, Prakash H (2015). Pharmacological activities of wild turmeric (*Curcuma aromatica* Salisb): A review. *Journal of Pharmacognosy and Phytochemistry* 3:1-4.
- Singh G, Kapoor IPS, Singh P, De Heluani CS, De Lampasona MP, Catalan CAN (2010). Comparative study of chemical composition and antioxidant activity of fresh and dry rhizomes of turmeric (*Curcuma longa* Linn.). *Food and Chemical Toxicology* 48:1026-1031. <http://dx.doi.org/10.1016/j.fct.2010.01.015>
- Singh G, Singh OP, Maurya S (2002). Chemical and Biocidal Investigations on Essential Oils of Some Indian *Curcuma* Species. *Progress in Crystal Growth and Characterization of Materials* 45:75-81.
- Sirirugsa P, Larsen K, Maknoi C (2007). The Genus *Curcuma* L. (Zingiberaceae): Distribution and Classification with Reference to Species Diversity in Thailand. *Gardens' Bull. Singapore* 59:1-2.
- Sirirugsa P (1998). Thai Zingiberaceae: Species Diversity and Their Uses. *International Conference on Biodiversity and Bioresources: Conservation and Utilization. Pure and Applied Chemistry* 70(11).
- Srinivasan V, Thankamani CK, Dinesh R, Kandiannan K, Zachariah TJ, Leela NK, Hamza S, Shajina O, Ansha O (2016). Nutrient management systems in turmeric: Effects on soil quality, rhizome yield and quality. *Industrial Crops and Products* 85:241-250.
- Srivilai J, Waranuch N, Tangsumranjit A, Khorana N, Ingkaninan K (2018). Germacrone and sesquiterpene-enriched extracts from *Curcuma aeruginosa* Roxb. increase skin penetration of minoxidil, a hair growth promoter. *Drug Delivery and Translational Research* 8:140-149.
- Sumbilla C, Lewis D, Hammerschmidt T, Inesi G (2002). The slippage of the Ca<sup>2+</sup> pump and its control by anions and curcumin in skeletal and cardiac sarcoplasmic reticulum. *Journal of Biological Chemistry* 277:13900-13906.
- Suryanarayana P, Krishnaswamy K, Reddy GB (2003). Effect of curcumin on galactose-induced cataractogenesis in rats. *Molecular Vision* 9:223-230.
- Su X, Jiang B, Wang H, Shen C, Chen H, Zeng Li (2017). Curcumin suppresses intestinal fibrosis by inhibition of PPAR $\gamma$ -mediated epithelial-mesenchymal transition. *Evidence-Based Complementary and Alternative Medicine* 92:57-66.
- Taher MM, Lammering G, Hershey C, Valerie K (2003). Curcumin inhibits ultraviolet light induced human immunodeficiency virus gene expression. *Molecular and Cellular Biochemistry* 254:289-97.
- Talukder FA, Howse PE (1993). Deterrent and insecticidal effects of extracts of pithraj, *Aphanamixis polystachya* (Meliaceae), against *Tribolium castaneum* in storage. *Journal of Chemical Ecology* 19:2463-2471. <http://dx.doi.org/10.1007/BF00980683>
- Tavares WDS, Freitas SDS, Graziottini GH, Parentec LML, Lia LM, Zanuncio JC (2013). Ar-turmerone from *Curcuma longa* rhizomes and effects on *Sitophilus zeamais* and *Spodoptera frugiperda*. *Industrial Crops and Products* 46:158-164.
- Theanphong O, Mingvanish W, Kirdmanee C (2015). Chemical constituents and biological activities of essential oil from *Curcuma aeruginosa* Roxb. rhizome. *Bulletin of Science, Technology & Society* 13:6-16.
- Thiyagarajan M, Sharma SS (2004). Neuroprotective effect of curcumin in middle cerebral artery occlusion induced focal cerebral ischemia in rats. *Life sciences* 74:969-985.
- Tsai SY, Huang SJ, Chyau CC, Tsai CH, Weng CC, Mau JL (2011). Composition and antioxidant properties of essential oils from *Curcuma* rhizome. *Asian Journal of Applied Sciences* 2:57-66.
- Tyag DK (2005). *Pharma Forestry: A Field Guide to Medicinal Plants*; Atlantic Publishers & Distributors: New Delhi, India.
- Uemura N, Okamoto S, Yamamoto S, Matsumura N, Yamaguchi S, Yamakido M, Kiyomi T, Naomi S, Ronald JS (2001). *Helicobacter*

- pylori* infection and the development of gastric cancer. *New England Journal of Medicine* 13:784-9.
- Ungphaiboon S, Supavita T, Singchangchai P, Sungkarak S, Rattanasuwan P, Itharat A (2005). Study on antioxidant and antimicrobial activities of turmeric clear liquid soap for wound treatment of HIV patients. *Songklanakarin Journal of Science and Technology* 27(2):269-578.
- Vairappan CS, Elias UM, Ramachandram TR, Kamada T (2013). Secondary Metabolites from Rhizome of *Curcuma caesia* Roxb. (Zingiberaceae). *Biochemical Systematics and Ecology* 48:107-110.
- Wu WY, Xu Q, Shi LC, Zhang WB (2000). Inhibitory effects of *Curcuma aromatica* oil on proliferation of hepatoma in mice. *World Journal of Gastroenterology* 6(2):216-219.
- Xiang H, Zhang L, Lu Xi, Yang Y, Wang X, Lei D, Xi Zheng, Liu X (2018). Phytochemical profiles and bioactivities of essential oils extracted from seven *Curcuma* herbs, *Industrial crops and products* 111:298-305.
- Xiang Z, Wang X, Cai X, Zeng S (2011). Metabolomics Study on Quality Control and Discrimination of Three *Curcuma* Species Based on Gas Chromatograph-Mass Spectrometry. *Phytochemical Analysis* 22:411-418.
- Xia Q, Zhao KZ, Huang ZG, Zhang P, Dong TXX, Li SP, Tsim KWK (2005). Molecular genetic and chemical assessment of Rhizoma *Curcumae* in China. *Journal of agricultural and food chemistry*, 53(15):6019-6026. <http://dx.doi.org/10.1021/jf0508495>
- Xia X, Cheng G, Pan Y, Xia ZH, Kong LD (2007). Behavioral, neurochemical and neuroendocrine effects of the ethanolic extract from *Curcuma longa* L. in the mouse forced swimming test. *Journal of Ethnopharmacology* 110:356-363. <http://dx.doi.org/10.1016/j.jep.2006.09.042>
- Xu Y, Ku B, Tie L, Yao H, Jiang W, Ma X, Li X (2006). Curcumin reverses the effects of chronic stress on behavior, the HPA axis, BDNF expression and phosphorylation of CREB. *Brain research* 1122(1):56-64. <http://dx.doi.org/10.1016/j.brainres.2006.09.009>
- Yu ZF, Kong LD, Chen Y (2002). Antidepressant activity of aqueous extracts of *Curcuma longa* in mice. *Journal of Ethnopharmacology* 83:161-165.
- Zhang L, Yang Z, Wei J, Su P, Pan W, Zheng X, Zhang K, Lin L, Tang J, Fang, Du Z (2017). Essential oil composition and bioactivity variation in wild-growing populations of *Curcuma phaeocaulis* Valetton collected from China. *Industrial Crops and Products* 103:274-282. <http://dx.doi.org/10.1016/j.indcrop.2017.04.019>

*Full Length Research Paper*

## **Nutritional status of three sugarcane varieties grown in the northeast region of Brazil**

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**The diagnosis of plant nutritional status was a tool to improve crop fertilization and thus ensure better productivity. This study aimed to evaluate the nutritional status of three sugarcane varieties (RB92579, RB98710 and RB961552) in the plant-cane and first regrowth cycles in the sub-humid region of the state of Alagoas, located in the Northeast of Brazil. The experiment consisted of a randomized complete block design with five replicates. Plant nutritional status was determined by chemical analysis of leaf +3 at the maximum growth phase of the crop. There was a varietal effect for macronutrient and micronutrient contents in both crop cycles, but no variety stood out in regards to leaf contents. However, all three varieties were deficient in Cu and Mn.**

**Key words:** Macronutrients, micronutrients, RB92579, RB961552, RB98710, *Saccharum* species.

### **INTRODUCTION**

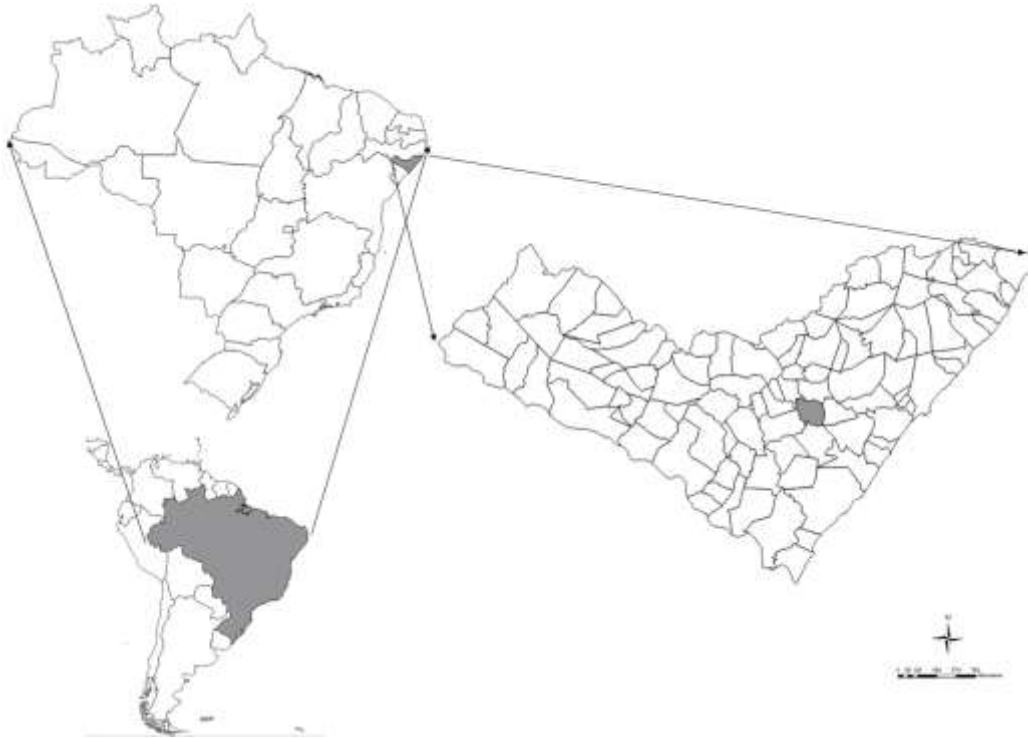
The evaluation of plant nutritional status is a tool to improve crop fertilization and thus ensure better productivity. The nutritional status of sugarcane influences the photosynthetic rate and metabolism of sucrose, consequently affecting yield, juice quality, longevity, and profitability of sugarcane plantations (Malavolta et al., 1997; Raij, 2011). Leaf analysis is widely used because leaves have high metabolic activity and exhibit the

changes occurring in plant nutritional status. In Brazil, the use of leaf analysis to diagnose the nutritional status of sugarcane began in the 1960s. Gallo et al. (1968) conducted some of the first studies on the nutritional status of sugarcane in the state of São Paulo, Brazil.

Leaf nutrient contents vary according to the part of the plant and sampling time due to crop growth rates (Rozane et al., 2008). Several studies use leaf +1, the

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**Figure 1.** Location of the city of Anadia, state of Alagoas (AL), Brazil.

first leaf of the stem, to assess plant nutritional status (Ferreira et al., 2015; Garcia et al., 2018). However, several authors recommend the use of leaf +3 collected during the stage of maximum growth of the crop to assess the nutritional status of sugarcane (Orlando Filho, 1983; Malavolta et al., 1997; Raji, 2011; Bennett et al., 2016; Oliveira et al., 2018; Rhodes et al., 2018).

The type of soil and plant variety also influences leaf nutrient contents (Faroni et al., 2009; Silva et al., 2018b). Therefore, correctly interpreting the results of leaf analysis leads to more efficient use of inputs. In the literature, adequate ranges of leaf nutrient content are found for sugarcane. Macronutrient contents of N, P, K, Ca, Mg and S range from 16 to 21, 1.5 to 3.5, 6 to 16, 2 to 10, 1.0 to 3.6 and 1.3 to 3.0 g kg<sup>-1</sup>, respectively. Micronutrient contents of Cu, Fe, Mn and Zn range from 6 to 50, 8 to 17, 40 to 500, 25 to 250 and 10 to 50 mg kg<sup>-1</sup>, respectively (Orlando Filho, 1983; Malavolta et al., 1997; Raji, 2011).

The studies that determined these value ranges were conducted with old varieties, which are practically no longer grown. This makes it difficult to use leaf analysis to identify and correct nutritional deficiencies and imbalances (Silva et al., 2017). Research using more recent varieties shows great variation in leaf nutrient contents (Oliveira, 2014; Silva et al., 2017). Sugarcane varieties have morphophysiological differences that influence nutrient uptake kinetics and consequently nutritional status. Therefore, studies that evaluate the

nutritional status of modern varieties are essential. In this respect, the aim of this study was to assess the nutritional status of three sugarcane varieties in the plant-cane and first regrowth cycles in the Northeast of Brazil.

## MATERIALS AND METHODS

### Study area and implantation of the experiment

The study was carried out in the city of Anadia (Figure 1), state of Alagoas (AL) (09°41'04''S and 36°18'15''W). The study period was from August 2011 to January 2014, which comprises the plant-cane and first regrowth cycles. The climate is tropical with autumn-winter rains (As) and a well-defined dry season, according to Köppen climate classification. Average annual precipitation is 1500 mm (Figure 2) and average annual temperature of 29°C. The relief varies from flat to gently undulating.

The soil of the experimental area was classified as Latossolo Amarelo Distrófico (Embrapa, 2018) and Oxisol (USDA Soil Taxonomy). Prior to the installation of the study, soil chemical analysis was carried out at depths of 0-20 and 20-40 cm. The results (Table 1) were used to calculate the amounts of limestone and gypsum to increase base saturation by 60% in topsoil and reduce aluminium saturation in subsurface soil, as proposed by Oliveira et al. (2018) and Raji (2011). After applying dolomitic limestone and gypsum (3:1 ratio) (Raji, 2011; Oliveira et al., 2018), the soil was plowed, harrowed and then furrowed.

Planting was carried out in August, 2011. At the bottom of the planting furrow, 500 kg ha<sup>-1</sup> of fertilizer 09-14-22 was applied. Three sugarcane varieties were planted (RB92579, RB961552 and RB98710) and treatments were arranged in randomized complete block design with five replicates. RB92579 was chosen as the study



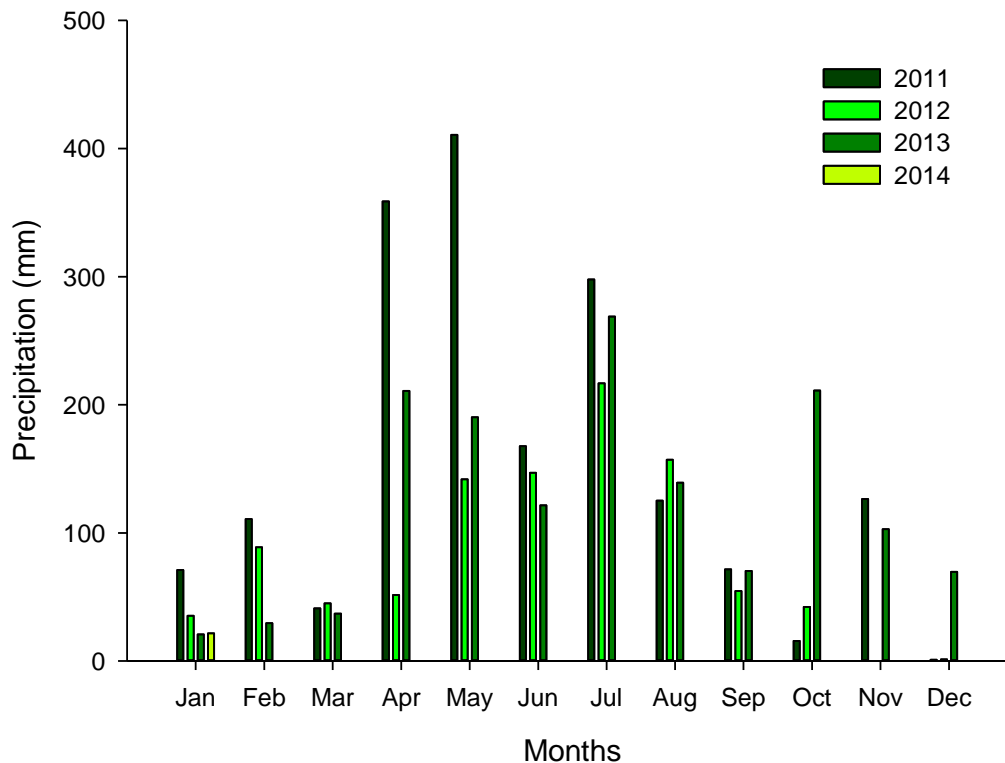


Figure 2. Average monthly precipitation in the study area.

Table 1. Soil chemical analysis at 0-20 cm and 20-40 cm of the experimental area.

Depth	pH	Ca	Mg	P	K	Fe	Cu	Zn	Mn
cm	H <sub>2</sub> O	cmol <sub>c</sub> dm <sup>-3</sup>			mg dm <sup>-3</sup>				
0-20	5.9	2.8	0.9	6.0	48.00	82.26	0.79	0.88	12.1
20-40	4.7	1.3	1.2	4.0	28.00	166.8	0.69	0.91	2.7
	Al	H+Al	BS	CEC (t)	CEC (T)	V	m	O.M.	
	cmol <sub>c</sub> dm <sup>-3</sup>			%					
0-20	0.05	3.0	3.91	3.96	6.91	56.6	1.3	1.4	
20-40	0.11	2.2	2.66	2.77	4.86	54.8	4.0	0.98	

pH in H<sub>2</sub>O (1:2.5 ratio). P, K, Fe, Zn, Mn, and Cu: Extracted by Mehlich. Ca, Mg and Al: Extracted by KCl. H+Al: Extracted by calcium acetate; CEC (t)= K + Ca + Mg + Al; CEC (T) = K + Ca + Mg + (H+Al).

reference because it is the most planted in the state of Alagoas (34% of the planted area) and the third most planted in Brazil (12% of the planted area). RB961552 and RB98710 are new varieties and there is little information in the literature.

The plots consisted of 7 furrows (8 m long) at a spacing of 1.0 m, totaling an area of 56 m<sup>2</sup> (30 m<sup>2</sup> of useful area). Planting density ranged from 15 to 18 buds per meter of furrow (Silveira et al., 2007; Oliveira et al., 2018). The buds were collected in the primary nursery area of Usina Triunfo. Fertilization of the first regrowth cane was carried out after the harvest of the plant-cane. 500 kg ha<sup>-1</sup> of fertilizer 20-05-25 was applied by hand. Weed and pest management used in the first regrowth cycle was the same as that used in the plant-cane cycle.

Plant nutritional status was evaluated at the maximum growth phase of the crop (8 months after planting and 6 months after the first harvest). Twenty (20) leaves were randomly collected in the useful area of the plot. The leaves were washed in deionized water. Then, the middle third of the leaf (minus the midrib) was separated for chemical analysis. The samples were dried in an oven with forced circulation at 65°C until reaching constant weight and ground in Wiley mill. Leaf contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Fe), manganese (Mn) and zinc (Zn) were determined according to the methods described by Malavolta et al. (1997). N was extracted by digestion with sulfuric acid and determined by the Kjeldahl method. B was extracted by dry digestion in a muffle

**Table 2.** Average macronutrient contents in leaf +3 of three sugarcane varieties at the maximum growth phase in the plant-cane (PC) and first regrowth (FR) cycles.

Variety	Nitrogen (g kg <sup>-1</sup> )			Phosphorus (g kg <sup>-1</sup> )		
	PC	FR	Average	PC	FR	Average
RB92579	30.45±1.7 <sup>b</sup>	21.44±2.0 <sup>a</sup>	22.21	1.27±0.1 <sup>a</sup>	1.64±0.2 <sup>b</sup>	1.46
RB961552	34.07±1.3 <sup>a</sup>	19.24±1.7 <sup>b</sup>	25.95	1.42±0.1 <sup>a</sup>	1.68±0.1 <sup>b</sup>	1.55
RB98710	25.28±1.2 <sup>c</sup>	19.13±2.3 <sup>b</sup>	26.67	1.30±0.2 <sup>a</sup>	2.18±0.2 <sup>a</sup>	1.77
Average	29.93	19.94	-	1.33	1.83	-

Variety	Potassium (g kg <sup>-1</sup> )			Calcium (g kg <sup>-1</sup> )		
	PC	FR	Average	PC	FR	Average
RB92579	10.18±1.1 <sup>a</sup>	14.70±1.2 <sup>a</sup>	12.44	2.80±0.3 <sup>a</sup>	2.42±0.3 <sup>a</sup>	2.61
RB961552	9.90±0.4 <sup>a</sup>	13.60±1.5 <sup>a</sup>	11.75	2.90±0.4 <sup>a</sup>	1.68±0.3 <sup>b</sup>	2.29
RB98710	9.68±0.4 <sup>a</sup>	14.78±1.0 <sup>a</sup>	12.23	3.32±0.3 <sup>a</sup>	2.34±0.2 <sup>a</sup>	2.83
Average	9.92	14.36	-	3.01	2.15	-

Variety	Magnesium (g kg <sup>-1</sup> )			Sulfur (g kg <sup>-1</sup> )		
	PC	FR	Average	PC	FR	Average
RB92579	1.38±0.1 <sup>a</sup>	1.50±0.1 <sup>b</sup>	1.44	1.42±0.1 <sup>a</sup>	1.16±0.1 <sup>b</sup>	1.29
RB961552	1.28±0.1 <sup>a</sup>	1.66±0.2 <sup>a</sup>	1.47	1.24±0.1 <sup>b</sup>	1.08±0.1 <sup>b</sup>	1.16
RB98710	1.26±0.1 <sup>a</sup>	1.70±0.2 <sup>a</sup>	1.48	1.54±0.2 <sup>a</sup>	1.40±0.2 <sup>a</sup>	1.47
Average	1.31	1.62	-	1.40	1.21	-

Averages followed by the same letter in the column do not differ statistically from one another by the Scott-Knott test at 5%.

furnace and determined by colorimetry. The other nutrients were extracted through nitric-perchloric digestion. P was determined by colorimetry through the development of blue color by the reduction of phosphomolybdenum complex and K by flame photometry. Ca, Mg, Cu, Mn, Zn and Fe were determined by atomic absorption spectrophotometry and S by turbidimetry (Malavolta et al., 1997; Silva and Queiroz 2002).

