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The Maize Journal is published half yearly by the Maize Technologists Association of India. The Journal publishes papers based on the results of original research on maize and related issues in the following areas:

i. **Crop Improvement**

ii. **Crop Production**

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REVIEW PAPER

Nutritional and medicinal importance of corn silk in human health

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Abstract: Corn silk is an unique byproduct of maize which can provide countless advantages for human health and serve as a source of income. Corn silk contains many bioactive compounds including proteins, carbohydrates, vitamins, minerals, volatile oils, steroids, flavonoids alkaloids, and phenolic compounds which perhaps are responsible for the potential health benefits. Several corn silk-derived extracts and bioactive constituents have been demonstrated to exhibits antidiabetic, anti-hyperlipidaemic, anti-obesity, anticancer, anti-hepatotoxicity, anti-nephrotoxicity, antidepressant, anti-inflammatory and antimicrobial effects. Several studies have demonstrated the therapeutic potential of corn silk extract against several diseases including diabetes, cancer, obesity, Alzheimer's disease, cardiovascular diseases, kidney disease and liver diseases. The corn silk powder has potential to contribute to the alleviation of dietary nutritional deficiencies and can be utilized in preparation of various traditional and snack products to enhance their nutritive values. Corn silk can help in value addition of the products as well as provide low-cost nutritious alternatives for combating malnutrition. Use of corn silk will lead to valorization of agricultural residue via waste utilization which increases farmer income as well as reduce environmental pollution due to agricultural wastes. There is a great need to strengthen research, testing, and product development activities for the proper, effective, and safe utilization of corn silk.

Keywords: Agricultural wastes · Corn silk · Diseases · Healthcare · Nutritional value

Introduction

Corn *(Zea mays)* hair or commonly known as corn silk (a thread which is soft, fine, yellowish color with mild sweetish taste) is a collection of the stigmas from the female flowers of maize plant. It is a rich source of proteins, vitamins, carbohydrates, fixed and volatile oils, sitsterol, stigma sterol, alkaloids, saponins, tannins and flavonoid. It can be used as dietary fibre and as a food additive for the prevention of several chronic diseases (Hasanudin *et al.,* 2012). Corn silk is a well-known traditional herb that has been used for treatment of varied diseases such as treating obesity, weight loss, immune enhancement, anti-cancer, anti-diabetic activity, regulation of blood sugar, kidney diseases, gastrointestinal and liver diseases. (Du *et al.*, 2007). In China, corn silk is well known as an important traditional Chinese medicine in treating several illnesses related to kidney (Zhao *et al.*, 2012), treatment of edema, cystitis, gout, treat rheumatism, rheumatoid arthritis and exert antimicrobial effects (Amreen *et al.*, 2012; Chen *et al.*, 2013). Decoction of the maize silk is useful for bladder problems, nausea, vomiting, and stomach complaints (Das and Karjagi, 2022). Recently Corn silk is gaining much interest in Asian and African countries particularly due to its several health promoting effects. Thus corn silk can be used for formulation of nutritious health food product as well as can useful in generation of additional income to farmers. The present review principally examine various experimental reports and highlights the potential health promoting effects of corn silk against chronic and age-linked diseases with emphasis on liver and kidney diseases,

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antidiabetic, anticancer, antibacterial, antifungal and antiviral effects.

Nutraceutical properties of corn silk

Corn silk contains nutritional elements that are essential for human health such as carbohydrate, protein, lipids, vitamins, and minerals (Guo *et al.*, 2009). In addition to these, Corn silk contains various phytochemicals including vitamins, alkaloids, tannins and mineral salts, steroids and flavonoids as well as other volatile chemicals and phenolic compounds with potential health promoting effects (Kwag, 1999). The dried cornsilk is the richest source of protein and dietary fibre (TDF). Also it has the higher percentage of ash and total sugar content (40.60 mg/100 g *i.e*. Fructose 14.2 ± 0.12%, Glucose 22.2 ± 1.10% and Sucrose 4.40 ± 0.20%). The energy value ranged from 361 to 390 kcal/100g. The concentrations of different nutrition's, minerals, total polyphenol and flavonoid in corn silk are given in Table 1, 2 and 3 (Nurhanan and Wan Rosli, 2012 & 2013).

Corn silk is a good source of antioxidant content, which provides quality and nutritional value, as well as anti-inflammatory, antidiabetic, antiviral and antioxidant properties and are important for human fitness. These antioxidants include polyphenolic compounds, flavonoids, and ascorbates. Different sterols found in corn silk are 24-methylcholesterol, 24-ethyl-5, 22-cholestadien-3β-ol, 24-ethylcholesterol and (28Z)-24-ethylidenecholesterol (Knights and Smith, 1976). Maksimovic *et al.*, (2004) reported that corn silk extract contains a mixture of stigmasterol and sitosterol in the ratio of 4:1 and sitosteroline (β-sitosteryl-3-O-β-*D*-glucoside). Elliger *et al.*, (1980) reported a flavonoid compound that known as c-glycosylflavones was isolated from methanol extract of corn silk. Snook *et al.* (1995) isolated the compounds 2"-*O*-α-L-rhamnosyl-6-C-quinovosylluteolin, 2"-*O*-α-L-rhamnosyl-6-Cfucosylluteolin, and 2"-*O*-α-L-rhamnosyl-6-C-fucosyl-3'-methoxyluteolin from the cornsilk extracts. The flavones identified by Zhang and Xu (2007) in cornsilk (water extract) are 7-hydroxy-4'- methoxyisoflavone and 2"-O-α-L-rhamnosyl-6-C-(6-deoxy-ax-5-methyl-xylo-hexos-4-ulosyl)-3' methoxyluteolin. Two flavone glycosides, isoorientin-2-2"-O-α-L-rhamnoside and 3'-methoxymaysin, were also isolated from the ethanol extract of corn silk (Liu *et al.*, 2011). The flavonoid, 3'-methoxymaysin and reduced derivatives of maysin have been isolated and identified from corn silks of several corn inbreeds. The 3-hydroxyanthocyanins occur in almost all corn plant parts, but the 3-deoxyanthocyanins is only found in corn silk (Halbwirth *et al.*, 2003). Five other flavonoid derivatives were isolated from CS ethanol extract (80%) and identified as 2"-*O*-α-L-rhamnosyl-6-C-3"-

Table 1. Nutritional compositions of corn silk

Nutritional compounds	Corn silks	
	Immature silks	Mature silks
[1]Moisture (fresh)	89.31 ± 0.74	84.42 ± 0.65
[2]Moisture (oven-dried)	4.15 ± 0.21	3.90 ± 0.22
[2]Crude lipid	1.27 ± 0.16	0.66 ± 0.17
[2]Crude protein	12.96 ± 0.38	8.95 ± 0.21
[2]Ash (%)	5.28 ± 0.13	5.51 ± 0.24
[3]Carbohydrate	27.80 ± 2.25	29.74 ± 1.26
[2]Total dietary fiber (g/100 g)	48.50 ± 2.88	51.24 ± 1.50

[1] Moisture content determined by fresh weight.

[2] Dry basis.

[3] Calculated by difference [=100–(crude lipid + crude protein + TDF + ash + moisture)].

Table 2. Mineral contents of corn silk

Minerals level (μg/g)	Corn silks	
	Immature silk	Mature silk
Macro elements		
Calcium (Ca)	1087.08 ± 105.51	707.04 ± 94.41
Magnesium (Mg)	1219.17 ± 143.07	361.50 ± 20.53
Potassium (K)	26281.67 ± 1379.7	35671.67 ± 2466
Sodium (Na)