Average nutrient contents in leaves were submitted to analysis of variance by the F test and the means compared by the Scott-Knott test at 5%. These analyses were carried out using the Sisvar software (Ferreira, 2011).

## RESULTS AND DISCUSSION

There was significant difference in leaf N contents in the two crop cycles evaluated in this study (Table 2). N is a component of amino acids, proteins and enzymes, in addition to being essential for adequate plant growth and development (Taiz et al., 2017). In the plant-cane cycle, RB961552 had the highest leaf N content (34.07 g kg<sup>-1</sup>), which was 11 and 25% higher than N contents in leaf +3 of RB92579 and RB98710, respectively. However, in the first regrowth cycle, RB92579 had the highest leaf N content (21.44 g kg<sup>-1</sup>), which was 10% higher than the other varieties (Table 2). In comparing leaf N contents of the three varieties with those reported by Orlando Filho (1983), Malavolta et al. (1997) and Raji (2011), RB98710 showed adequate N contents in the plant-cane cycle, while RB92579 and RB961552 contents exceeded those considered adequate. Nutrient contents higher than those

required for the plant may characterize luxury consumption, or another factor may have limited growth (Faroni et al., 2009). In the first regrowth cycle, all varieties had adequate contents according to the authors mentioned earlier.

Higher leaf N content in the plant-cane cycle is due to the higher efficiency of nitrate uptake by the crop at this stage when compared with the first regrowth cycle (Table 2) (Silva et al., 2017). Soil preparation (plowing and harrowing) and correction (lime and gypsum application) in sugarcane renovation areas stimulates microbial activity. This results in higher mineralization rate of soil organic matter and increased nitrate content available to plants (Oliveira et al., 2011a; Ferreira et al., 2015). Furthermore, N uptake and translocation is influenced by endogenous availability of P (Magalhães, 1996). Higher endogenous P availability results in lower  $K_m$  (Michaelis-Menten constant) and higher N uptake, thus, fertilization results in increased P availability in soil, which favors increased N uptake.

Leaf P content differed significantly only in the first regrowth cycle (Table 2). P is essential for cell division and plant energy metabolism. It influences the uptake of several various nutrients (including N), tillering and initial growth of sugarcane, in addition to improving juice quality for industrialization (Taiz et al., 2017; Garcia et al., 2018; Oliveira et al., 2018). In the plant-cane cycle, the average P content for the three varieties was 1.33 g kg<sup>-1</sup> (Table 2), which is considered inadequate according to Orlando

Filho (1983), Malavolta et al. (1997) and Raij (2011). However, plants did not show any deficiency symptoms even if leaf P content was below the recommended level. Oliveira et al. (2018) stresses that nutrient content in leaf +3 cannot be related to nutrient accumulation in shoot biomass, because plant growth is a result of dry matter accumulation, with a dilution of elements in biomass. This phenomenon is known as the "dilution effect". As stalk yield in the plant-cane cycle was 44% higher than in the first regrowth cycle, there was dilution effect for phosphorus in the plant-cane cycle (Oliveira et al., 2017). Silva et al. (2017) reported the occurrence of this phenomenon for N and P contents in varieties SP813250, RB867515, RB92579 and VAT90212 grown in Anadia (AL).

In the first regrowth cycle (Table 2), all varieties had adequate leaf P contents according to Raij (2011), but lower than those recommended by Orlando Filho (1983) and Malavolta et al. (1997). RB98710 had the highest leaf P content, which was 25% higher than RB92579 and RB961552. Oliveira et al. (2017) found that RB98710 had higher inorganic phosphorus content in juice than RB92579.

The varieties did not present significant difference for leaf K contents in any of the crop cycles (Table 2). Average K contents in leaf +3 in the plant-cane and first regrowth cycles were 9.92 and 14.36 g kg<sup>-1</sup>, respectively (Table 2). These values are 10.89 and 36.21% higher than those found in the study of Silva et al. (2017) which were 8.84 and 9.1 g kg<sup>-1</sup> in the plant-cane and first regrowth cycles. K is the nutrient that sugarcane most absorbs and accumulates (Oliveira et al., 2018; Silva et al., 2018a). It plays a key role in stomatal movement and as an enzyme activator, which is essential for the growth of sugarcane (Taiz et al., 2017). All varieties had adequate leaf K contents in both crop cycles, according to Orlando Filho (1983), Malavolta et al. (1997) and Raij (2011).

There was a significant effect in leaf Ca contents among the varieties only in the first regrowth cycle (Table 2). In the plant-cane cycle, average Ca content of the three varieties was 3.01 g kg<sup>-1</sup>, which is considered adequate by Raij (2011). In the first regrowth cycle, Ca content did not differ between RB92579 and RB98710 (2.38 g kg<sup>-1</sup>) (Table 2). Ca content in RB961552 was 1.68 g kg<sup>-1</sup>, which was considered low by Orlando Filho (1983), Malavolta et al. (1997) and Raij (2011).

Sugarcane varieties did not exhibit significant difference in Mg content in both the plant-cane and the first regrowth cycles (Table 2). The average leaf Mg content of the three varieties was 1.31 g kg<sup>-1</sup> in the plant-cane cycle and 1.62 g kg<sup>-1</sup> in the first regrowth cycle. In both crop cycles, Mg content was considered adequate by Orlando Filho (1983) and Raij et al. (2011), and inadequate according to Malavolta et al. (1997). In regard to S contents in leaf +3, there was a significant effect among the varieties in both crop cycles (Table 2).

RB92579 and RB98710 have similar content in the plant-cane cycle of 1.48 g kg<sup>-1</sup>, which is considered adequate by Orlando Filho (1983). S deficiency was found in RB961552, which had S content of 1.24 g kg<sup>-1</sup>. S is a component of three amino acids (methionine, cysteine and cystine), and its deficiency is initially observed in younger leaves (Malavolta et al., 1997; Taiz et al., 2017). In the first regrowth cycle, RB98710 had the highest leaf S content of 1.40 g kg<sup>-1</sup>, which was considered adequate by Orlando Filho (1983). RB92579 and RB961552 were similar to each other and showed an average content of 1.12 g kg<sup>-1</sup>, which was below the reference value.

Ca and S deficiency was not expected, as limestone and gypsum were applied in the study area to increase base saturation to 60% (Malavolta et al., 1997; Raij 2011; Oliveira et al., 2018). However, the fact that RB961552 was deficient in both nutrients leads us to speculate that it has different nutrient uptake kinetics from the other varieties, which resulted in lower uptake.

The results showed a varietal effect for leaf B contents only in the first regrowth cycle (Table 3). In the plant-cane cycle, the average leaf B content was 13.91 mg kg<sup>-1</sup>. In the first regrowth cycle, RB98710 and RB92579 showed an average B content of 14.37 mg kg<sup>-1</sup>, which is 27% higher than RB961552. All three varieties had leaf B contents considered adequate in both crop cycles.

Leaf Fe contents exhibited a varietal effect only in the plant-cane cycle (Table 3), in which RB98710 had the highest Fe contents in leaf +3, while RB92579 and RB961552 did not differ from each other (97.2 mg kg<sup>-1</sup>, on average). In the first regrowth cycle, leaf Fe content was similar for all three varieties. The high Fe content in the plant-cane cycle is a result of precipitation distribution in 2011 and 2012 (Figure 2), which promoted increased Fe solubility and uptake (Kirkiby and Römheld, 2007). According to Orlando Filho (1983), plants had adequate Fe contents in both cycles.

There was no significant effect among the varieties for leaf Cu and Mn contents (Table 3). The average leaf Cu content of the three varieties was 3.2 and 4.27 mg kg<sup>-1</sup> in the plant-cane and first regrowth cycles, respectively, while average Mn content was 16.2 and 17.53 mg kg<sup>-1</sup>, respectively (Table 3). Plants exhibited inadequate leaf contents for both nutrients according to Orlando Filho (1983), Malavolta et al. (1997) and Raij (2011). According to Oliveira et al. (2011b), the soils located between the Northeast of the state of Minas Gerais and Rio Grande do Norte are commonly deficient in these nutrients. Oliveira et al. (2014) and Silva et al. (2017) have also reported Cu and Mn deficiency in sugarcane plantations in the state of Alagoas.

Cu and Mn act as components and activators of several enzymes, including polyphenol oxidase, which is involved in the synthesis of lignin from phenolic compounds (Kirkiby and Römheld, 2007). Reduced lignin synthesis as a result of the deficiency of these metals causes accumulation of phenols that negatively influence

**Table 3.** Average micronutrient contents in leaf +3 of three sugarcane varieties at the maximum growth phase in the plant-cane (PC) and first regrowth (FR) cycles.

Variety	Boron (mg kg <sup>-1</sup> )			Iron (mg kg <sup>-1</sup> )		
	PC	FR	Average	PC	FR	Average
RB92579	13.76±1.5 <sup>b</sup>	14.24±1.5 <sup>a</sup>	14.00	95.20 ±8.2 <sup>b</sup>	42.40±3.8 <sup>a</sup>	68.80
RB961552	13.72±1.0 <sup>b</sup>	10.46±1.2 <sup>b</sup>	12.09	99.20 ±10.7 <sup>b</sup>	40.60±6.0 <sup>a</sup>	69.96
RB98710	14.26±2.0 <sup>a</sup>	14.50±1.0 <sup>a</sup>	14.38	114.80±13.8 <sup>a</sup>	40.40±5.0 <sup>a</sup>	76.50
Average	13.91	13.07	-	103.07	40.40	-

Variety	Copper (mg kg <sup>-1</sup> )			Manganese (mg kg <sup>-1</sup> )		
	PC	FR	Average	PC	FR	Average
RB92579	3.4±0.5 <sup>a</sup>	4.2±0.8 <sup>a</sup>	3.8	16.20±3.2 <sup>a</sup>	16.80±3.8 <sup>a</sup>	16.50
RB961552	3.0±0.7 <sup>a</sup>	4.4±1.1 <sup>a</sup>	3.7	16.40±5.4 <sup>a</sup>	18.80±1.9 <sup>a</sup>	17.60
RB98710	3.2±0.8 <sup>a</sup>	4.2±0.8 <sup>a</sup>	3.7	16.00±2.7 <sup>a</sup>	17.00±1.6 <sup>a</sup>	16.50
Average	3.2	4.27	-	16.20	17.53	-

Variety	Zinc (mg kg <sup>-1</sup> )		
	PC	FR	Average
RB92579	12.20±1.3 <sup>b</sup>	11.00±1.2 <sup>b</sup>	11.60
RB961552	13.30±1.1 <sup>b</sup>	13.40±1.7 <sup>a</sup>	13.40
RB98710	16.40±2.7 <sup>a</sup>	13.80±1.9 <sup>a</sup>	15.10
Average	14.00	12.73	-

Averages followed by the same letter in the column do not differ statistically from one another by the Scott-Knott test at 5%.

the color of the juice and hinders the manufacturing process of sugar and alcohol. Moreover, Cu and Mn deficiency results in lower photosynthetic rates because these elements are components of enzymes responsible for electron transport and water splitting in photosynthesis (Kirkiby and Römheld, 2007; Taiz et al., 2017). Thus, adequate supply of these nutrients to plants is important. In evaluating the application of steel slag in sugarcane cultivars, Madeiros et al. (2009) reported an increase in Mn leaf contents. Benett et al. (2016) evaluated different sources and doses of Mn in RB851552 and found that the application of Mn linearly influences leaf Zn contents.

There was a varietal effect for Zn contents in leaf +3 in the plant-cane and first regrowth cycles (Table 3). In the plant-cane, RB98710 had the highest leaf content. However, it did not differ from RB961552 in the first regrowth cycle and presented an average content of 13.6 mg kg<sup>-1</sup>. RB92579 had the lowest Zn content in both crop cycles, and it did not differ from RB961552 in the plant-cane cycle. The three varieties presented leaf Zn contents in both cycles considered adequate by Raji et al. (2011) but low by Malavolta et al. (1997). Silva et al. (2017) found Zn contents in leaf +3 of four sugarcane varieties of 14.3 and 13.4 mg kg<sup>-1</sup> in the plant-cane and first regrowth cycles, respectively. These results were similar to those found in this study in the plant-cane cycle and 5% higher in the first regrowth cycle.

In general, the liming, gypsuming in the implantation of

the sugarcane field and the fertilization used in the two cycles of cultivation was sufficient to adequately supply the need for most nutrients. However, it is necessary to fertilize with Cu and Mn to increase productivity.

## Conclusion

There was a varietal effect for macronutrient and micronutrient contents in both crop cycles. RB961552 was the only variety to present Ca deficiency in the first regrowth cycle, and S deficiency in both crop cycles, which indicates that it has different uptake kinetics from the other varieties evaluated in this study. All three varieties presented Cu and Mn deficiency, which is one of the limiting factors of sugarcane production.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

## REFERENCES

- Benett CGS, Buzetti S, Benett KSS, Teixeira Filho MCM (2016). Productivity and nutrient levels in the culture of sugar cane after application of manganese in successive cuts. *Pesquisa Agropecuária Pernambucana* 21(1):1-6.
- Embrapa (2018). *Sistema Brasileiro de Classificação de Solos*, 5th ed.

- Brasília: Embrapa: Empresa Brasileira de Pesquisa Agropecuária Embrapa Solos 356 p.
- Faroni CE, Trivelin PCO, Franco HCJ, Vitti AC, Otto R, Cantarella H (2009). Nutritional status of sugar cane (planted cane) in 15N experiments. *Revista Brasileira de Ciencia do Solo* 33:1919-1927.
- Ferreira DA, Franco HCJ, Otto R, Vitti AC, Fortes C, Faroni CE, Garside AL, Trivelin PCO (2015). Contribution of N from green harvest residues for sugarcane nutrition in Brazil. *GCB Bioenergy* 8:859-866.
- Ferreira DF (2011). Sisvar: a computer statistical analysis system review sisvar: a computer statistical analysis system Sisvar: um sistema computacional de análise estatística. *Ciência e Agrotecnologia* 35:1039-1042.
- Gallo JR, Hiroce R, Alvares R (1968). Survey of nutritional State of São Paulo sugar cane through leaf analysis. *Bragantia* 27:365-382.
- Garcia JC, Mendes MB, Beluci LR, Azania CAM, Scarpari MS (2018). Sources of mineral and organomineral phosphate in the nutrition status and initial growth of sugarcane. *Nucleus* 15:523-531.
- Kirkby EA, Römheld V (2007). Micronutrientes na fisiologia de plantas: funções, absorção e mobilidade. *Informações Agrônomicas* 188:1-24.
- Madeiros LB, Vieira AO, Aquino BF (2009). Micronutrients and silicon in the leaves of sugar cane: Steel slag used in Soil. *Engenharia Ambiental* 6:27-37.
- Magalhães J (1996). Absorção e translocação de nitrogênio por plantas de milho (*Zea mays* L.) submetidas a períodos crescentes de omissão de fósforo na solução nutritiva (Dissertation, Federal University of Viçosa) 76 p.
- Malavolta E, Vitti GC, Oliveira S (1997). Avaliação do estado nutricional das plantas - princípios e aplicações. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato 226 p.
- Oliveira DC, Oliveira MW, Pereira MG, Gomes, TCA, Silva VSG, Oliveira TBA (2017). Stalk productivity and quality of three sugarcane varieties at the beginning, in the middle, and at the end of the harvest. *African Journal of Agricultural Research* 12:260-269.
- Oliveira ECA, Freire FJ, Oliveira RI, Oliveira AC, Freire MBGS (2011a). Acúmulo e alocação de nutrientes em cana-de-açúcar. *Revista Ciência Agrônômica* 42:579-588.
- Oliveira MW, Magrini JL, Lyra FEV, Valduga GR, Perreira MG, Tenorio CJM, Aristides EVS (2011b). Produção da RB867515 influenciada pela aplicação de substâncias húmicas, aminoácidos e extrato de algas marinhas. *STAB - Açúcar, Álcool e Subprodutos* 30:30-33.
- Oliveira MW, Silva VSG, Oliveira DC, Silva JCT (2014). Produção e qualidade de três variedades de cana-de-açúcar cultivadas no nordeste de minas gerais. *Revista Ciência Agrícola* 12:916.
- Oliveira MW, Macêdo GAR, Martins JA, Silva VSG, Oliveira AB (2018). Mineral nutrition and fertilization of sugarcane. In *Sugarcane - Technology and Research*, 1st ed (Ed AB de Oliveira) Londres: Intech - Open Science pp. 169-191.
- Orlando Filho J (1983). Nutrição e adubação da cana-de-açúcar no Brasil. Piracicaba: Programa Nacional de Melhoramento da Cana-de-Açúcar. *Planalsucar* 368 p.
- Raj B (2011). Fertilidade do solo e manejo dos nutrientes. Piracicaba: International Plant Nutrition Institute 420 p.
- Rhodes R, Miles N, Hughes JC (2018). Interactions between potassium, calcium and magnesium in sugarcane grown on two contrasting soils in South Africa. *Field Crops Research* 223:1-11.
- Rozane DE, Prado RM, Romualdo LM, Pancelli MA, Franco CF (2008). Amostragem de folha em cana-de-açúcar submetida à adubação nitrogenada. *Revista de Agricultura* 83:8-18.
- Silva DJ, Queiroz AC (2002). Análise de alimentos: métodos químicos e biológicos, 3rd ed. Viçosa: UFV. 235 p.
- Silva VSG, Oliveira MW, Ferreira VM, Oliveira TBA, Galvão ER, Silva AF, Machado PAS (2018b). Nutritional Requirement of Sugarcane Cultivars. *Journal of Agricultural Science* 10:361-367.
- Silva VSG, Oliveira MW, Ferreira VM, Oliveira TBA, Santana MB, Galvão ER (2018a). Stalk yield and nutrients accumulation of sugarcane varieties in three crop cycles. *Revista de Ciências Agrárias* 41:415-423.
- Silva VSG, Oliveira MW, Oliveira DC, Oliveira TBA, Pereira MG, Nogueira CHDC (2017). Nutritional diagnosis of sugarcane varieties in a Yellow Oxisol during three agricultural seasons. *African Journal of Agricultural Research* 12:50-57.
- Silveira LCI, Barbosa MHP, Chaves JMP (2007). Variedades melhoradas de cana-de-açúcar para Minas Gerais. Belo Horizonte. *Informe Agropecuário* 28:25-29.
- Taiz L, Zeiger E, Oller IM, Murph A (2017). *Fisiologia Vegetal*, 6th ed. Porto Alegre: Artmed 858 p.

*Full Length Research Paper*

# Mathematical modelling of greenhouse drying of red chilli pepper

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The purpose of this study was to examine twelve different mathematical models for red pepper plant (*Capsicum annum* L.) and to investigate the appropriate models of mass fraction ( $M_t / M_o$ ) in relation to drying time. This study attempted to assess the efficiency and profitability of the drying of red pepper under the plastic tunnel greenhouse and a total of twelve models, including Newton, Page, Improved Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion, Two-Term Exponentia, Two-Term, and Simplified Fick Diffusion, were evaluated. The drying process was carried out in three different periods. During each application period, separate drying experiments were carried out for the product densities of 2, 3, 4, and 5 kg/m<sup>2</sup>. The data obtained in the experiments were compared with the values found in the twelve different separable moisture content models in the literature and the most suitable model was determined by evaluating the expression coefficient ( $R^2$ ), the sum of the squares of the residuals (RSS) and the estimated standard error (SEE). The best values were obtained in the first period when drying tests were carried out at a product density of 5 kg/m<sup>2</sup>. According to statistical analysis results obtained using mathematical models, it was determined that the most appropriate mathematical model with the highest expression coefficient ( $R^2$ ) was the Two-Term model given an equality of  $(M_t / M_o) = a \exp(-k_1 t) + b \exp(-k_2 t)$ . When the coefficients of model, model coefficients and calculated values were compared with experimental data, the highest expression coefficient was obtained with Two-Term model and was at 0.9886-0.9977 level. This suggested that the model experiment could be used in practice for estimating conditions.

**Key words:** Red pepper, drying, greenhouse type dryer, mathematical model.

## INTRODUCTION

In large scale, dried agricultural products in our country are known to be found in medical and aromatic products besides apricot, grape, fig and tea which have an export potential (Öztekin and Soysal, 2000). An essential

product in massive drying in aromatic products is spice red pepper (*Capsicum annum* L.).

The production of red pepper spice is mainly concentrated in the Southeastern Anatolia Region, and

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the consumption is mostly the inner market-oriented. The spicy red pepper is not nearly as cheap to sell as the outside because the product does not comply with relevant norms in terms of food safety and quality. The first applied processing material is dried entirely in the sun without pulling the handle due to the high humidity of pepper cultivated by hand in the production of spice red pepper (>80%). Dried red pepper with stalked does not comply with food safety and quality norms due to the known negativities of diseases and other product pests such as moldy mildew that has been dried asphalt or soil on the ground. Moreover, the cost of red berry produced in our country as a spice is about 4 times more than that of competing countries in the world market. In that case, red flake or powdered pepper is costly in our country, and it has various doubts in its quality. More importantly, the traceability of the red pepper spice, which is at risk for health, becomes completely impossible if used in food products such as sausages, prepared soups, sauces, etc. In the last decade, especially in the Southeastern Anatolia region, serious efforts have been made to replace the wrong habits of producers and industrialists with research and development studies for the solution of these problems (Işıkber et al., 2003; Soysal et al., 2005a, b; Öztekin et al., 2005, 2006a, b; Duman et al., 2007a, b; Işıkber et al., 2007). Today, it is observed that the producers are gradually abandoning their drying habits of fresh harvested red pepper directly on the soil or asphalt pavement. Whether it is research studies or the efforts of publishers, red pepper is laid on net or plastic mesh 40-50 cm high from the ground. This is undoubtedly a positive development. However, even if the product is higher than the ground, it is still threatened by illness and harmful elements in the external environment. These factors are also effective in the storage process since no sterilization is performed in the product processing stage. The main aim should then be to dry the product in an environment isolated from external factors while keeping operating costs at a minimum. Drying in the industrial production of spice red pepper is usually provided by hot air in belt dryers. However, it is known that both the investment and operating costs of this process are high. It is expected that the use of solar energy in drying will be positively affected because the Southeastern Anatolian region will be beneficial in sunbelt and is advantage of sunbathing, also the drying season of agricultural products is encountered during periods when solar energy is intense (Ergüneş and Gerçekçioğlu, 1999). On the other hand, when the pepper harvest season is sufficiently available in the summer months, the potential of solar energy makes it possible to do drying process. The basic design of this work is to make the drying of the sunshine, which the manufacturer has already done in the outdoor environment, take a closed and controlled environment to make drying faster and cleaner. Here, besides the selection of the energy source as the sun,

another important point is the drying area. One of the drying systems that can be built with the local facilities used to produce cleaner products at the manufacturer level is the greenhouse. It is known in the literature that the researches have concentrated upon with lab-scale greenhouse type dryers because of their ease of application. However, adapting the results obtained on a small scale to the enterprise scale may not always give the expected results. A greenhouse drying system designed at the plant scale was also tested by Finkelman et al. (2006) in the process of drying date palm fruit. One of the original aspects of this study is that they do not approach the researchers as mere drying, but have examined the effects of temperature elevation in the drying environment on the different developmental stages of *Carpophilus hemipterus*, an important storage pest in the world. With the application of drying and disinfection, it was proved that this harmful completely destroyed larvae, pupae and adults at temperature of 55°C. At this temperature level, the harmful fruit is forced out of the fruit and dies in the outside environment. This is a very positive effect in terms of storage of the date palm without insect remains. In that case, red pepper can still be removed from storage pests while still on the manufacturer's hand. Although spicy red pepper is only due to aflatoxin problem in our country, it is known to be under serious threat of *Plodia interpunctella* and *Lasioderma serricorne* pests in Southeastern Anatolia region (Işıkber et al., 2008). In this study, a dryer with a polyethylene high tunnel greenhouse type shelf was used in order to dry spicy red pepper which is produced intensively in the province of Kahramanmaraş.

## MATERIALS

This study aimed to dry *Sena* type of red pepper (*C. annuum* L.) with a solar greenhouse type dryer in Kahramanmaraş province conditions. The greenhouse used in drying process was a high plastic tunnel type drier module, which was designed and manufactured by TARTES ([www.tartes.com.tr](http://www.tartes.com.tr)). This structure was 8 × 6 × 2.86 m in size and was connected to a solar collecting chamber measuring 6 × 6 m on the northern edge. In order to achieve this forced convection, a compartmentalized Alfan fan (2007) with a maximum airflow of 8500 m<sup>3</sup>/h was installed on the high-plastic tunnel entrance door in 0.3675 kW of power and 0.98 × 0.95 m of dimensions (Figure 1).

The product was dried on top of shelves in a drying tunnel located in the middle of the high plastic tunnel. For the drying process, five shelves 2.5 × 1 m in size were placed on a shelf with a vertical spacing of 0.30 m (Figure 2). Fresh material was dried on a plastic fly screen stretched to the rack frame. In the open-air control drying experiments, thin-wire sieve-covered drying stands, which were manufactured from wood material, with a height of 0.50 m and dimensions of 2.50 × 1 m were used. In the experiments carried out in 2008, the first crushed red pepper was harvested in August and the second crushed in September.

## METHODS

During the drying process, the temperature and relative humidity

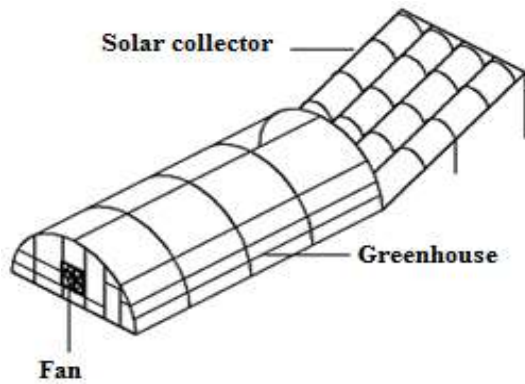


Figure 1. Solar greenhouse type dryer.

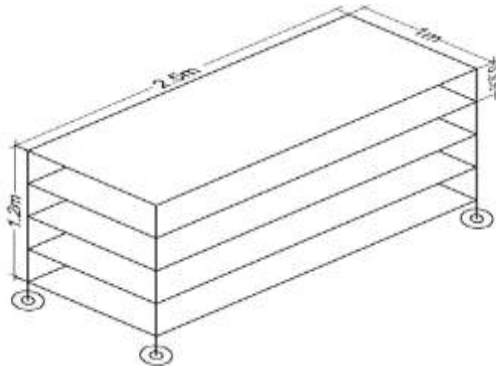


Figure 2. Product drying shelves.

values in the outdoor and in the solar greenhouse dryer were recorded with portable data measuring and recording systems (Sensitivity: 0.6°C temperature and 0.5% relative humidity, Software: Box Car Pro 3.7). The initial moisture contents of three 20 g products were determined by the oven method (24 h at 105°C) to determine the initial temperature prior to drying process. Sartorius BL 15005 digital scale, which can measure at a sensitivity of ± 0.01 g, was used in the weighing process. The following equation was used to determine the percent mass changes of dried red pepper samples.

$$m_y = \frac{m_o - m_t}{m_o} * 100 \tag{1}$$

where  $m_y$  = Percent mass changes of dried red pepper samples (%),  $m_o$  = Mass of the samples before drying (g), and  $m_t$  = Mass of samples during weighing during drying (g).

The experiments were carried out using triplicate and randomized plot design. Percent mass change data was used as a dependent variable in the analysis of variance to determine the effects of drying conditions on drying of products. Analysis of variance was made with the help of SPSS 13.0 statistical program. Minolta Spectrometer (Minolta CR-100) was used to measure the color of fresh and dried products. In order to determine the color changes in fresh and drier dried products, color measurements were made in 20 fresh products and 3 repeated ones in dried

products used in each experiment. The measurements were made in the  $L^* a^* b^*$  mode at C position of the device. During color measurements, product color change was also observed and recorded. The Lab scale has a vertical  $L^*$  axis brightness value that varies from black to white, and can range from 0 to 100 depending on the measured color (Soysal, 2000). When the  $a^*$  axis value on the color space has a positive value, the measured color is red. On the other hand, it is green when it has a negative value. Likewise, when the  $b^*$  axis has positive value, the measured color is yellow and when it is negative value it is blue. The metric color tone ( $\alpha$ ; hue) was calculated from the following equation based on  $a^*$  and  $b^*$  values:

$$\alpha = \arctan \frac{b^*}{a^*} \tag{2}$$

$C^*$  is a dimensionless value that specifies the metric chroma and can range from 0 to 60. The metric color chroma was also calculated from the following equation based on the  $a^*$  and  $b^*$  values:

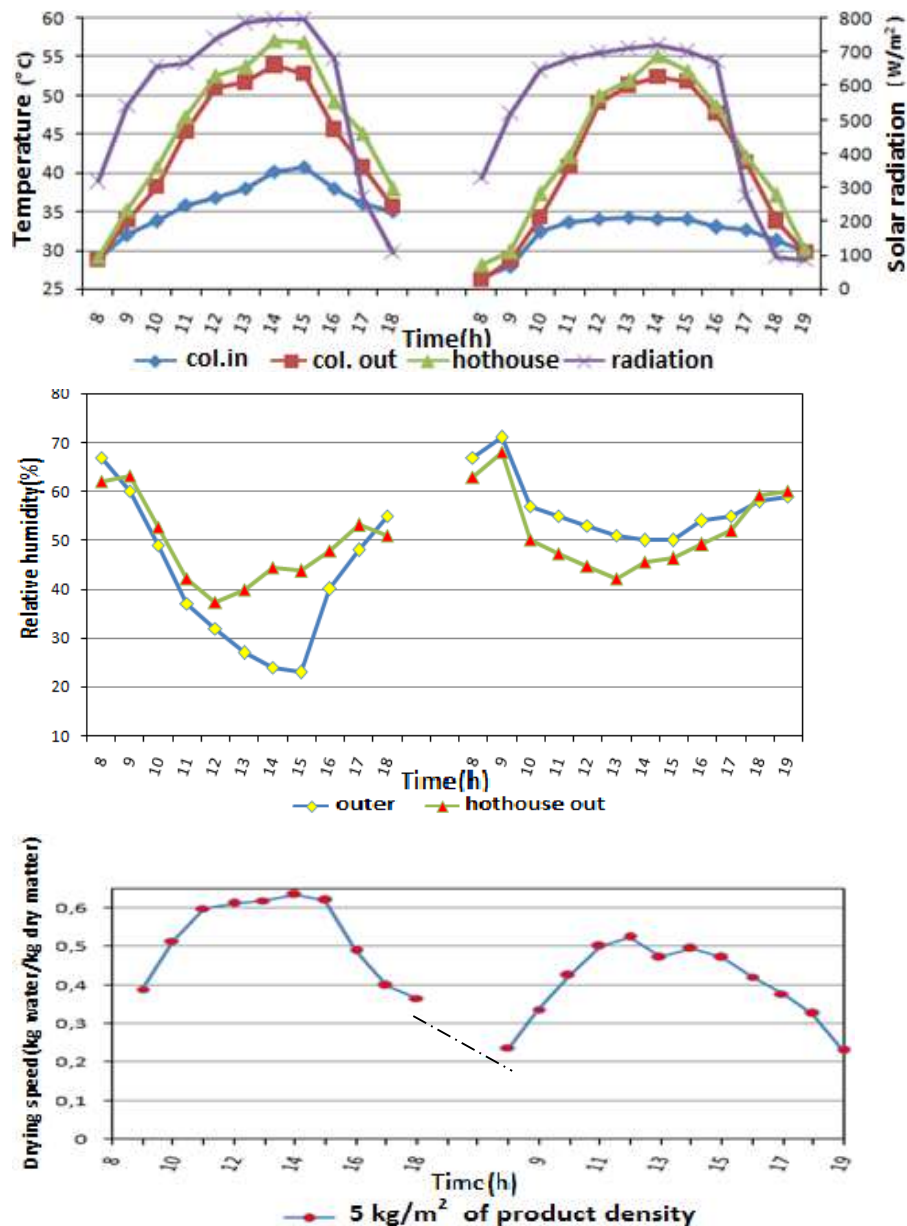
$$C^* = \sqrt{a^{*2} + b^{*2}} \tag{3}$$

Dried red peppers were washed, then stalked and separated into two, rather than whole, as opposed to the drying method common in practice, and dried after the seed house was removed. In the Southeastern Anatolia Region, red pepper varieties which are rich in spicy red pepper production are preferred by spice industrialists because they appeal more to consumer taste. Thick fleshy red pepper varieties can be marketed more easily and at a higher price if the manufacturer does not entirely remove the stalk and after the seed nest is removed and dried neatly. The thickness of the flesh of the two varieties of *Sena* type red pepper registered in the Southeastern Anatolia Region varies between 1.4 and 1.8 mm and 1.2 and 1.4 mm in Kahramanmaraş (Arpacı et al., 2008). No research has been done on the effect of fruit flesh thickness on drying in spicy red pepper. However, thick fleshy red pepper is expected to dry out later. In order to compare red peppers dried in a greenhouse type dryer, the same amount of product was laid outdoors on a drying rack under direct sun and at a height of 50 cm from the ground. In the experiments, drying time and color measurements were made and temperature, relative humidity, wind speed, and radiation values were also recorded. During the drying process, reductions in product mass were measured 2 to 3 h due to the long drying process. The drying process operation was continued until the mass of the product in each shelf was reduced by about 1/5.

## RESULTS AND DISCUSSION

Red pepper drying applications in high plastic tunnel type dryer were made in three periods. The first semester was held on 21-29.08.2008, the second semester was held on 09-16.09.2008 and the third semester was held on 01-07.09.2009. During each implementation period, separate drying experiments were carried out for the product densities of 2, 3, 4, and 5 kg/m<sup>2</sup>. Only natural radiation was used in the first two periods and an additional electric heater in the third period was used in the high plastic tunnel. The best values were obtained in the first period in which drying tests were carried out at a product density of 5 kg/m<sup>2</sup>.





**Figure 3.** Experimental temperature, solar radiation, relative humidity, drying rate and product humidity values for the product density of 5 kg/m<sup>2</sup> in the first period.

### Drying test in 5 kg/m<sup>2</sup> product density in the first period

In the first period, it was determined that the solar radiation values in the experiment of product density of 5 kg/m<sup>2</sup> were changed between 318.1 and 798.3 W/m<sup>2</sup>. It was also determined that the temperature difference between the inlet and outlet temperatures of the heat collecting unit changed between 10 and 20°C again (Figure 3). In this experiment, the temperature value at the exit of the heat collection unit (at the entrance of the plastic tunnel) varied between 26.2 and 53.9°C. The

temperature in the plastic tunnel was measured as 28.1°C and the highest as 57.4°C. The relative humidity measured at the exit of the plastic tunnel was 60 to 65% on the first day and 65 to 70% on the second day in the morning hours and 35 to 40% on the first day and 40-45% on the second day at noon. Relative humidity increased again in the evening hours, reaching around 50% on the first day and about 55 to 60% on the second day (Figure 3). When we compared drying rate and relative humidity data, it was observed that the relative humidity was high in morning and evening hours and the drying rate was low. The increase in drying speed was

**Table 1.** Duncan test results between the columns of the cumulative mass loss (%) values obtained in the product density of 5 kg/m<sup>2</sup> (p<0.05).

Time(h)	Racks					Sun dried	p
	Top R. 1	2	3	4	Bottom R. 5		
2	7.23 <sup>a</sup>	7.19 <sup>ab</sup>	7.17 <sup>ab</sup>	7.15 <sup>bcd</sup>	7.13 <sup>bcd</sup>	6.85 <sup>cde</sup>	0
4	16.92 <sup>a</sup>	16.86 <sup>ab</sup>	16.82 <sup>ab</sup>	16.78 <sup>bcd</sup>	16.74 <sup>bcd</sup>	16.10 <sup>cde</sup>	0
6	26.96 <sup>a</sup>	26.88 <sup>ab</sup>	26.82 <sup>ab</sup>	26.76 <sup>bcd</sup>	26.71 <sup>cde</sup>	25.69 <sup>cde</sup>	0
8	35.84 <sup>a</sup>	35.73 <sup>ab</sup>	35.66 <sup>bc</sup>	35.59 <sup>bcd</sup>	35.52 <sup>cde</sup>	34.05 <sup>def</sup>	0
10	41.97 <sup>a</sup>	41.83 <sup>bc</sup>	41.72 <sup>bcd</sup>	41.63 <sup>cde</sup>	41.55 <sup>cde</sup>	39.60 <sup>def</sup>	0
24	43.87 <sup>a</sup>	43.72 <sup>bc</sup>	43.60 <sup>bcd</sup>	43.51 <sup>cde</sup>	43.41 <sup>cde</sup>	41.19 <sup>def</sup>	0
26	49.97 <sup>a</sup>	49.79 <sup>bc</sup>	49.66 <sup>bcd</sup>	49.55 <sup>de</sup>	49.44 <sup>def</sup>	46.74 <sup>def</sup>	0
28	58.18 <sup>a</sup>	57.97 <sup>bc</sup>	57.82 <sup>cd</sup>	57.70 <sup>def</sup>	57.57 <sup>def</sup>	54.37 <sup>def</sup>	0
30	65.94 <sup>a</sup>	65.69 <sup>bc</sup>	65.51 <sup>cd</sup>	65.37 <sup>def</sup>	65.24 <sup>def</sup>	61.09 <sup>ef</sup>	0
32	73.09 <sup>a</sup>	72.82 <sup>bc</sup>	72.62 <sup>cd</sup>	72.46 <sup>def</sup>	72.33 <sup>def</sup>	67.46 <sup>ef</sup>	0
34	78.72 <sup>a</sup>	78.44 <sup>bc</sup>	78.22 <sup>cd</sup>	78.05 <sup>def</sup>	77.89 <sup>def</sup>	73.36 <sup>ef</sup>	0
35	80.57	80.27	80.04	79.86	79.71	75.00	1

related to the drop in relative humidity in the afternoon. The air will approach saturation value at high relative humidity values. This makes it difficult to transmit the moisture from the air to the air.

The reason why the drying rates are low in the morning and evening hours can be explained in this way. According to the shelf order (1: top shelf), the product moisture values obtained at a product density of 5 kg/m<sup>2</sup> are as shown in Figure 3. The Duncan test results for bulk product mass loss between the columns are shown in Table 1 depending on the loss of moisture after the beginning of the drying. It was seen that there was a statistically significant difference between the mass change values of the products dried in the different racks and the external environment until a certain time between the trial materials (p <0.05). This statistical difference continued until weighing at the 33rd hour. Later, this difference between them got out of the way. As expected, the fastest drying occurred again in the first rack, which was the top shelf. For example, the fastest drying at the end of the 6th hour of drying due to mass loss was at the 1st rack, the slowest drying at the 5th rack. According to the multiple comparison test conducted, it was determined that the percent mass loss of the products on the 2nd and 3rd racks was the same as the percentage mass loss change of the products on the 4 and 5th racks. During the first 6 h of drying process, the product at 1st rack lost about 30% of its initial mass while the material at 5th rack lost 28% of its initial mass. The first rack product lost about 2% more moisture. In the samples dried under the external conditions, there was a mass loss of 27.13% at the end of the drying period of 6 h. The product on the top of the plastic tunnel lost 2.8% more mass than the outer layer, while the material on the 5th floor lost about 1% more mass than the outer control group. At the 33rd hour of the experiment, the product in the first rack lost 80.53% of the moisture while the

product in the fifth rack suffered a loss of 79.41% moisture. Humidity loss was 72.93% in the dried product in outdoor conditions. When these results were taken into consideration, red pepper samples on the 1st, 2nd, 3rd, and 4th racks dropped below 20% humidity after 33 h. On the other hand, it was observed that the samples in the outdoor environment needed more drying time than 33 h. Taking these results into consideration, it can be said that the heat-collecting high-quality plastic tunnel-type desiccant drier system is partially superior to the desiccant made at a specific height from the outside (in terms of total drying time).

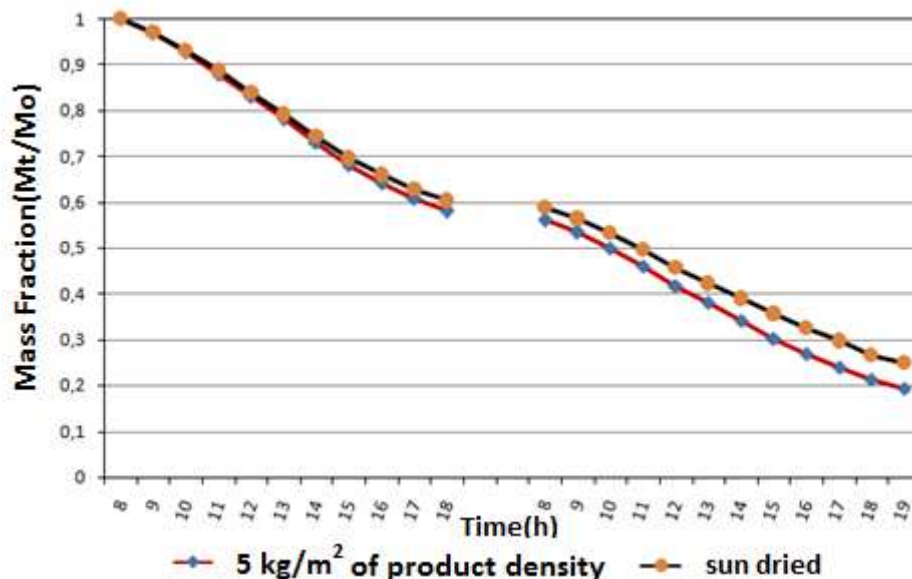
### Findings related to mass fraction change

For the first period, time dependent graphs of the mass fraction (Mt/Mo) change measured in the dryer and in the external environment are as shown in Figure 4.

Looking at the mass fraction time graphs, it was seen that the products dried in the racks of the plastic tunnel dryer in the first days were drying out faster than those dried in the outdoor environment. On the second days, the mass losses of the products in the dryer were parallel to those dried out on the outside. This was related to the fact that the mass fraction ratios of the products in the outdoor environment and the plastic tunnel are close to each other at the end of drying. When the mass fraction and the drying rate diagrams are compared, the parallelism of these parameters depending on the amount of moisture removed from the product is also important for the applicability of the tunnel type dryer.

### Findings related to mathematical modeling of drying curves

As a result of the experiments, changes in the moisture



**Figure 4.** The mass fraction rate of red pepper recorded in the experiment for the first period product density of 5 kg/m<sup>2</sup>.

content of the product depending on the time were investigated. Twelve equations were worked out to find the most suitable model that related the drying time of the mass fraction ( $M_{MF}$ ), which was defined as the ratio of the moisture content ( $M$ ) of the product to the initial moisture content ( $M_0$ ) of the product at a given time. In the experiments performed, the results for  $R_2$ , RSS and SEE for all model equations are shown in Table 2.

According to statistical analysis results obtained using mathematical models, it was determined that the most suitable mathematical model with the highest expression coefficient ( $R_2$ ) was the two-term model given by equality.

$$(M_t / M_0) = a \exp(-k_1 t) + b \exp(-k_2 t) \quad (4)$$

When the models, model coefficients and calculated values were compared with experimental data, the highest expression coefficient was obtained with Two-Term model and it was at a level of 0.9886-0.9977 (Table 3). This has shown that this model can be used in practice for estimating the conditions under which the experiment is performed.

The fresh and after drying brightness ( $L^*$ ), redness ( $a^*$ ) and yellowness ( $b^*$ ) values of first period red pepper dried at a product density of 5 kg/m<sup>2</sup> are as shown in Figure 5. In addition, the color parameters are shown in Table 4.

## CONCLUSION AND RECOMMENDATIONS

This research is the first study on the drying of spicy red pepper in a module high plastic tunnel on the operating

scale in Turkey. According to the results obtained in this research, the product dried in the high plastic tunnel was dried in a shorter period of time than the product dried in the outdoor environment. This process was very rapid in the first stage of drying when water was physically removed from the product. Mass loss was reduced after the first 5 to 6 h of drying and thus drying seemed to slow down in the study. The study shows that rapid drying was not to be expected as in artificial dryers in high tunnel drying. The products in high tunnel and outdoor environment are practically dried in close proximity. However, the most important advantage emerging in favor of a high tunnel dryer is that the product is dried in a clean environment without being exposed to any contaminants. It is undoubtedly an unwanted condition that the disease and pests originating from the soil in the outdoor environment drift with the wind and dust. Today, increasingly competitive conditions make it possible to ensure that the final product produced is not only price-neutral, but also superior in terms of food safety and quality. For example, it has been found that the samples dried in a high plastic tunnel in terms of color, one of the quality parameters, have a brighter red color than the samples dried in the outside. It is then essential to dry the product in a clean environment with reasonable investment and operating costs and with minimal loss of quality and quantity. It is not surprising to predict that the profit margin of the manufacturer, which does not dry the product cleanly in the future, will decrease. On the other hand, it is possible that temperatures above 60°C in a high plastic tunnel could provide a significant advantage in the disinfection of storage pests in the product. In this study, it was determined that the optimum loading

**Table 2.** Analysis results of the model equations used for drying of red pepper harvested in the first period.

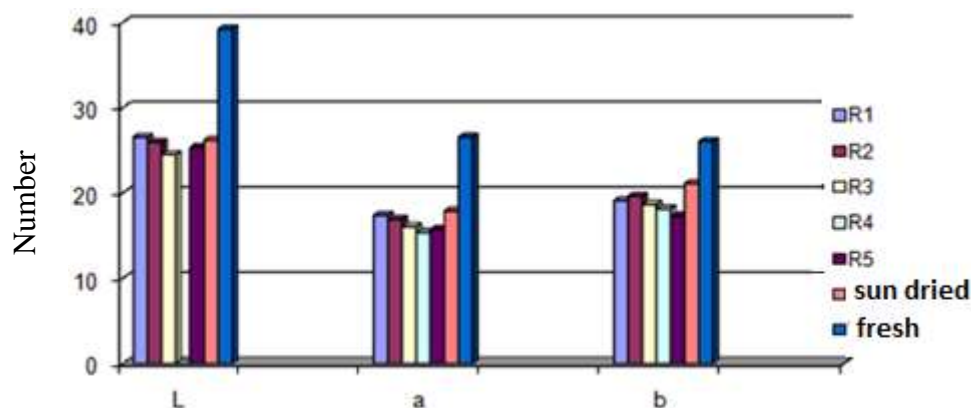
No		1	2	3	4	5	6	7	8	9	10	11-12
Model		Newton Model (Ayensu, 1997)	Page Model (Zhang and Litchfield, 1991)	Henderson and Pabis M (Chhnanman, 1984)	Logarithmic Model (Yaldiz et al., 2001)	Wang and Singh Model (Wang and Singh, 1978)	Diffusion Model (Toğrul and Pehlivan, 2002)	Verma Model (Verma et al., 1985)	Two-Term Exponential (Sharaf-Elden et al., 1980)	Two-Term Model (Henderson, 1974)	Simplified Fick Model (Toğrul and Pehlivan, 2003)	Midilli and Küçük (Sacılık 2006); Improved Page Model (White et al., 1981)
2 kg/m <sup>2</sup>	RSS	0.0254	0.0212	0.0252	0.0087	0.0130	0.0254	0.0194	0.0254	0.0052	0.0252	0.0055-0.0212
	SEE(±)	0.0442	0.0421	0.0458	0.0282	0.0329	0.0480	0.0420	0.0460	0.0228	0.0478	0.0236-0.0421
	R <sup>2</sup>	0.9671	0.9725	0.9674	0.9887	0.9831	0.9671	0.9748	0.9671	0.9933	0.9674	0.9928-0.9725
3 kg/m <sup>2</sup>	RSS	0.0390	0.0161	0.0296	0.0082	0.0084	0.0082	0.0159	0.0391	0.0052	0.0296	0.0076-0.0161
	SEE(±)	0.0442	0.0291	0.0395	0.0214	0.0210	0.0214	0.0298	0.0453	0.0174	0.0406	0.0211-0.0291
	R <sup>2</sup>	0.9682	0.9869	0.9758	0.9933	0.9932	0.9933	0.9870	0.9682	0.9958	0.9758	0.9938-0.9869
4 kg/m <sup>2</sup>	RSS	0.0401	0.0134	0.0294	0.0055	0.0056	0.0056	0.0133	0.0401	0.0034	0.0294	0.0051-0.0138
	SEE(±)	0.0448	0.0265	0.0393	0.0176	0.0172	0.0176	0.0272	0.0459	0.0142	0.0404	0.0173-0.0270
	R <sup>2</sup>	0.9672	0.9891	0.9760	0.9955	0.9954	0.9954	0.9891	0.9672	0.9972	0.9760	0.9958-0.9887
5 kg/m <sup>2</sup>	RSS	0.0371	0.0093	0.0254	0.0036	0.0038	0.0038	0.0092	0.0372	0.0032	0.0254	0.0035-0.0093
	SEE(±)	0.0411	0.0211	0.0348	0.0135	0.0135	0.0137	0.0215	0.0421	0.0131	0.0356	0.0136-0.0211
	R <sup>2</sup>	0.9734	0.9933	0.9818	0.9974	0.9973	0.9973	0.9934	0.9734	<b>0.9977</b>	0.9818	0.9975-0.9933

SEE is the standard error of the estimate, R<sup>2</sup> is the coefficient of specification, RSS is the sum of the squares of the residuals.

**Table 3.** Model coefficients of Two-Term model in working conditions of solar energy greenhouse type shelf dryer of red pepper samples.

Controlled variable parameter		R <sup>2</sup>	SEE (±)	RSS
I. Period (kg/m <sup>2</sup> )	2	0.9933	0.0228	0.0052
	3	0.9958	0.0174	0.0052
	4	0.9972	0.0142	0.0034
	5	<b>0.9977</b>	0.0131	0.0032
II. Period (kg/m <sup>2</sup> )	2	0.9924	0.0246	0.0073
	3	0.9964	0.0166	0.0050
	4	0.9966	0.0157	0.0044
	5	0.9975	0.0138	0.0036
III. Period (kg/m <sup>2</sup> )	2	<b>0.9886</b>	0.0326	0.0105
	3	0.9946	0.0216	0.0061

(a=-0.01009 k<sub>1</sub>=-0.07854 k<sub>2</sub>= 0.04674 ve b=1.08), the sum of the squares of the remaining (RSS), standard error of estimation (SEE), and specification coefficient (R<sup>2</sup>) values.



**Figure 5.** The fresh and after drying brightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ). Values of first period red pepper dried at a product density of  $5 \text{ kg/m}^2$ .

**Table 4.** First period color parameters of dried red pepper at a product density of  $5 \text{ kg/m}^2$ .

Variant	Color Parameters					
	L	a	b	a/b	X	$\alpha$
Fresh	38.79	28.46	26.38	1.07	38.80	42.82
Sun dried	26.11	18.02	20.31	0.88	27.15	48.42
1	26.63	17.52	19.85	0.88	26.47	48.56
2	25.91	16.84	19.79	0.85	25.98	49.60
3	25.06	16.04	19.67	0.81	25.38	50.80
4	25.30	16.46	18.92	0.87	25.07	48.97
5	24.41	15.68	18.53	0.84	24.27	49.76

capacity could be increased up to  $187.5 \text{ kg}$  due to the technical and economic performance criteria taken into account in the red pepper drying study carried out in 3 different periods. Taking into consideration the maximum loading capacity, it is calculated that a mass of about  $187.5/48=3.9 \text{ kg/m}^2$  can be dried in this trial scale installation if this plastic tunnel is deemed to have a floor area of  $48 \text{ m}^2$ . If the base area and elevation of the prototype plastic tunnel used in the trial are effectively assessed, there should be no doubt that this figure will increase in a commercial plastic tunnel. On the other hand, according to the results obtained in the optimum loading capacity calculated in the first period, it has been determined that the plastic tunnel dryer is a profitable investment that can meet initial investment, operation and fixed expenses within one season. Only this result is convincing reason why plastic tunnel dryers can be offered to producers. Moreover, the product transport and transportation costs as well as the reduction of quality and quantity losses should not be forgotten in case of the positive contribution of drying in a closed environment in terms of food safety and quality, the system being suitable for other undergrowth and drying activities outside the drying season, and the establishment at the

place of production in the plastic tunnel. In this way, the economic profitability of the system can be increased by making maximum use of the plastic tunnel. Another measure to take in the high plastic tunnel dryers is to take technical measures to increase the collecting efficiency and raise the ambient temperature within the high plastic tunnel. It was determined that the temperatures in the high plastic tunnel were around  $60^\circ\text{C}$  for 3 to 4 h during the experiments. As the length of the high tunnel module increases, it will be more beneficial for the beam that is accumulated either in the high plastic tunnel or the collectors. So, hot air will go a long way in high plastic tunnel. Undoubtedly, the provision of good insulation in order to prevent heat losses in the high plastic tunnel and the recirculation of the high plastic tunnel air by recirculating it are other measures that can make it possible to take longer advantage of the heat obtained from the collecting. In addition, the use of heat perception in the system contributes significantly to the prevention of heat losses. On the other hand, if there is a condition in which the manufacturer can sell a different product in the greenhouse, the option of heating with a burner may be necessary in order to continue drying in the nighttime. Because heating in the night time will increase unit drying

costs in terms of both burner investment and operating costs.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## REFERENCES

- Arpacı BB, Balıkcı T, Abak K (2008). Plant Characteristics and Yield and Quality of Kahramanmaraş Pepper Breeding and Pepper Lines Developed. 7th Vegetable Agriculture Symposium. Proceedings pp. 116-121.
- Ayensu A (1997). Dehydration of Food Crops Using A Solar Dryer With Convective Heat Flow. *Solar Energy* 59(4-6):121-126.
- Chhninman MS (1984). Evaluation Of Selected Mathematical Models For Describing Thin Layer Drying Of In-Shell Pecans. *Transactions of the ASAE* 27:610-615.
- Duman AD, Öztekin S, Soysal Y, Işıkber AA, Dayısoylu S (2007a). Determination of Microbiological Parameters and Aflatoxin Level in Traditionally Stored Red Chili Pepper. XII<sup>th</sup> International IUPAC Symposium on Mycotoxins and Phytotoxins. 21-25 May 2007, İstanbul, Turkey.
- Duman AD, Öztekin S, Erdem T, Işıkber AA (2007b). Sterilizing Red Peppers with Ozonated Water and Drying with Microwave Energy. 24th National Congress of Agricultural Mechanization 05-07 September 2007, Kahramanmaraş. Proceedings pp. 394-401.
- Ergüneş G, Gerçekçioğlu R (1999). Drying Characteristics of Kütahya Cherry in Greenhouse Type Dryer and Effects on Dry Product Quality. 3. Bah Crops Congress of Turkey, Ankara. 14 - 17 September 1999:833-837.
- Finkelman S, Navarro S, Rindner M, Dias R (2006). Use of Heat for Disinfestation and Control of Insects in Dates: Laboratory and Field Trials. *Phytoparasitica* 34(1):37-48.
- Henderson SM (1974). Progress in Developing The Thin Layer Drying Equation. *Transactions of the ASAE* 17:1167-1178.
- Işıkber AA, Öztekin S, Duman AD, Dayısoylu S, Soysal Y (2003). Research on Increasing the Storage Quality of Red Pepper in Southeastern Anatolia Region. DPT 2003 Project Final Report No. K120730 P. 131.
- Işıkber AA, Öztekin S, Duman AD, Dayısoylu S, Soysal Y (2007). Comparison of Vacuum, Hermetic and Traditional Storage Methods in Spicy Red Pepper in Business Scale. 24th National Congress of Agricultural Mechanization, 05-07 September 2007, Kahramanmaraş. pp. 365-374.
- Işıkber AA, Öztekin S, Duman AD, Dayısoylu S, Soysal Y (2008). Application of Sealed Flexible Vacuum-Hermetic Storage System for Quality Preservation of Turkish Red Chili Pepper. Proceedings of 8. International Conference on Controlled Atmosphere and Fumigation in Stored Products Chengdu, China September 21-26 (Eds.: G. Daolin, S. Navarro, Y. Jian, T. Cheng, J. Zuxun, L. Yue, L. Yang and W. Haipeng) pp. 387-393.
- Öztekin S, Soysal Y (2000). Designed for Aromatic Plants Injured at Flower Level Dryer: Cukurova II. 19th National Congress of Agricultural Mechanization 1-2 June 2000, Erzurum.
- Öztekin S, Soysal Y, Işıkber AA, Duman AD, Dayısoylu S (2005). Present Status of Turkish Red Chili Pepper, 8. Symposium des Verbandes deutsch-türkischer Agrar- und Naturwissenschaftler, 04-08 October 2005, Braunschweig, Germany, Proceedings pp. 201-207.
- Öztekin S, Soysal Y, Işıkber AA, Duman AD, Dayısoylu S (2006a). Current Applications and Problems of the Industry in the Production of Spicy Red Pepper. 23rd National Congress of Agricultural Mechanization, 06-08 September 2006 Çanakkale. Publications p.11 (Summary) and *Journal of Agricultural Machinery Science* 2(3):231-237.
- Öztekin S, Soysal Y, Işıkber AA, Duman AD, Dayısoylu S (2006b). Quality Losses During Storage of Red Chili Pepper. I. Agricultural Engineering for a Better World, CIGR World Congress, 3-7 September 2006, Bonn, Germany, Proceeding-CD: P. 6.
- Sacılık K, Elicin AK (2006). The Thin Layer Drying Characteristics of Organic Apple Slices. *Journal of Food Engineering*, (73) : 281-289.
- Sharaf-Eldeen YI, Blaisdell JL, Hamdy MY (1980). A model for ear corn drying. *Transactions of the ASAE* 5(4):1261-1265.
- Soysal Y (2000). A Scale for Drying of Various Medicinal and Aromatic Plants in Business Scale Research. CU Ph.D. Thesis, Adana 123 p.
- Soysal Y, Öztekin S, Işıkber AA, Duman AD, Dayısoylu KS (2005a). The Importance of a Quality Parameter of Dried Red Pepper Color. 3. Agricultural Product Drying Workshop, 02 - 04 May 2005, Akdeniz University, Z.F. Department of Agricultural Machinery pp. 74-81.
- Soysal Y, Öztekin S, Işıkber AA, Duman AD, Dayısoylu KS (2005b). Assessing the Color Quality Attributes of Turkish Red Chili Peppers (*Capsicum annum* L.) and Color Stability During Storage, 9. Int. Congress on Mechanization Energy in Agriculture, Proceedings pp. 99-104.
- Toğrul İT, Pehlivan D (2002). A Solar Energy System with Cone Concentrator for Apricot Drying. *Engineering Congress*. 6-8 June, Şanlıurfa pp. 162-169.
- Toğrul İT, Pehlivan D (2003). Mathematical Modelling Of Solar Drying Of Apricots In Thin Layers, *Journal of Food Engineering* 55:209-216.
- Verma LR, Bucklin, RA, Endan JB, Wratten FT (1985). Effects of Drying Air Parameters on Rice Drying Models. *Transactions of The ASAE*, (28):296-301.
- Wang CY, Singh RP (1978). A Single Layer Drying Equation For Rough Rice. ASAE Paper No:78-3001, ASAE, St. Joseph, MI.
- White GM, Bridges TC, Loewer OJ, Ross IJ (1981). Thin Layer Drying Model For Soybeans. *Transactions of The ASAE* 24:1643.
- Yaldız O, Ertekin C, Uzun Hİ (2001). Mathematical Modelling Of Thin Layer Solar Drying of Sultana Grapes, *Energy* 26:457-465.
- Zhang Q, Litchfield JB (1991). An Optimisation Of Intermittent Corn Drying In A Laboratory Scale Thin Layer Dryer. *Drying Technology* 9:383-395.

*Full Length Research Paper*

## **Qualitative response of super basmati rice to different nitrogen levels under varying rice ecosystem**

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Planting methods and nitrogen rates play pivotal role in the production and quality of fine grain rice. A field experiment was carried out at Rice Research Institute, Kala Shah Kaku, Pakistan during 2015 and 2016 using four planting methods namely drilling of dry seed in well prepared dry soil (DSR-drill), ridges made after broadcast of dry seed in dry soil (DSR-ridge), broadcast of dry seed in well prepared dry soil (DSR-broadcast), followed by irrigation and Puddled transplanted rice (PTR)-conventional transplanting. Four nitrogen levels viz.  $N_0$ : control,  $N_1$ : 133 kg N ha<sup>-1</sup> (recommended),  $N_2$ : 166 kg N ha<sup>-1</sup> and  $N_3$ : 199 kg N ha<sup>-1</sup> were compared for a fine grain rice variety Super basmati. Data were collected on quality parameters namely Brown Rice (BR) %, Total Milled Rice (TMR) %, Head Rice (HR) %, Average Grain Length (AGL), length Width Ratio (LWR), Cooked Grain Length (CGL) mm, Bursting (%), Elongation ratio (ER), Amylose Content %, Protein Content % and grain yield (t ha<sup>-1</sup>). Results indicated that planting methods behaved the same with respect to the parameters BR %, TMR %, AGL, LWR, amylose and protein content %. However, HR % was the highest in DSR-ridge sowing as compared to other planting methods. AGL, CGL, and ER were more in PTR-conventional transplanting followed by DSR-ridge sowing and bursting % was more in DSR broadcast method. Nitrogen affected positively all the parameters under study up to maximum level of its application. So it can be concluded that PTR-conventional transplanting and DSR ridge sowing with nitrogen at the rate of 199 kg ha<sup>-1</sup> gave better quality compared to other DSR methods and nitrogen doses.

**Key words:** Grain quality, Nitrogen levels, rice (*Oryza sativa* L.), sowing methods.

### **INTRODUCTION**

Rice is a staple food of more than half population of the globe. In Pakistan, after wheat, rice (*Oryza sativa* L.) is the second largest cereal crop and an important exportable national commodity. It contributes 3.1% of value addition to agriculture and 0.6% of Gross Domestic

Product (GDP). During the fiscal year 2016-17, rice was planted on an area of 2.72 million hectares showing a decline of 0.6% as compared to last year; its production was 6.85 million tonnes that was 0.7% lower than that of the last year (Anonymous, 2017).

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In Asian rice growing countries transplanting the rice seedling manually into puddled soil is most widely adopted method of rice planting but it consumes much water (Bouman and Tuong, 2001). As the water resources are declining thus judicious use of irrigation water has gained a pivotal importance to cope with the water and food needs of rapidly growing human population (Mahajan et al., 2012; Hanjar and Quereshi, 2010). Conventional method of transplanting the rice seedlings in puddled soil not only consumes more water but also involves intensive labour. It needs 25-50 man-days  $\text{ha}^{-1}$  as compared to direct seeded rice which requires about 5 man-days  $\text{ha}^{-1}$  (Dawe, 2005; Balasubramanian and Hill, 2002). Scarcity of labour and increasing wages resulting in an increase in cost of production is gradually replacing this conventional planting method with direct rice seeding (Dawe, 2003; Naklang et al., 1996).

With the availability of better quality rice, farmers can get ahead better income, as good quality rice can be priced higher (Maloles, 2008). The rice grain quality is a complicated term; there are many components involved such as appearance, hulling, milling, head rice recovery and protein contents, cooking and eating quality. However, more attention is paid to appearance of rice after cooking than the other properties by the ultimate consumers (Guo et al., 2011). The grain quality is equally important to quantity as it has a vital role in fetching the foreign exchange for Pakistan as indicated from the rice exports of 676,630 million tons pricing 681.55 million dollars in 2015 of basmati exported to over one hundred countries (REAP 2014-15). Quality of rice grain may be affected by several factors such as variety, production, and postharvest practices (Bandoniill and Corpuz, 2015). Planting methods not only significantly affect yield, influence health and productivity of soil and but also affect the grain quality (Iqbal, 2014; Sanjitha and Jayakiran, 2010). Bandoniill and Corpus (2015) reported that transplanted rice had higher brown and head rice recovery than direct seeded rice, but did not find difference in terms of milling recovery. However, direct seeded rice had higher chalkiness and amylose contents as compared to transplanted rice which deteriorate the quality of rice grain.

Nitrogen is integral component of amino acids that are building blocks for protein and its availability in the soil solution and uptake at early growth stage determines the plant growth (Awan et al., 2011). In addition to that it also has impact on the quality of grain particularly of rice through amylose and protein content, grain length and width (Maqsood et al., 2013; Ahmad et al., 2009), cooking / eating quality (Hu-lin et al., 2007; Ya-Jie et al., 2009), milling recovery %, hulling % (Kandil et al., 2010) and head rice % (Saeed Firouzi, 2015). Protein contents become high in rice grains if nitrogen is applied at flowering stage (Perez et al., 1996). Gautam et al. (2008) reported that protein content increased significantly with increased nitrogen dose resulting in improved brown and

head rice recovery. This is due to more resistance during the abrasive milling process owing to higher protein content (Cagampang et al., 1966). However, the physical parameters, amylose content and cooking quality decreased with increasing rate of nitrogen application. An appropriate nitrogen rate could lower the amylose content that is good for cooking quality which contributes to improving starch pasting properties (Da-wei et al., 2017). Maqsood et al. (2013) reported that transplanting with higher nitrogen application rates stimulates growth resulting in increased amylose content than direct seeded rice.

Different crop establishment methods have varying plant population, moisture availability conditions and may have different nitrogen requirements. Earlier study reports do not show the effect of varied doses of nitrogen application and different planting techniques on grain quality parameters in rice for Super Basmati. Therefore it is the dire need of today to investigate the quality parameters of rice under different planting methods and varied nitrogen levels.

## MATERIALS AND METHODS

The study was conducted at experimental area of Rice Research Institute, Kala Shah Kaku, Pakistan during the year 2015 and 2016. Four rice establishment methods viz. drilling of dry seed in well prepared dry soil by drill (DSR-drill), broadcasting of dry seed in well prepared dry soil (DSR-broadcast), ridge sowing that is ridges made by tractor drawn ridger after broadcasting of dry seed in dry soil (DSR-ridge) and puddled transplanted rice were compared (PTR-conventional transplanting) and Four nitrogen levels (viz  $\text{N}_0$ : Control,  $\text{N}_1$ : 133  $\text{kg N ha}^{-1}$ ,  $\text{N}_2$  166  $\text{kg N ha}^{-1}$  and  $\text{N}_3$ : 199  $\text{kg N ha}^{-1}$ ) were studied. Randomized complete block design (RCBD), having planting methods in main plots and nitrogen levels in subplots, was used with three replications. The area of the main plot was 486  $\text{m}^2$  (18m  $\times$  27m). The physico-chemical characteristics of the experimental soil are given in Table 1. Super basmati rice variety was directly seeded on 14 June in both years. Drilling and broadcasting of dry seed was done in a well prepared dry seed bed. In ridge sowing ridges were made just after broadcasting of the seed on well prepared soil with a tractor drawn ridge. Irrigation was applied just after sowing of the direct seeded treatments and it was repeated 5 days after sowing (DAS) to enhance germination. Seed soaking for 24 h in fungicide (Topsin-M at the rate of 2.5  $\text{g kg}^{-1}$  seed) dissolved water was done before sowing. Seed at the rate of 30  $\text{kg ha}^{-1}$  was used in case of dry seeded of rice and 15  $\text{kg ha}^{-1}$  was used for nursery raising for transplanting an area of one hectare. For weed control in DSR methods, Clover (Bispyribac sodium) 20% SC at the rate of 250  $\text{g ha}^{-1}$  was sprayed at 20 days after seeding at saturated soil condition. The spray of Clover was repeated at 38 days after seeding as weeds again germinated in the field. Traditional rice transplanting was done on 18 July in each year with 9 inches row to row distance. Thirty days old rice nursery plants were used for transplantation in both years. Weed control in transplanted method was done by applying Butachlor 60% EC weedicide at the rate of 2000  $\text{ml ha}^{-1}$  at 5 days after transplanting (DAT) in standing water with shaker bottle. Phosphate and Potash were used at the rate of 85 and 62  $\text{kg ha}^{-1}$  respectively. All phosphorus and potash and 1/3<sup>rd</sup> nitrogen were applied as basal dose at the time of land preparation. Remaining 2/3<sup>rd</sup> of N was applied in two splits at 35 and 55 days after transplanting or seeding. In case of transplanting methods, continuous flooding of



**Table 1.** Physico-chemical properties of experimental field.

Parameter	Soil depth	
	0-6 inch	6-12 inch
EC (dS m <sup>-1</sup> )	1.40	0.93
Soil pH	8.19	8.05
Organic matter (%)	0.45	0.27
Nitrogen (%)	0.42	0.21
Available P (ppm)	5.1	4.95
Available K (ppm)	87	69
Saturation (%)	36	32
Texture	Clay loam	Clay loam
SAR (m mol L <sup>-1</sup> ) <sup>1/2</sup>	7.27	7.18

water was done for 30 DAT and after that irrigation was applied at about one week interval. Whereas, irrigation to direct sown rice was applied almost at 5-7 days interval till the crop matured. Other agronomic practices were same for all the treatments under study. For insects and disease control, recommended measures were adopted to save the crop from their ill effects. The crop was harvested at full physiological maturity, sun dried for 3 days and threshed manually.

#### Quality parameters

For the quality parameters, initially paddy samples taken from the field were sun dried and then drying was done on laboratory test dryer made by STAKE Japan, to reduce the moisture percentage up to required level for milling, that is, 12.0%.

#### De-husking the paddy and polishing the rice grains

Paddy samples were husked using SATAKE husking machine model No. THU-35 made by SATAKE Incorporation Tokyo, Japan. Whitening of husked rice was done for 35 s under 1 kg pressure by Seed Buro Whitening Mill (McGill Mill number 3) made by Seed Buro Incorporation, USA.

#### Measurement of Physical parameters

Rice grain length, width and thickness of 25 grains was measured by a dial gauge micrometer, provided and calibrated by Pakistan Council for Scientific and Industrial Research (PCSIR) Laboratory, Lahore and after that average was taken.

Amylose and protein were determined by Near Infra-Red Transmittance (NIRT) auto analyzer made by Kett Incorporation Japan No. AN 900 version 1.13. For internal calibration purpose, before analyzing unknown samples, there were determined reference samples of Basmati group and Non-Basmati long grain group. After measurement of values of amylose and protein of known reference samples on auto analyzer, experimental samples under study were determined for the amylose and protein content in the grains.

#### Statistical analysis

Statistical analysis of recorded parameters was carried out using

the Statistix version 8.1 and MS Excel 2016.

## RESULTS AND DISCUSSION

### Brown rice (BR) %

In both years under study non-significant effect of crop establishing methods was found on brown rice (BR) %. These findings are in agreement with those of Yadav et al. (2014) who investigated five different crop establishment methods in Philippines and came with likewise findings and observed non-significant effect. Maximum BR (%) was found in the treatment DSR-ridge sowing and lowest in DSR-broadcast (Figures 1 and 3). This might be due to more retention of water in ridges facilitating higher availability of water throughout growing season and might be associated to more nutrient availability that promoted healthier grain formation. However, for nitrogen rates (Figures 1 and 3), BR (%) increased with increased nitrogen doses and maximum was observed at 199 kg N ha<sup>-1</sup>. Nitrogen might have promoted more assimilate accumulation and probably led to lower husk formation. These findings coincide with those of Da-wei et al. (2017) who studied seven different nitrogen levels for two soft Japonica rice cultivars in China and found highest BR (%) value with maximum level of nitrogen application (337.5 N kg ha<sup>-1</sup>). In case of interaction of both parameters (Table 2), maximum value was seen in DSR-ridge sowing with maximum nitrogen dose (199 kg ha<sup>-1</sup>) and minimum value in DSR-broadcast along with no nitrogen application. Similar trend was found in the results of 2016 (Table 4).

### Total Milled Rice (TMR) %

During 2015 and 2016 (Figures 1 and 3), total milled rice (TMR) % was found non-significant for different crop establishing techniques and more TMR % was found in DSR- ridge sowing in comparison with the other crop establishing methods; lowest TMR value was noted in PTR-conventional transplanting. The research outcomes agrees with those of Yadav et al. (2014) who investigated non-significant effect of establishing techniques in a different location of Philippines. Among the different nitrogen levels, TMR % increased with the gradual increment of nitrogen and highest value was recorded for the treatment where 199 kg N ha<sup>-1</sup> was applied and lowest in those ones receiving no nitrogen at all. Similar findings are reported by Da-wei et al. (2017) who investigated TMR (%) is higher in the plots receiving 337.5 kg N ha<sup>-1</sup>. While studying the interaction of the factors (Table 3), both year results revealed that DSR-ridge sowing with maximum dose of nitrogen application (199 kg N ha<sup>-1</sup>) resulted in highest milling recovery and bottle rank was occupied by PTR-conventional transplanting along with no nitrogen application (Table 3

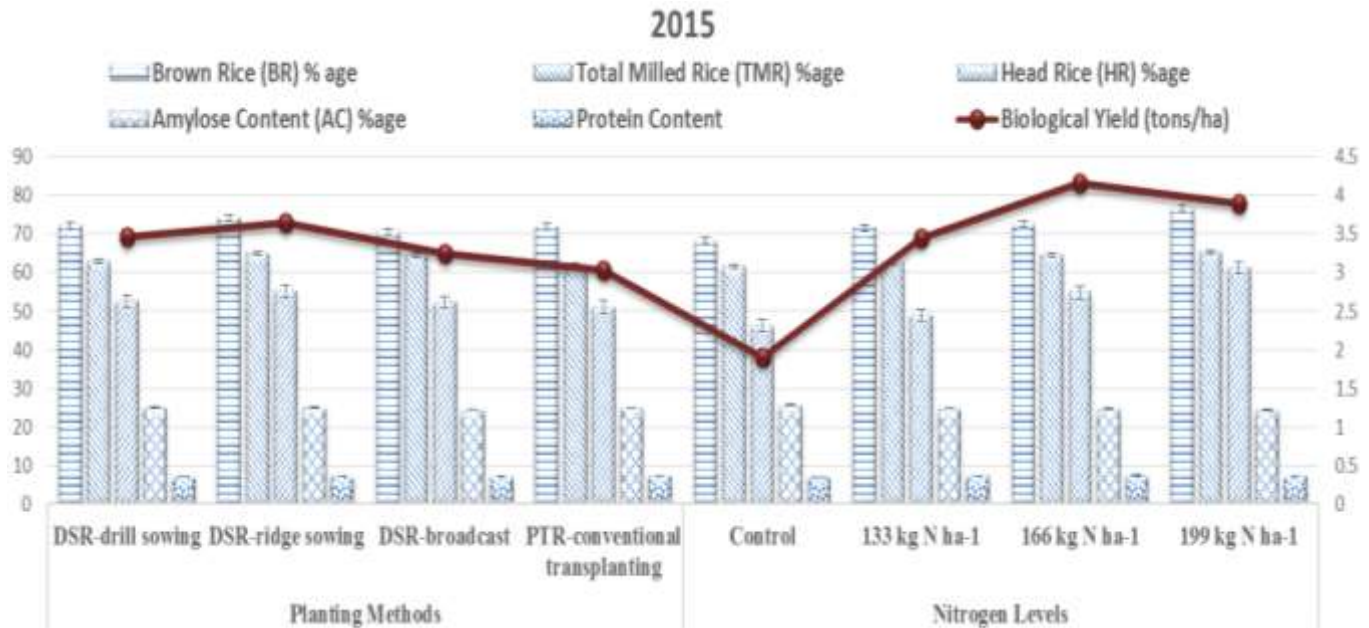


Figure 1. Effect of planting methods and nitrogen levels on grain yield and grain quality parameters of Super Basmati during 2015

and 5).

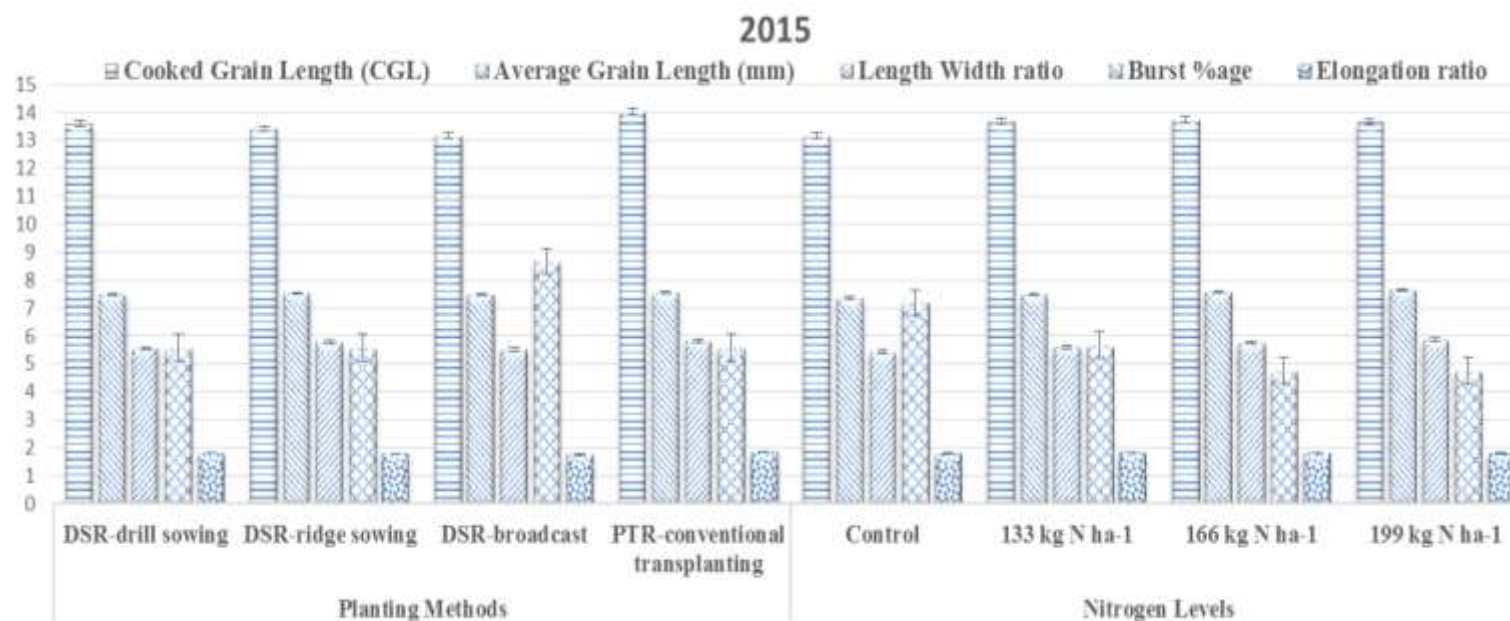
#### Head Rice (HR) %

Significantly higher HR % was recorded in DSR-ridge sowing as compared to other methods of rice establishment and minimum HR % was observed with PTR-conventional transplanting in both years (Figures 1 and 3). This might be due to the better performance of rice crop on that resulted into healthier grain, reducing breakage, more brown rice %, higher total milled rice % and at last giving high HR %. These observations are in conformity with those of Zein El-Din et al. (2008) who also found similar behavior of different planting methods on the head rice recovery of rice and found more head rice in DSR sown crop as compared to transplanting in ecological zone of Egypt. For nitrogen (Figures 1 and 3), maximum HR % was recorded with maximum dose of nitrogen (199 kg N ha<sup>-1</sup>) and lowest value was seen in case of zero nitrogen application. The reason behind this might be that highest nitrogen rate enhanced vegetative growth producing more assimilates which could be utilized during grain formation stage. This led to healthier grains that resisted mechanical injury during milling ultimately resulting in higher HR %. Rice crop in the plots receiving nitrogen below the optimum level remained under fed producing relatively weaker grains more vulnerable to breakage. These findings are quite similar to those of Da-wei et al. (2017) who found maximum HR (%) at 337 kg N ha<sup>-1</sup>. This is because of the reason that the gliadin content in rice grains is increased with the enhancement of nitrogen dose. In case of interaction

highest value of this parameter (63.00 and 50.67) was observed in DSR-ridge sowing with nitrogen rate 199 kg ha<sup>-1</sup> and lowest recorded (44.44 and 39.68) in PTR-conventional transplanting having no nitrogen application in 2015 and 2016 respectively.

#### Average grain length (AGL) mm

The AGL varied significantly from 7.47 to 7.55 mm (Figure 2) in all of the planting methods and the maximum value was observed in PTR-conventional transplanting and minimum in DSR- broadcast. However in the second year similar behavior was seen with non-significant effect (Figure 4). Such kind of results is also reported by Maqsood et al. (2013) who studied two planting methods dry seeded rice and transplanted rice by maintaining five different nitrogen levels in each and found more AGL in transplanted rice than DSR. These results are also supported by Ahmad et al. (2009) who maintained different plant population under this experimentation and noted higher AGL in transplanting than dry seeded rice crop. Different nitrogen levels significantly affected average grain length in both years (Figures 2 and 4). It was observed that increasing rates of nitrogen have more average grain length than the control. These findings are quite similar to those of Guatam et al. (2008) who investigated three nitrogen levels using three varieties and three plant spacing; they found maximum length where nitrogen was applied at the rate of 160 kg ha<sup>-1</sup>. For the interaction (Tables 3 and 5), maximum AGL (7.73 and 7.63 mm) was recorded in PTR-conventional transplanting along with nitrogen dose of 199 kg N ha<sup>-1</sup> and minimum



**Figure 2.** Effect of planting methods and nitrogen levels on grain quality traits of Super Basmati during 2015.

**Table 2.** Analysis of variance of different quality traits 2015.

Characters	MS (Rep.)	MS (Pm)	MS Error (Rep*Pm)	MS N Levels	MS Error (pm*nl)	MS Error (Rep*pm*nl)	CV (Rep*Pm)	CV (Rep*Pm*nl)
Brown Rice (BR) %	35.380	27.607	44.821	138.007	10.691	27.760	9.27	7.29
Total Milled Rice (TMR) %	87.3023	24.7146	20.1116	33.1400	1.3219	15.2754	7.05	6.14
Head Rice (HR) %	5.206	34.695	7.858	533.093	8.366	28.641	5.31	10.13
Average Grain Length (AGL) mm	0.00334	0.01629	0.00308	0.16031	0.00485	0.00143	0.74	0.50
Average Grain width (AGW) mm	0.13266	0.01936	0.00760	0.00801	0.00026	0.00103	6.57	2.42
Length Width ratio	2.04413	0.31727	0.12040	0.43533	0.00867	0.01985	6.12	2.49
Cooked Grain Length (CGL) mm	0.75724	1.67464	0.24682	0.84325	0.04227	0.16387	3.66	2.98
Bursting %	0.0208	52.7778	0.3819	15.6111	1.3148	1.0972	11.07	18.76
Elongation ratio	0.01069	0.02336	0.00420	0.00500	0.00084	0.00308	3.59	3.07
Amylose Content (AC) %	5.93453	0.72815	2.39964	3.25495	0.28278	2.09024	6.22	5.81
Protein Content (PC) %	0.16673	0.05732	0.05645	0.31763	0.03145	0.13185	3.27	5.00
Grain yield (tons/ha)	0.7186	0.8269	0.1877	12.1677	0.2996	0.1426	12.92	16.51

**Table 3.** Interactive effect of planting methods and nitrogen levels on rice grain quality for the year 2015.

Treatment	Brown Rice (BR) %	Total Milled Rice (TMR) %	Head Rice (HR) %	Average Grain Length (AGL) mm	Length Width ratio	Cooked Grain Length (CGL) mm	Bursting %	Elongation ratio	Amylose Content %	Protein Content %	Grain yield (tons/ha)
P1N0	68.650	60.757	45.773	7.35	5.39	13.200	6.000	1.797	25.517	7.050	2.01
P1N1	72.583	61.750	48.667	7.43	5.47	13.867	5.000	1.863	25.300	7.150	3.50
P1N2	72.880	64.827	55.607	7.56	5.62	13.717	4.000	1.813	54.983	7.367	4.33
P1N3	75.383	65.047	60.793	7.60	5.69	13.667	3.667	1.797	24.250	7.350	4.05
P2N0	73.110	63.777	47.457	7.44	5.57	13.150	5.333	1.779	25.750	7.017	2.45
P2N1	73.250	64.167	51.553	7.52	5.72	13.400	3.667	1.783	24.990	7.15	3.45
P2N2	73.333	65.167	58.667	7.57	5.86	13.633	3.667	1.800	24.900	7.450	4.45
P2N3	77.063	66.220	63.000	7.64	5.99	13.467	3.333	1.763	24.817	7.207	4.21
P3N0	63.150	62.260	47.407	7.34	5.26	12.833	9.667	1.745	25.813	7.100	1.65
P3N1	70.237	64.777	50.000	7.44	5.41	13.367	9.000	1.797	24.200	7.300	3.73
P3N2	72.083	65.463	52.443	7.56	5.66	13.300	7.333	1.760	24.180	7.433	3.60
P3N3	76.667	66.250	59.283	7.58	5.74	13.233	8.667	1.747	24.000	7.200	4.05
P4N0	67.947	59.983	44.443	7.34	5.55	13.517	7.667	1.843	25.350	7.050	1.51
P4N1	70.280	60.427	45.470	7.56	5.80	14.117	5.000	1.867	25.083	7.567	3.11
P4N2	72.393	63.137	52.650	7.58	5.88	14.367	4.000	1.897	24.717	7.550	3.11
P4N3	76.667	63.673	61.960	7.73	6.10	14.250	3.333	1.840	24.450	7.283	3.25
	*	Ns	*	*	*	*	*	*	Ns	Ns	*
SE	4.6206	3.3151	3.9535	0.0350	0.1732	0.3508	0.07825	0.473	1.2021	0.2745	0.3203
LSD 0.05	10.156	7.2292	8.2865	0.0778	0.4018	0.7690	1.6461	0.1033	2.6085	0.5796	0.6985

P1= DSR-drill sowing; P2= DSR-ridge sowing; P3=DSR-broadcast; P4= PTR- conventional transplanting; N0=Control; N1=133 kg N ha<sup>-1</sup>; N2= 166 kg N ha<sup>-1</sup>; N3=199 kg N ha<sup>-1</sup>; ns= Non-significant; \*= Significant at P< 0.05.

(7.34 and 7.35 mm) in DSR-drill sowing and DSR-broadcast in 2015 and 2016 respectively.

### Length width ratio (LWR)

The length width ratio (LWR) did not vary significantly among different planting methods during both years under study (Figures 2 and 4). However, in 2015 highest LWR (5.83) was recorded in PTR-conventional transplanting, DSR-ridge (5.79) and minimum (5.52) in DSR-broadcast. The results are similar to those of Naresh et al. (2014) who investigated eight

sowing techniques and observed that transplanted rice had better LWR as compared to all direct seeding techniques. Varying nitrogen levels were also affected LWR in both years (Figures 2 and 4). Increasing rates of nitrogen enhanced LWR over the control. In 2015, maximum LWR (5.88) was noted in the treatment having 199 kg N ha<sup>-1</sup> whereas minimum (5.44) was observed in control. These findings are in line with that of Ya-Jie et al. (2009) who studied two varieties Zhonghan 3 and Yangjing 9538 and three nitrogen levels viz. low (100 kg N ha<sup>-1</sup>), normal (200 kg N ha<sup>-1</sup>) and high (300 kg N ha<sup>-1</sup>) in China. They recorded maximum

LWR for variety Yangjing 9538 cultivated under both dry and moist cultivation methods at nitrogen level of 200 kg ha<sup>-1</sup>. These results are also confirmed by Singh et al. (2011) who maintained four nitrogen levels for three rice cultivars under this experimentation in India. He found that nitrogen has positive role in the LWR and its highest value was recorded in the treatment with maximum nitrogen level (60 kg ha<sup>-1</sup>). For the interaction (Tables 3 and 5), maximum LWR (6.10) was recorded in PTR-recommended conventional transplanting along with 199 kg N ha<sup>-1</sup> and minimum (5.26) receiving no nitrogen.

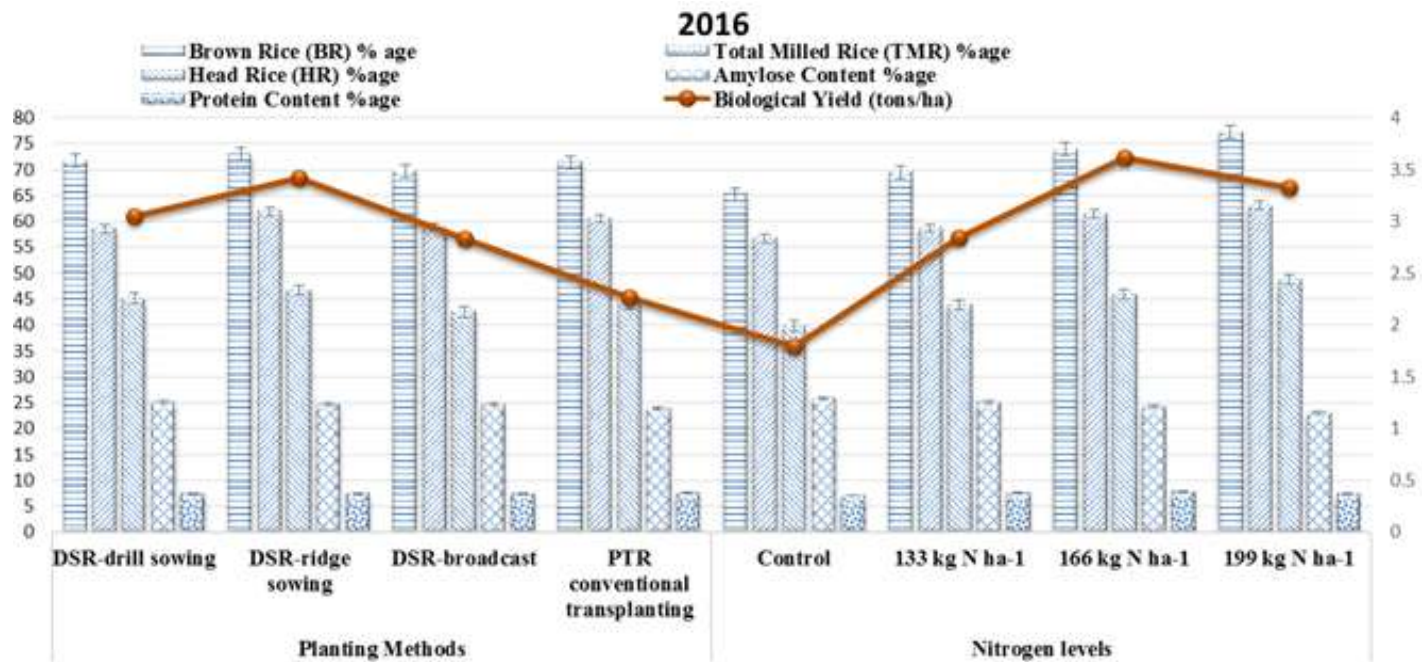


Figure 3. Effect of planting methods and nitrogen levels on grain yield and grain quality parameters of Super Basmati during 2016.

Table 4. Analysis of Variance 2016.

Characters	MS (Rep.)	MS (Pm)	MS Error (Rep*Pm)	MS N Levels	MS Error (pm*nl)	MS Error (Rep*pm*nl)	CV (Rep*Pm)	CV (Rep*Pm*nl)
Brown Rice (BR) %	105.943	20.740	49.354	332.622	3.819	25.163	9.83	7.02
Total Milled Rice (TMR) %	5.6262	27.5775	27.6070	96.5978	8.2505	29.2957	8.76	9.02
Head Rice (HR) %	3.461	36.918	10.775	171.739	3.142	28.161	7.36	11.89
Average Grain Length (AGL) mm	0.00930	0.01619	0.01886	0.08308	0.00205	0.01986	1.83	1.88
Length Width ratio	0.03366	0.62728	0.08324	0.67970	0.01054	0.05777	5.15	4.29
Cooked Grain Length (CGL) mm	0.20146	1.70583	0.17646	0.23139	0.27639	0.42326	3.20	4.96
Bursting %	0.4375	18.7431	1.6597	7.4097	0.1505	1.7153	19.63	19.96
Elongation ratio	0.00250	0.02193	0.00223	0.00565	0.00481	0.01005	2.70	5.73
Amylose Content (AC) %	2.0626	3.5201	0.4803	16.4073	0.4572	0.9635	2.82	4.00
Protein Content (PC) %	0.10974	0.08783	0.07793	0.98172	0.06190	0.07644	3.75	3.71
Grain yield (tons/ha)	0.00028	2.80917	0.06838	7.68542	0.18020	0.03058	9.05	6.05

**Table 5.** Interactive effect of planting methods and nitrogen levels on rice grain quality for the year 2016.

Treatment	Brown Rice (BR) %	Total Milled Rice (TMR) %	Head Rice (HR)	Average Grain Length (AGL) mm	Length Width ratio	Cooked Grain Length (CGL) mm	Burst %	Elongation ratio	Amylose Content (AC) %	Protein Content (PC) %	Grain yield (tons/ha)
P1N0	65.910	56.903	40.383	7.42	5.213	12.833	7.333	1.727	26.483	7.100	1.86
P1N1	69.800	57.607	44.333	7.43	5.383	13567	7.000	1.827	25.683	7.500	3.19
P1N2	75.053	59.300	45.760	7.50	5.583	13.133	6.667	1.750	24.450	7.600	3.58
P1N3	76.500	60.617	50.220	7.59	5.853	12.967	5.667	1.707	23.500	7.400	3.56
P2N0	66.000	60.000	40.667	7.44	5.450	13.033	7.000	1.753	26.183	7.000	1.95
P2N1	70.667	60.667	47.333	7.46	5.573	13.267	6.333	1.780	25.467	7.633	3.26
P2N2	75.610	62.807	48.080	7.57	5.793	13.400	5.667	1.767	24.183	7.800	4.33
P2N3	79.607	64.153	50.667	7.61	5.830	13.700	5.000	1.800	22.850	7.283	4.13
P3N0	63.883	52.763	38.600	7.35	5.060	12.267	9.333	1.670	25.717	7.033	1.86
P3N1	68.513	58.687	40.193	7.41	5.247	12.700	8.667	1.713	24.700	7.250	2.78
P3N2	70.200	60.423	44.230	7.53	5.447	13.100	7.667	1.737	24.917	7.733	3.54
P3N3	76.573	64.000	47.113	7.59	5.693	12.333	7.333	1.627	23.750	7.550	3.16
P4N0	65.027	57.333	39.683	7.47	5.607	13.633	6.333	1.827	24.933	7.100	1.47
P4N1	69.097	57.693	43.700	7.54	5.853	13.467	5.333	1.787	24.533	7.850	2.13
P4N2	75.140	63.327	45.520	7.58	5.957	13.233	5.000	1.743	23.300	7.800	2.98
P4N3	76.420	63.660	47.383	7.63	6.170	13.433	4.667	1.763	22.367	7.550	2.46
	*	*	*	*	*	*	*	*	*	*	*
SE	4.5615	4.3874	3.9845	0.1143	0.2068	0.4910	1.0650	0.0735	0.7495	0.2263	0.1634
LSD 0.05	10.105	9.4568	8.3962	0.2465	0.4525	1.0362	2.2976	0.1536	0.4890	73.249	0.3639

P1= DSR-drill sowing; P2= DSR-ridge sowing; P3=DSR-broadcast; P4= PTR- conventional transplanting; N0=Control; N1=133 kg N ha<sup>-1</sup>; N2= 166 kg N ha<sup>-1</sup>; N3=199 kg N ha<sup>-1</sup>; ns= Non-significant; \*= Significant at P< 0.05.

Similar trend was observed in 2016 (Table 5).

#### Cooked grain Length (CGL) mm

PTR-conventional transplanting produced best cooked grain length (CGL) (14.06 mm and 13.44 mm) and minimum CGL (13.18 mm and 12.60 mm) was seen in DSR-broadcast in 2015 and 2016 respectively (Figures 2 and 4). Ali et al.

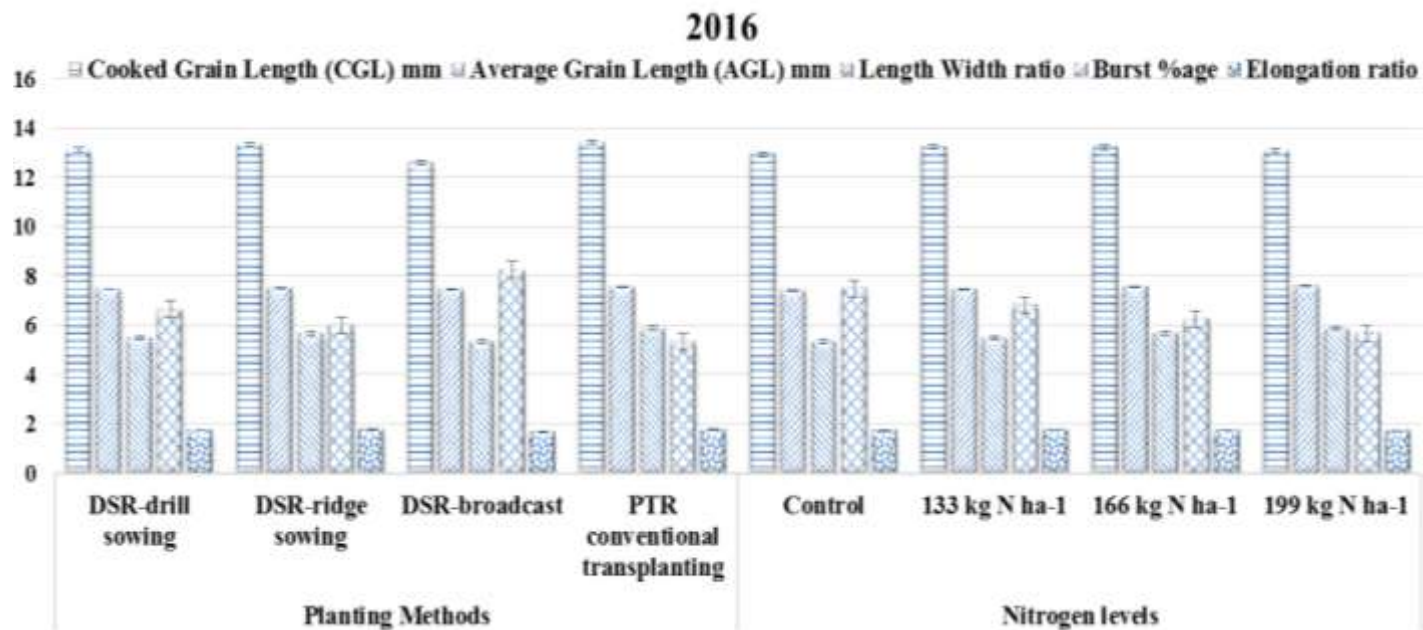
(2012) reported the same and recorded maximum CGL (14.4 mm) in transplanting in puddled soil as compared to broadcast of pre-germinated seed in wet puddled soil (13.8 mm) in Pakistan. Whereas for nitrogen application best CGL (13.75 mm and 13.25 mm) was observed at 166 kg N ha<sup>-1</sup> in 2015 and 2016 respectively and CGL decreased with further increase of nitrogen. For the interaction (Table 3) best CGL was noted in PTR-conventional transplanting (14.36 mm) with

nitrogen application of 166 kg ha<sup>-1</sup> and minimum CGL (12.83 mm) was seen in DSR-broadcast along with zero nitrogen level in 2015; similar trend was recorded in 2016 (Table 5).

#### Bursting %

In 2015 (Figures 2 and 4), DSR-broadcast gave maximum bursting % whereas PTR-conventional





**Figure 4.** Effect of planting methods and nitrogen levels on grain quality traits of Super Basmati during 2016

transplanting had lower bursting. This might be due to more nitrogen uptake in transplanted rice and ultimately leading to more protein content that increased compactness and resisted bursting at high temperature while boiling. Ali et al. (2012) also found lower bursting in rice crop established through seedling transplanting as compared to broadcast of pre-germinated seed in wet puddled soil in Pakistan. However for different doses of nitrogen, bursting decreased with its increments. Maximum bursting was recorded in the plots where no nitrogen was applied and at 199 kg N ha<sup>-1</sup> level minimum bursting was recorded. This can be strengthened by the argument that grain developed with maximum nitrogen level might be thick having higher protein content than resisted bursting. For the interaction (Table 3), highest bursting (9.67 %) was seen in DSR-Broadcast with no nitrogen application. On the other hand, lower was found in PTR-conventional transplanting (3.33 %) and DSR-ridge sowing (3.33 %) with nitrogen application of 199 kg ha<sup>-1</sup>. Similar results were found in 2016 (Table 5).

#### Elongation ratio (ER)

The ER varied significantly among different planting methods during both years under study (Figures 2 and 4). In 2015, higher ER was recorded in PTR-conventional transplanting (1.86), DSR-drill sowing (1.82) and DSR-ridge sowing (1.78) whereas minimum (1.76) was in DSR-broadcast. The ER was maximum in case of 133 kg N ha<sup>-1</sup> and below and above that level ER decreased. Among different nitrogen treatments, maximum ER (1.90)

was recorded in PTR-conventional transplanting along with nitrogen rate of 166 kg N ha<sup>-1</sup> and minimum in DSR-broadcast (1.74) with no nitrogen.

#### Amylose content (%)

Amylose content is among the important physicochemical parameters that determine the quality of cooked rice. Amylose content differed significantly among different planting methods during 2016. The DSR-planted rice through drill sowing consistently had higher amylose content (25.03%) compared with PTR- conventional transplanted rice (23.78%). These finding are in accordance with that of Ya-Jie et al. (2009) who studied dry and moist cultivation methods for upland and lowland rice receiving different doses of nitrogen fertilizer and found more amylose content in dry cultivation than moist cultivation. In case of nitrogen application, the amylose content declined with the increment of nitrogen fertilizer. This might be due to the enhanced photosynthetic activity affecting negatively amylose content and boosting the other parameters. Hu-lin et al. (2007) maintained three nitrogen levels for two cultivation methods in their study and found that amylose content decreased when nitrogen dose was enhanced. From the interaction of both factors, it was revealed that DSR-drill sown crop receiving no nitrogen gave highest amylose content in the grains whereas lowest value was recorded in the transplanted rice with 166 kg N ha<sup>-1</sup>. Similar findings were in 2015 for nitrogen application whilst for the planting method and interaction non-significant effect was recorded.

### Protein content (%)

Different planting methods have non-significant effect on the protein content in the grains during both years though PTR-conventional transplanting produced more protein content in the rice grains as compared to the other three treatments of DSR sown crop consistently in both years. This is because of the reason that in standing water position, plant takes nutrients more efficiently especially nitrogen, integral part of the amino acid and protein and eventually resulted in higher protein content. These findings are confirmed by Maqsood et al. (2013). On the other hand, during 2016 highest protein content was found where nitrogen was applied at the rate of 166 kg N ha<sup>-1</sup>; however the protein content (7.33) decreased as proceeded forward to upper nitrogen input level and minimum value was noted where no nitrogen was applied. The reason for declining of protein content at higher rates seems to be higher vegetative growth and less photosynthate assimilation in the grains, ultimately lowering protein content. Findings match those of Hu-lin et al. (2007); Ya-Jie et al. 2009) and Kandil et al. (2010) and found that nitrogen increases the protein content in rice grains. For the interaction maximum protein content was observed in PTR-recommended conventional transplanting having nitrogen at the rate of 133 kg ha<sup>-1</sup> and lowest value was recorded in DSR- ridge sowing receiving no nitrogen at all. During 2015 non-significant effect was seen.

### Grain yield (t ha<sup>-1</sup>)

Grain yield varied significantly among different planting methods and nitrogen levels during both years (Figures 1 and 3). The maximum biological yield during 2015 was achieved with the planting method of DSR-ridge (3.64 t ha<sup>-1</sup>) that was statistically similar with drilling of dry seed (DSR-drill) (3.48 t ha<sup>-1</sup>). Broadcast of seed (DSR-broadcast) in well prepared seed bed produced 3.36 t ha<sup>-1</sup> that was similar with PTR-conventional transplanting which produced the lowest grain yield of 3.04 t ha<sup>-1</sup>. For application of different levels of nitrogen, maximum grain yield (4.16 t ha<sup>-1</sup>) was harvested from the treatment in which N was applied at the rate of 166 kg ha<sup>-1</sup> and it was statistically similar with the treatment in which maximum dose of N at the rate of 199 kg ha<sup>-1</sup> was applied (3.89 t ha<sup>-1</sup>). The lowest grain yield (1.91 t ha<sup>-1</sup>) was observed in the control treatment receiving no nitrogen. In case of interaction of both the factors under trial (Tables 3 and 5), it was found the highest value for grain yield (4.45 t ha<sup>-1</sup>) was achieved in the DSR-ridge sowing method of rice cultivation and receiving nitrogen dose at the rate of 166 kg ha<sup>-1</sup> while lowest yield (1.52 t ha<sup>-1</sup>) was recorded from the treatment PTR-conventional transplanting along with no nitrogen application. Our outcomes are in agreement with the research studies of Farooq et al. (2008) who

observed poor yield in transplanted rice and more in directly sown crop. For nitrogen application, our results are confirmed by Yosef (2013) and Chen et al. (2014) who investigated three nitrogen levels viz 0, 150 and 225 kg N ha<sup>-1</sup> for different rice cultivars using two establishing methods and found that at 225 kg N ha<sup>-1</sup> highest yield was found.

### Conclusion

Direct seeded rice is gaining popularity in the agro climatic zones of Pakistan and is replacing the conventional transplanting. Among different crop establishment techniques, DSR ridge sowing produced better milling recovery parameters along with maximum grain yield. Though conventional transplanting exceeded in cooking and chemical traits but it was almost similar with DSR ridge sowing. So, DSR ridge sowing can be best alternative option to conventional transplanting that can be adopted. Nitrogen application at the rate of 199 kg ha<sup>-1</sup> resulted in good quality parameters over all other applied doses. However, quality traits evaluation of rice was limited by time and space, so there is a need to evaluate multi locations and multi years. There is also a need to measure the grain quality parameter using the DSR along with manual transplanting of rice at different location.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

### REFERENCES

- Ahmad S, Zia-ul-Haq M, Ali H, Ahmad A, Khan MA, Khaliq T, Husnain Z, Hussain A, Hoogenboom G (2009). Morphological and quality parameters of *oryza sativa* L. as affected by population dynamics, nitrogen fertilization and irrigation regimes. *Pakistan Journal of Botany* 41(3):1259-1269.
- Ali RI, Iqbal N, Saleem MU, Akhtar M (2012). Effect of different planting methods on economic yield and grain quality of rice. *International Journal of Applied Agricultural Sciences* 4(1):28-34.
- Anonymous (2017). Economic survey of Pakistan. Government of Pakistan, Finance Division, Economic Advisory Wing, Islamabad. [http://www.finance.gov.pk/survey/chapters\\_17/pakistan\\_es\\_2016\\_17\\_.pdf](http://www.finance.gov.pk/survey/chapters_17/pakistan_es_2016_17_.pdf)
- Awan TH, Ali RI, Manzoor Z, Ahmad M, Akhtar M (2011). Effect of different nitrogen levels and row spacing on the performance of newly evolved medium grain rice variety, KSK 133. *Journal of Animal and Plant Sciences* 21(2):231-23.
- Balasubramanian V, Hill JE (2002). Direct seeding of rice in Asia: Emerging issues and strategic research needs for the 21<sup>st</sup> century. In "Direct Seeding: Research Strategies and Opportunities" (S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, and B. Hardy, Eds.), International Rice Research Institute, Los Banos, Philippines pp. 15-39.
- Bandonill EH, Corpuz GG (2015). Grain quality of irrigated lowland rice varieties as affected by season and crop establishment. *The Philippine Journal of Crop Sciences* 40(2):74-77.
- Bouman BAM, Tuong TP (2001). Field water management to save



- water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* 49:11-30.
- Cagampang GB, Cruz LJ, Espiritu SG, Santiago RG, Juliano BO (1966). Studies on the extraction and composition of rice proteins. *Cereal Chemistry* 43:145-155.
- Chen S, Wang D, Xu C, Ji C, Zhang X (2014). Responses of super rice (*Oryza sativa* L.) to different planting methods for grain yield and nitrogen-use efficiency in the single cropping season. *Plos One* 9(8):1-9.
- Dawe D (2003). The current challenges. In: New challenges and technological opportunities for rice-based production systems for food security and poverty alleviation in Asia and the Pacific. P. Roland and G.P. Hettel, 2004 (Eds). FAO Rice Conference, Rome, Italy, February 12-13. <http://www.fao.org/rice/2004/en/pdf/Cantrell.pdf>.
- Dawe D (2005). Increasing water productivity in rice-based systems in Asia-Past trends, current problems, and future prospects. *Plant Production Science* 8:221-230.
- Da-wei Z, Hong-cheng Z, Bao-wei G, Ke X, Qi-gen D, Hai-yan W, Hui G, Ya-jie H, Pei-yuan C, Zhong-yang H (2017). Effects of nitrogen level on yield and quality of japonica soft super rice. *Journal of Integrative Agriculture* 16(5):1018-1027.
- Farooq M, Basra SMA, Asad SA (2008). Comparison of conventional puddling and dry tillage in rice-wheat system. *Paddy and Water Environment* 6:397-404.
- Gautam AK, Kumar D, Shivay YS, Mishra BN (2008). Influence of nitrogen levels and plant spacing on growth, productivity and quality of two inbred varieties and a hybrid of aromatic rice. *Archives of Agronomy and Soil Science* 54(5):515-532.
- Guo T, Liu XL, Wan X, Weng J, Liu S (2011). Identification of a stable quantitative trait locus for percentage grains with white chalkiness in rice (*Oryza sativa* L.). *Journal of Integrative Plant Biology* 53:598-607.
- Hanjar MA, Quereshi ME (2010). Global water crisis and food security in an era of climate change. *Food Policy* 35:365-377.
- Hu-lin H, You-zhang W, Xiao-e Y, Ying F, Chun-yong W (2007). Effects of different nitrogen fertilizer levels on Fe, Mn, Cu and Zn concentrations in shoot and grain quality in rice (*Oryza sativa*). *Rice Science* 14(4):289-294.
- Iqbal MA (2014). Productivity and quality of direct seeded rice under different types of mulches and planting patterns. *American-Eurasian Journal of Agricultural and Environmental Sciences* 14(11):1240-1247.
- Kandil AA, El-Kalla SE, Badawi AT, El-Shayb OM (2010). Effect of hill spacing, nitrogen levels and harvest date on rice productivity and grain quality. *Journal of Crop and Environment* 1(1):22-26.
- Mahajan G, Chauhan BS, Timsina J, Singh PP, Singh K (2012). Crop performance and water and nitrogen use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. *Field Crops Research* 134:59-70.
- Maloles JS (2008). Quality rice, quality price. *PhilRice Newsletter* 21(3):24-25.
- Maqsood M, Shehzad MA, Syed N, Ali A, Iqbal M (2013). Rice cultures and nitrogen rate effects on yield and quality of rice (*Oryza sativa* L.). *Turkish Journal of Agriculture and Forestry* 37:665-673.
- Naklang K, Fukai S, Nathabuk K (1996). Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. *Field Crops Research* 48(2-3):115-123.
- Naresh RK, Tomar SS, Kumar D, Samsher P, Singh SP, Dwivedi A, Kumar V (2014). Experiences with Rice Grown on Permanent Raised Beds: Effect of Crop establishment Techniques on Water Use, Productivity, Profitability and Soil Physical Properties. *Rice Science* 21(3):170-180.
- Perez CM, Juliano BO, Liboon SP, Alcantara JM, Cassman KG (1996). Effects of late nitrogen fertilizer application of head rice yield, protein content and grain quality of rice. *Cereal Chemistry* 73(5):556-560.
- REAP (Rice exporters association of Pakistan) (2014-15). QRC Rice inspection cell Karachi, Lahore, Quetta and TCP country wise position of export of basmati rice. [http://reap.com.pk/admincp/download/Upload\\_files/cw20142015.pdf](http://reap.com.pk/admincp/download/Upload_files/cw20142015.pdf) (Accessed January 30, 2018)
- Saeed F (2015). Grain, milling, and head rice yields as affected by nitrogen rate and biofertilizer Application. *Acta Agriculturae Slovenica* 105(2):241-248.
- Sanjitha RT, Jayakiran K (2010). Evaluation of different planting techniques for economic feasibility in Rice. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 9(1):150-153.
- Singh N, Pal N, Mahajan G, Singh S, Shevkani K (2011). Rice grain and starch properties: Effects of nitrogen fertilizer application. *Carbohydrate Polymers* 86:219-225.
- Yadav S, Henry A, Evangelista G, Faronilo J, Humphreys E, Fernandez L (2014). Establishment method effects on crop performance and water productivity of irrigated rice in the tropics. *Field Crops Research* 166:112-127.
- Ya-Jie Z, Ying-Ying C, Guo-Jun Y, Bin D, Yu-Ran Z, Jian-Chang Y (2009). Effects of nitrogen nutrition on grain quality in upland rice Zhonghan 3 and paddy rice Yangjijing 9538 under different cultivation methods. *Acta Agronomica Sinica* 35(10):1866-1874.
- Yosef TS (2013). Effect of Nitrogen and Phosphorus fertilizer on spikelet structure and yield in rice (*Oryza sativa* L.). *International Journal of Agriculture and Crop Sciences* 5(11):1204-1208.
- Zein EL- Din AM, Zein El-Abedin TK, EL-Hesawy AA, Abd El-Hameed RG (2008). Effect of tillage and planting practices on rice yield and engineering characteristics of milling quality. *Misr Journal of Agricultural Engineering* 25(3):778-803.

*Full Length Research Paper*

# **A synthesis of Ethiopian agricultural technical efficiency: A meta-analysis**

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**In Ethiopia, technical efficiency studies started about three decades ago. These studies have reached different conclusions regarding agriculture efficiency based on technical efficiency scores. This study represents the first attempt to use meta-analysis to examine the mean technical efficiency estimates in agriculture in Ethiopia. The current study employed 45 frontier studies published from 1993 to 2014 for the meta-analysis. The study employed fractional regression to model for the meta-regression analysis. The result of the study shows that there is no publication bias in technical efficiency studies in Ethiopia. The meta-analysis result shows the overall mean technical efficiencies are 68 and 71% based on fixed effect model and random effect model, respectively, suggesting that there are still opportunities for improvement in the efficiency of Ethiopian agriculture. The result also shows that technical efficiency was found to be decreasing over years for studies carried out in all the four regions together (Tigray, Amhara, Oromia, and South). Overall, the study obtained moderator variables (that is, wheat, maize, sample size, food crop, number of inputs) significantly affecting the estimation of the reported mean technical efficiencies in primary studies across the four meta-regression model specifications. The finding of the decline in technical efficiency over years implies that even though there is a scope of improving efficiency in the country, government should also consider side by side introduction and dissemination of new agricultural technologies to reverse the decreasing technical efficiency. This will ultimately boost the country's agricultural and food production. Besides, the results call upon researchers and academicians to be curious in identifying study-specific attributes, which are essential for modeling farm-level efficiency.**

**Key words:** Meta-analysis, technical efficiency, fixed effect and random effect models.

## **INTRODUCTION**

In Ethiopia, a range of policies and investments have been pursued to boost agricultural production and

productivity, especially with respect to staple food crops to ultimately reduce poverty in the country at different

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times. The main goal of these efforts is to enhance and speed up the availability and adoption of improved seed, chemical fertilizers, and extension services for small-scale, resource-poor farmers, particularly those cultivating staple food crops, ultimately improving agricultural performance.

In order to document and justify the efforts done thus far, scholars have filled this gap using frontier approaches to technical efficiency (TE) measurement. To this end, a plethora of technical efficiency studies have been conducted in the country.

Although these TE literatures suggest evidence that the efforts of the governments have led to improvements in both production and productivity, these studies in literature in the country have reached different conclusions regarding agriculture efficiency based on TE scores. Some have revealed high scores (Ahmed, 2014; Tefaye and Beshir, 2014), while others have revealed low scores (Asres et al., 2013; Abebe, 2014; Yami et al., 2013). Obviously, the empirical estimates of technical efficiency will vary across several factors, e.g., the methodology used, the data type used, and the country or region where the studies are situated (Odeck and Bråthen, 2012).

Given TE studies in Ethiopian agriculture, to the best of the author no statistical study has summarized the available information across studies using meta-analysis in the country to provide overview of how frontier estimates of smallholder farmers' TE vary with different studies' circumstances. This study will be a pioneer attempt in the country in the realm of meta-analysis.

Henceforth, the current paper presents the results of a meta-analytical regression model that seeks to summarize the available literature on smallholder agricultural technical efficiency in Ethiopia. In doing so, the paper provides the readers with inference based on overview of how frontier estimates of smallholder farmers' TE vary. Thus, the study poses two questions that seek to answer:

- (1) How did the average technical efficiency estimates of Ethiopian agriculture develop (that is, their direction) over the years?
- (2) To what extent do variations in the study's characteristics influence reported average technical efficiency estimates from the case studies?

### **Review of stochastic frontier methodology and meta-analysis**

Farrell (1957) was the pioneer that developed the concept of technical efficiency based on input and output relations. According to Farrell, technical efficiency is related to the physical input and output relation and refers to the success of the producer in approaching the frontier (the maximum possible) from a given set of input. If a producer approaches the frontier, its level of technical

efficiency will be high, and this is attained by efficient utilization of the inputs.

The stochastic frontier production function, which was described by Aigner et al. (1977) and Meeusen and Broeck (1977), decomposes the error term into two components. A systematic component permits random variation of the frontier across firms, and captures the effects of measurement errors, caused from outside the firms' control, random shocks and other statistical noise. A one sided component captures the effects of inefficiency relative to the stochastic frontier. This is the strength of stochastic frontier production function and makes it increasingly popular among researchers.

There are two standard ways by which firm-level efficiency could be implemented under stochastic frontier production function: the primal frontier function (production or distance frontier function) and the dual frontier function (cost, revenue or profit frontier function), depending on the direction of the research, data availability or the decision to impose behavioral objectives on the study.

### **Meta-analysis**

Meta-analysis is a quantitative method of combining the results of independent studies, exploring heterogeneity, and synthesizing summaries if appropriate. The principal purpose of a meta-analysis of observational studies is not to derive an overall estimate of effect but to investigate the reasons for differences in estimates among studies and to discover patterns of estimates (Card, 2012).

Meta-analysis is quite popular in medical and marketing research, but few reported studies in agricultural and resource economics have employed the technique to investigate how study-specific characteristics influence the empirical estimates from several outcomes over time (Ogundari and Brümmer, 2011).

Thus far, meta-analysis in agricultural efficiency is applied to investigate the efficiency estimates from primary studies by different authors. Thiam et al. (2001) applied meta-analysis first time in technical efficiency studies in developing countries, while Bravo-ureta et al. (2007) used a meta-regression analysis including 167 farm level technical efficiency (TE) studies of developing and developed countries. In Africa, Ogundari and Brümmer (2011) have used meta-analysis in efficiency studies in Nigeria.

### **EMPIRICAL MODEL**

#### **Publication bias test**

There have been at least two attempts to produce significance tests to identify publication bias. These are Begg's test (Begg and Mazumdar, 1994) and Egger's test (Egger et al., 1997). Both methods test whether the study estimate is related to the size of the study. The test proposed by Egger et al. (1997) is algebraically

identical to a test that there is no linear association between the treatment effect and its standard error. Furthermore, you can formally test for asymmetry by regressing effect sizes onto sample sizes. The presence of an association between effect sizes and sample sizes is similar to an asymmetric funnel plot in suggesting publication bias (Card, 2012). In this study, the publication bias will be evident if the association between sample size and mean technical efficiency estimates is negative and significant.

In the current study, the regression method was employed to test for asymmetric funnel plot in suggesting publication bias.

$$MTE_i = \beta_0 + \beta_1 n_i + \varepsilon_i \quad (1)$$

where  $MTE_i$  mean technical efficiency of study  $i$ ,  $n_i$  sample size of study  $i$  and  $\varepsilon_i$  error terms.

### Meta-regression model

The thrust of this model is to provide answer to the second questions. In this model, the dependent variable will be the reported mean technical efficiency estimates of each primary study. Authors undertaking a meta-regression have used different regression models. For instance, Bravo-ureta et al. 2007 in their meta-regression analysis employed tobit model. On the other hand, Ogundari (2009) and Ogundari and Brümmer (2011) employed truncated regression model. In the current study, fractional regression is employed for the meta-regression analysis. Ogundari (2014) used fractional regression to model for the meta-regression.

$$MTE_i = \beta_0 + \beta_d x_{di} + \sum_{k=1}^k \beta_k x_{ki} + \varepsilon_i; \varepsilon_i \sim (0, \sigma_\varepsilon) \quad (2)$$

The Quasi-Maximum Likelihood Estimation (QMLE) method is the asymptotically efficient and consistent method used in estimating the fractional regression model (Ogundari, 2014). The STATA software was used in estimating the model using generalized linear model (glm) command with family (binomial), link (logit), and robust standard error option. The description of the variables employed in the regression model are presented in Table 1.

### Data source and collection

The primary studies used for this meta-analysis were compiled from different sources. To this end, a variety of sources were used to compile the selected case studies in the present study, mainly Google scholar, Libraries and other economic database such as web of science. Besides, Masters' Theses were collected from the Website of Haramaya University, Ethiopia.

The inclusion and exclusion criteria used in selecting studies for the present analysis were the study reports mean efficiency estimates, data year, sample size functional forms, parametric models and cross-sectional studies. Accordingly, the study selected 45 frontier studies published from 1993 to 2014 for the current analysis.

Hence, the study collected around 20 aspects of studies, such as the characteristics of data, estimation, inclusion of control variables, region, and information on the publication outlet.

## RESULTS AND DISCUSSION

### Descriptive statistics

Table 2 presents the descriptive summary of the selected primary case studies employed in this meta-analysis. In

Table 2, the average TE ratio of the total set of studies is 0.708 that is slightly lower than the Cobb-Douglas functional form. In terms of functional forms, the result shows that the Cobb-Douglas production functional form yields on average a higher estimate (0.717) than the Translog functional form (0.644).

With regard to the distribution of the reported mean efficiency of the selected primary studies, Figure 1 portrays the distribution of the mean technical efficiency estimates of the studies and it was found that the distribution is normal for the whole sample. However, when the efficiency estimates plotted by grouping the sample using publication type (Journal and Thesis), it was observed that the distribution skewed to the right for those unpublished studies (thesis) and normal for the published studies (journals).

Furthermore, a closer look at the result of Table 2 of efficiency estimates by disaggregating it across various moderator variables, the results revealed more information; for instance, with regard to product type maize crop yielded higher efficiency. While in relation to output measure, the result shows that studies that focus on single output reported higher efficiency estimates. The disaggregation by region shows that the Tigray Region shows the highest efficiency estimates; however, the sample is very small. Hence, the interpretation of this result should be taken with care.

Table 2 also presented that compared to studies published on journals, unpublished studies (thesis) reported higher efficiency. While the result obtained studies conducted in the 2000s have higher efficiency estimates compared to studies in 1990s and 2010s.

### Meta-regression analysis

Before employing the meta-regression model, first we have to look at the publication bias and the heterogeneity problems using funnel plot and regression model (Card, 2012) to identify the publication bias and forest plot to identify the heterogeneity problem.

### Exploring publication bias

Published studies do not represent all studies on a specific topic. Publication selection exists when editors, reviewers, or researchers have a preference for statistically significant results (Stanley, 2005). Publication bias is one type of publication selection. Publication bias refers to the possibility that studies finding null (absence of statistically significant effect) or negative (statistically significant effect in opposite direction expected) results are less likely to be published than studies finding positive effects (statistically significant effects in expected direction) (Card, 2012). Publication bias can be detected either visually using funnel-plot or

**Table 1.** The moderator (independent) variables and their description.

Variable	Description
MTI ( $MTE_i$ )	Mean efficiency score reported
Data year ( $x_{di}$ )	Year of the data that a primary study used
Wheat ( $x_{1i}$ )	Equal to 1 if article focused on wheat crop production and 0 otherwise
Maize ( $x_{2i}$ )	Equal to 1 if article focused on maize crop production and 0 otherwise
Publication type ( $x_{3i}$ )	Equal to 1 if article is published in journal and 0 if thesis
Sample size ( $x_{4i}$ )	Number of observation in a primary study
Food Crop ( $x_{5i}$ )	Equal to 1 if article focused on food crop production and 0 otherwise
Output measure ( $x_{6i}$ )	Equal to 1 if article is with aggregated output measure and 0 if single output
Number of inputs ( $x_{7i}$ )	Number of inputs in a primary study
Functional form ( $x_{8i}$ )	Equal to 1 if article used Cobb-Douglas functional form and 0 if Translog functional form
National_dummy ( $x_{9i}$ )	Equal to 1 if article is conducted in Tigray, Amhara, Oromiya and South regions and 0 otherwise
South_dummy ( $x_{10i}$ )	Equal to 1 if article is conducted in South region only and 0 otherwise
Amhara_dummy ( $x_{11i}$ )	Equal to 1 if article is conducted in Amhara region only and 0 otherwise
Oromiya_dummy ( $x_{12i}$ )	Equal to 1 if article is conducted in Oromiya region only and 0 otherwise
Tigray_dummy	Equal to 1 if article is conducted in Tigray region only and 0 otherwise (reference)
Dummy_1990s ( $x_{13i}$ )	Equal to 1 if article is conducted in the 1990s and 0 otherwise
Dummy_2000s ( $x_{14i}$ )	Equal to 1 if article is conducted in the 2000s and 0 otherwise
Dummy_2010s	Equal to 1 if article is conducted in the 2010s and 0 otherwise (reference)

**Table 2.** Summary statistics for the moderator variables used in meta-regression model.

Category	Moderator variables	Number of case studies	Number of observations	Mean technical efficiency	Standard deviation
All case studies	-	45	50	0.7085	0.1159
Functional form	Cobb-Douglas	39	44	0.7171	0.1160
	Translog	6	6	0.6448	0.1029
Product	Wheat	12	13	0.7311	0.1133
	Maize	8	8	0.7622	0.0831
	Food crops	37	41	0.7029	0.1172
Output measures	Aggregated output	12	14	0.6759	0.0948
	Single output	33	36	0.7211	0.1220
Region	All four region (National)	5	8	0.6979	0.1340
	Tigray	4	4	0.7537	0.1007
	Amhara	12	12	0.6901	0.1478
	Oromiya	23	24	0.7182	0.1027
	South	4	4	0.6785	0.0392
Publication	Journal	26	31	0.6867	0.1318
	Thesis	19	19	0.7439	0.0743
Data year	Dummy_1990s	6	7	0.6513	0.0908
	Dummy_2000s	13	16	0.7254	0.0985
	Dummy_2010s	25	25	0.7155	0.1328

**Egger test.**

Funnel plots are commonly used to investigate

publication and related biases in meta-analysis (Sterne and Harbord, 2004). Funnel plots are a visual tool for

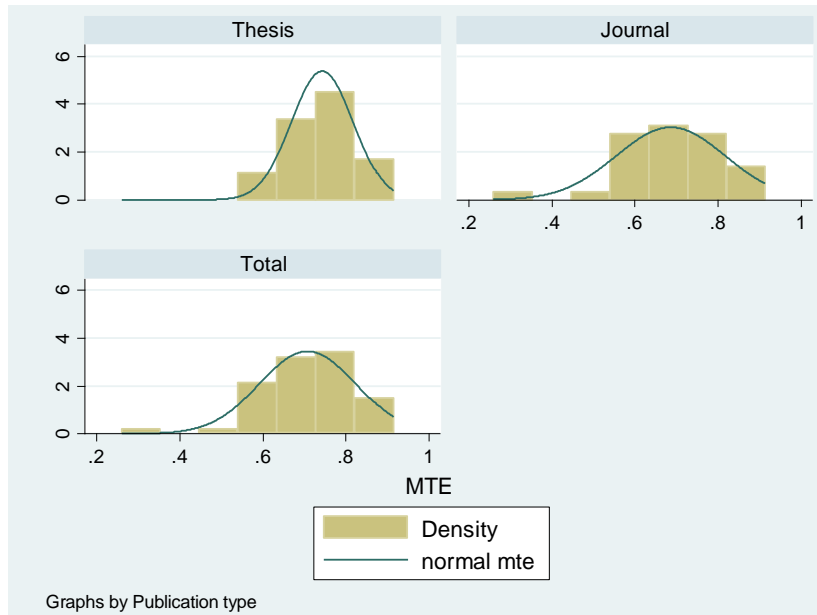


Figure 1. Distribution of mean technical efficiency.

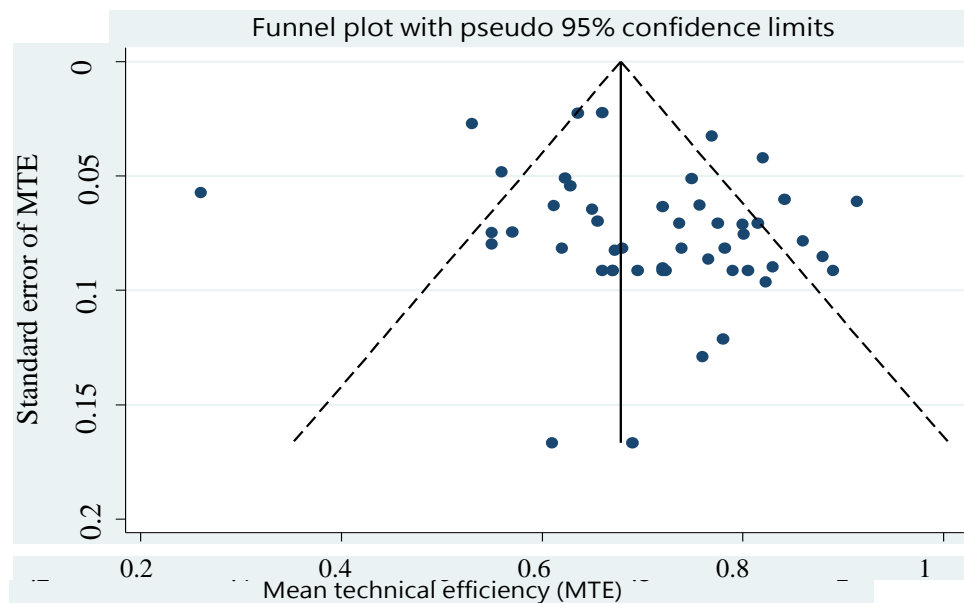
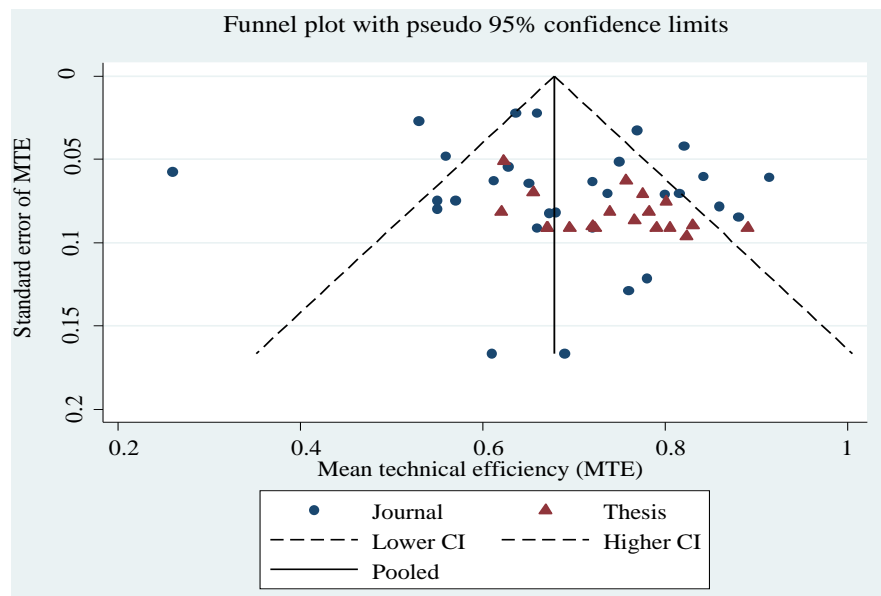


Figure 2. Funnel plot.

investigating publication and other bias in meta-analysis. They are simple scatter plots of the treatment effects estimated from individual studies (horizontal axis) against a measure of study size (vertical axis) or some other indicator of the precision of the estimate like standard deviations, inverse standard error or inverse variance (weight). Standard error is likely to be the best choice for the vertical axis (Sterne and Egger, 2001). Asymmetry in funnel plots may indicate publication bias. Figure 2 shows

the funnel plot for the mean technical efficiencies of the sampled studies. It is found to be asymmetric.

Figure 3 shows the funnel plot stratified by publication type. As shown in Figure 3, compared to studies published in journals, theses' studies show some asymmetry. Whereas the majority of the confidence intervals are from studies published on journals. This implies the main source of the heterogeneity came from studies published on journals.



**Figure 3.** Funnel plot stratified by publication type.

**Table 3.** Regression model for publication bias.

MTE	Coef.	Std. Err.	t
Sample size	-0.0000547	0.0000372	-1.47
_cons	0.7257538	0.0226482	32.04***

### Significance tests for publication bias

In Table 3, though the association between the mean technical efficiency estimates and sample size is found to be negative, the regression model result shows that the effect of sample size on mean technical efficiency is not significant. This suggests the absence of publication bias. The economic interpretation of the result is that, as sample size increases, the mean reported ATE from all the selected studies tends to approach 0.725.

Henceforth, these tests show that the selected frontier studies used in the Meta regression analysis can be relied on as a close or true representation of the distribution of technical efficiency in Ethiopian agriculture for further analysis.

### Detecting heterogeneity among studies

Heterogeneity in meta-analysis refers to differences in underlying effects, so that estimates are more variable across studies than would be expected by chance alone. Heterogeneity can be graphically explored using forest plot. In this study to identify heterogeneity, forest plot is used. A forest plot provides at a glance a complete visual

summary of results from individual studies included in the meta-analysis. Figure 4 also present the forest plot with 49 observations. The squares in the plots represent the mean technical efficiency estimated in each of the 49 observations, with the area of each square proportional to the studies weight in the meta-analysis. Figure 4 presents the forest plot for the mean technical efficiency for each study by publication type (that is, journal or thesis) using the random effect meta-analysis model. As shown in Figure 4, those studies published on journals have an average mean technical efficiency less than the unpublished studies (Theses). Besides, the forest plot portrays studies published in journals are more heterogeneous ( $I^2=82.4\%$ ) while studies not published (Theses) are relatively homogenous. Hence, this makes the overall meta-analysis average mean technical efficiency estimate to be substantially heterogeneous ( $I^2=75\%$ ) due to the heterogeneity of the published studies. Figure 5 shows the forest plot using the fixed effect model. Both results yield different estimates.

### Moderator analysis: Meta-regression (MRA)

First, the study attempts to provide the first research

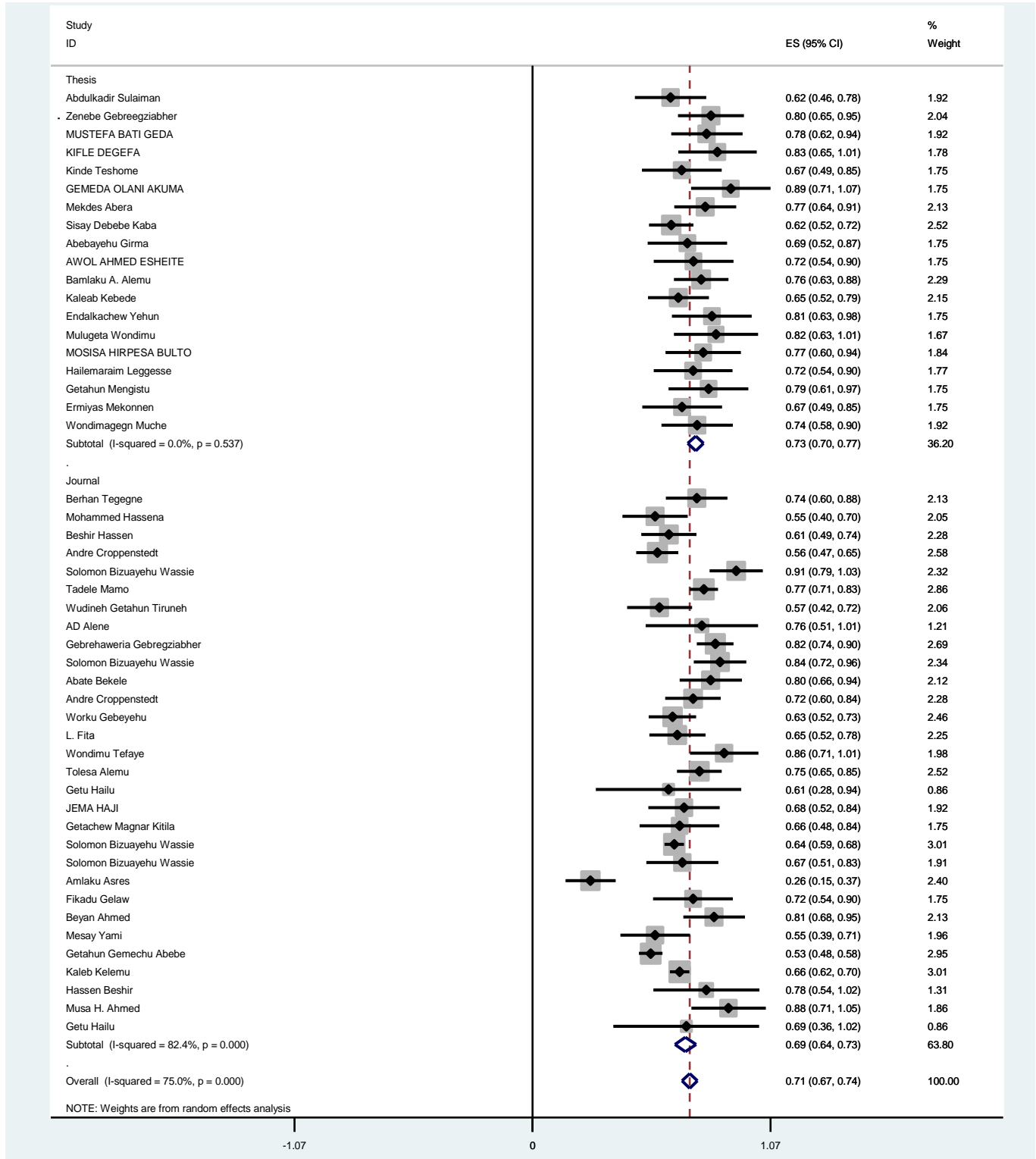


Figure 4. Forrest plot stratified by publication: Random effect.

question using the bubble plot with a fitted line of the relationship between the reported mean technical efficiency estimates and the year of survey in primary

study. Figure 6 shows a positive linear relationship between reported mean efficiency estimates per study and year of survey for the whole sample under



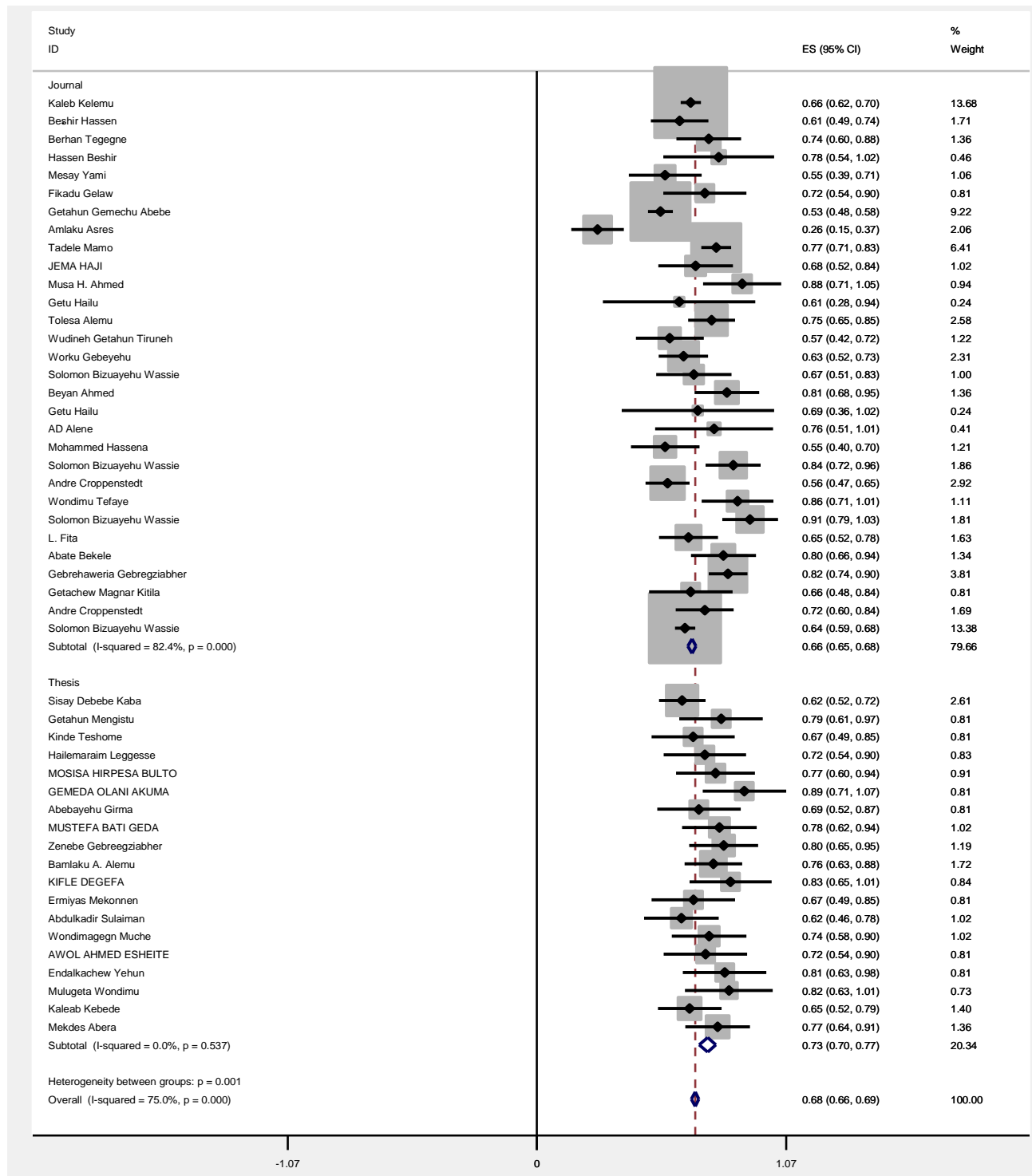
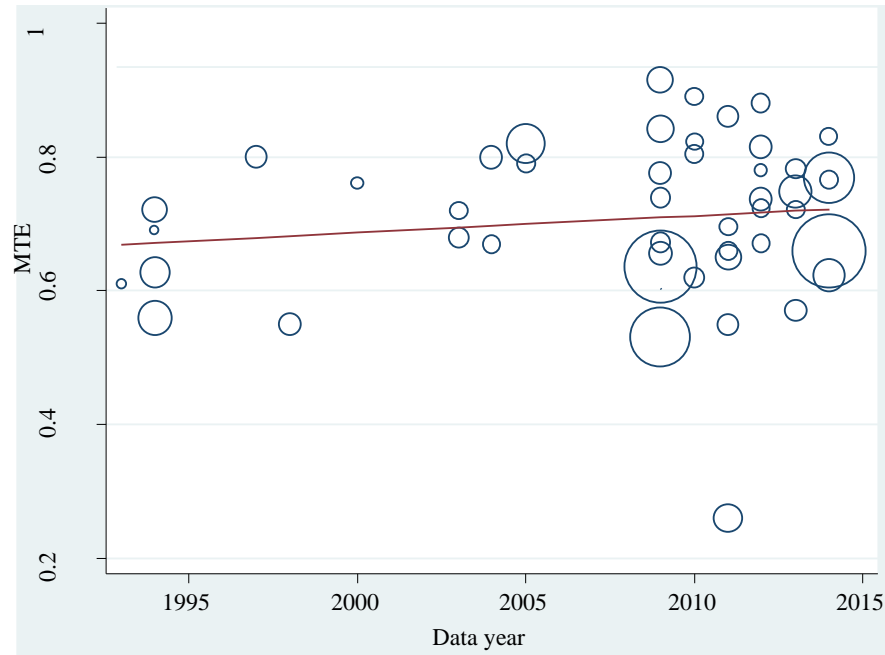


Figure 5. Forrest plot stratified by publication: Fixed effect.

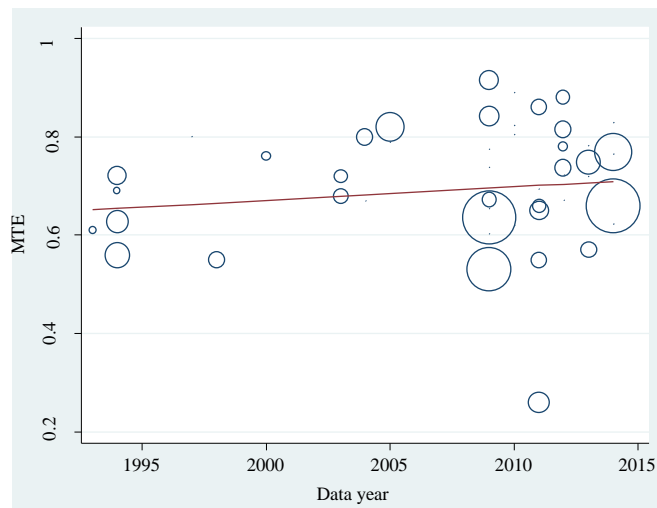
consideration. However, when the relationship is stratified by publication type and pooled plot for each group are displayed (that is, by Journals and Thesis) presented in Figures 7 and 8, the results are mixed. The results reveal evidence of linear positive correlation for journal studies

and negative linear correlation for thesis studies. However, the regression result using only single covariates yields non-significant results. Henceforth, this result might be inconclusive.

Subsequently by including other study characteristics



**Figure 6.** “Bubble plot” with fitted meta-regression line for the whole sample.

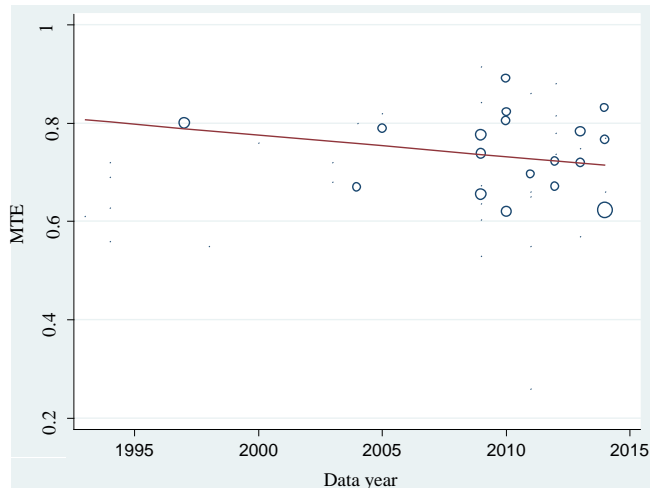


**Figure 7.** Bubble plot with fitted meta-regression for the published journals.

variables, a further investigation of the relationship between the estimates of the mean technical efficiency and year of survey using the meta-regression analysis was conducted using fractional regression model. For this, the study estimated five different models to enhance robustness for the variable data year particularly and for the all moderator variables employed generally. Ogundari (2014) employed five different models in meta-analysis study of technical efficiency in Africa to provide robustness check especially for the variable data year of

the primary studies. The results of all the five fractional regression models are presented in Table 4. With regard to the models, model 1 is employed for all the moderator variables. While the rest models are estimated by stratifying with the national variable (model 2 for studies conducted in all the four regions, that is, Tigray, Amhara, Oromiya and South and model 3 for studies conducted either of the four regions) and publication type (that is, journal studies and thesis studies).

Among the results of the models, only model 3 shows a



**Figure 8.** Bubble plot with fitted meta-regression for the theses.

negative significant result for the relationship between data year and mean technical efficiency estimates, suggesting that the mean technical efficiency estimates from the selected primary case studies decrease significantly, as survey in the primary study increases for studies conducted on all the four regions. The plausible explanation for this might be that on average, the efficiency levels of Ethiopian agriculture and food production have declined over the years (1993-2014). This finding is consistent with study by Ogundari (2014) who obtained the mean efficiency estimates from studies that decrease significantly as year of survey in the primary study increases. However, this result is not robust and should be taken in caution. First sample size of the selected primary studies conducted for all the four regions is small and is not found significant in the rest of the models.

With regard to the effects of the other study's characteristics on the reported efficiency estimates, we again take a closer look at the results of the five models presented in Table 4. As per the results, more or less a similar significant pattern was obtained for models 1, 2, 4 and 5 while model 3 is different a little bit.

Studies with a focus on wheat crops reported significantly higher efficiency estimates, compared to other crops and livestock studies on models 1, 2 and 4. The plausible explanation for this might be in relation to other crops and livestock; smallholder farmers have more access to improved wheat technologies and extension services than other crops and livestock. While studies with a focus on maize crops reported significantly lower mean efficiency estimates for models 3 and 5 and higher mean efficiency for model 4 as compared to studies with other crops and livestock.

The findings show that studies with a focus on food crops reported significantly lower efficiency estimates, compared to other crops and livestock studies for models

2 and 5, while model 3 yields a positive significant effect on efficiency estimates. A study by Ogundari (2014) showed that studies on food crop were found to have insignificantly lower mean efficiency estimates compared to studies on non-food crops. By contrast, studies on cash crops were found to have higher and significant efficiency estimates (Ogundari and Brummer, 2011). But similar to the finding of the present study, Bravo-Ureta et al. (2007) found consistently lower mean efficiency scores for studies on grain crops.

With regard to region or location effect, the empirical results show that South (models 2 and 3), Amhara (models 4 and 5) and Oromiya (model 2) regions report significantly lower mean efficiency estimates, while studies carried out in all the four regions (National\_dummy) show insignificantly lower mean efficiency estimates compared to Tigray region. This suggests that regional differences to some extent play a significant role in the systematic heterogeneity that exists in the reported mean efficiency estimates based on specific attributes in the study.

The mean technical efficiency estimates of studies using an aggregated dependent variable (Output type) appears to be higher as compared to studies with non-aggregated output measures according to the result of model 2; but this result is in conflict with the result of model 3.

The regression model also revealed that the studies published on journals have a significant negative impact on the reported mean technical efficiency estimates for model 2 but it was found insignificant for the rest of the models. This implies that compared to the thesis studies (unpublished), studies published on journals yield lower mean technical efficiency estimates. This result is in contrast with the finding of Ogundari (2014).

Furthermore, it is observed that input size (number of inputs) of the selected studies has a significant positive impact on the reported mean technical efficiency estimates across all the models with the exception of model 3. A similar finding was observed by Bravo-Ureta et al. (2007) and Ogundari (2009).

The study also obtained that the mean technical efficiency of studies surveyed between 2000 and 2009 years was significantly lower as compared to that of studies conducted between 2010 and 2014 (reference) for the model 5; while this result is insignificant for models 1, 2, 3 and 4. This implies technical efficiency estimates decreased over the years 2000 to 2014.

## Conclusions

This study represents the first attempt to use a meta-analysis to examine the mean technical efficiency estimates in Ethiopian agriculture. It investigates whether Ethiopian agricultural efficiency levels have been improving or not as well as the variation of the reported mean technical efficiency estimates by different

**Table 4.** Meta-regression results.

Moderator variable	Total (Model 1)	Tigray, Amhara, Oromiya and South (Model 2)	National (Tigray, Amhara, Oromiya and South) (Model 3)	Journal (Model 4)	Thesis (Model 5)
	Coef.	Coef.	Coef.	Coef.	Coef.
Wheat	0.3430* (0.2029)	0.8082*** (0.1835)	0.4110 (0.4240)	0.5266** (0.2137)	-0.0031 (0.1415)
Maize	0.2599 (0.2053)	0.1120 (0.1864)	-2.2850*** (0.7820)	0.7209 (0.27689)	-0.4949*** (0.1100)
Publication type	-0.1358 (0.2053)	-0.4024*** (0.1530)	-	-	-
Sample size	-0.0004* (0.0002)	-0.0015** (0.0007)	0.0016** (0.0007)	-0.0004 (0.0003)	-0.0026*** (0.0003)
Food Crop	-0.0432 (0.2462)	-0.5108*** (0.19701)	2.1739*** (0.7767)	0.2636 (0.2608)	-0.9274*** (0.1182)
Data year	-0.0264 (0.03645)	0.0158 (0.0423)	-0.2590*** (0.0637)	-0.0231 (0.0658)	-0.0600 (0.0414)
Output type	-0.0776 (0.2361)	0.6042*** (0.2296)	-3.5366*** (0.9206)	-0.4495 (0.2876)	-0.2800 (0.6292)
Number of inputs	0.3331*** (0.1070)	0.3006*** (0.0832)	-	0.3429** (0.1489)	0.12697*** (0.0314)
Functional form	0.2352 (0.2091)	0.0698 (0.1682)	-	0.3489 (0.2521)	-
National_dummy	0.1289 (0.4045)	-	-	-0.3547 (0.4140)	-
South_dummy	-0.1908 (0.2296)	-0.5738*** (0.1540)	-	0.5607 (0.6425)	-0.6986*** (0.0753)
Amhara_dummy	-0.3682 (0.2254)	-0.2903 (0.1893)	-	-1.1712** (0.5854)	-0.3004* (0.1627)
Oromiya_dummy	-0.0996 (0.1897)	-0.3001* (0.1652)	-	-0.3525 (0.5026)	-
Dummy_1990s	-0.3514 (0.5479)	0.1585 (0.6459)	-	-0.0258 (1.0971)	-
Dummy_2000s	-0.1176 (0.3519)	-0.1475 (0.3476)	-	0.2334 (0.6241)	-0.2729** (0.1312)
_cons	52.3641	-31.3604	519.0151*** (127.4074)	45.4867 (132.2933)	122.7375 (83.2285)
Log pseudolikelihood	-16.7900	-13.2327	-3.1357	-11.6967	-4.8049
AIC	1.5614	1.6608	1.7839	1.7722	1.9700
BIC	-95.5701	-66.3846	-8.1680	-49.4888	-12.8128

characteristics which included: survey year, year of publication, functional form used, sample size, number of inputs used, location of the study, product type and output measure. The study employed fractional regression to model for the meta-regression analysis. The result of the study shows there is no publication bias in Ethiopian agricultural efficiency studies. The meta-analysis result shows the overall mean technical efficiencies are 68 and 71% based on fixed effect model and random effect model, respectively, suggesting that there are still opportunities for improvement in the efficiency of Ethiopian agriculture. The result also shows that technical

efficiency was found to be decreasing over years for studies carried out in all the four regions together (Tigray, Amhara, Oromia, and South). Overall, the study obtained moderator variables (that is, wheat, maize, sample size, food crop, number of inputs) significantly affecting the estimation of the reported mean technical efficiencies in primary studies across the four meta-regression model specifications.

The finding of the decline in technical efficiency over years implies that even though there is a scope of improving efficiency in the country with the available agricultural technologies, government should also consider side by side introduction and

dissemination of new agricultural technologies to reverse the decreasing technical efficiency. This will ultimately boost the country's agricultural and food production.

Besides, the results call upon researchers and academicians to be curious in identifying study-specific attributes, which are essential for modeling farm-level efficiency.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

## REFERENCES

- Abebe G (2014). Off-Farm Income and Technical Efficiency of Smallholder Farmers in Ethiopia - A Stochastic Frontier Analysis. Master's thesis, Swedish University of Agricultural, Uppsala.
- Ahmed HM, Lemma Z, Endrias G (2014). Technical Efficiency of Maize Producing Farmers in Arsi Negelle, Central Rift Valley of Ethiopia: Stochastic Frontier Approach. *Agriculture and Forestry* 60(1):157-167.
- Aigner D, Lovell CAK, Schmidt P (1977). Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics* 6:21-37.
- Asres A, Johann S, Wurzing M (2013). Innovation and Technical Efficiency in the Smallholder Dairy Production System in Ethiopia. *Journal of Agricultural Science and Technology B*. 3(3):151-164.
- Begg CB, Mazumdar M (1994). Operating Characteristics of a Rank Correlation Test for Publication Bias. *Biometrics* 50(4):1088-1101.
- Bravo-Ureta BE, Solís D, Moreira V, Maripani J, Thiam A, Rivas T (2007). Technical efficiency in farming: a meta-regression analysis. *Journal of Productivity Analysis* 27:57-72.
- Card NA (2012). *Applied Meta-Analysis for Social Science Research*. (Todd D. Little, Ed.). New York, London: The Guilford Press.
- Egger M, Smith GD, Schneider M, Minder C (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 315:629-634.
- Farrell MJ (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society* 120(3):253-290.
- Meeusen W, Broeck JVD (1977). Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review* 18(2):435-444.
- Odeck J, Bråthen S (2012). A meta-analysis of DEA and SFA studies of the technical efficiency of seaports: A comparison of fixed and random-effects regression models. *Transportation Research Part A*. 46(10):1574-1585.
- Ogundari K (2009). A Meta-Analysis of Technical Efficiency in Nigerian Agriculture. In *International Association of Agricultural Economists Conference*. Beijing.
- Ogundari K (2014). The Paradigm of Agricultural Efficiency and its Implication on Food Security in Africa: What Does Meta-analysis Reveal? *World Development* 64(1920):690-702.
- Ogundari K, Brümmer B (2011). Technical efficiency of Nigerian agriculture A meta-regression analysis. *Outlook on Agriculture* 40(2):171-180.
- Stanley TD (2005). Beyond Publication Bias. *Journal of Economic Surveys* 19(3):309-345.
- Sterne JAC, Egger M (2001). Funnel plots for detecting bias in meta-analysis: Guidelines on choice of axis. *Journal of Clinical Epidemiology* 54(2001):1046-1055.
- Sterne JAC, Harbord R (2004). Funnel plots in meta-analysis. *The Stata Journal* 4(2):127-141.
- Tefaye W, Beshir H (2014). Determinants of Technical Efficiency in Maize Production: The Case of Smallholder Farmers in Dhidhessa District of Illuababora. *Journal of Economics and Sustainable Development* 5(15):274-285.
- Thiam A, Bravo-ureta BE, Rivas TE (2001). Technical efficiency in developing country agriculture: a meta-analysis. *Agricultural Economics* 25:235-243.
- Yami M, Solomon T, Begna B, Fufa F, Alemu T, Alemu D (2013). Source of technical inefficiency of smallholder wheat farmers in selected waterlogged areas of Ethiopia: A translog production function approach. *African Journal of Agricultural Research* 8(29):3930-3940.

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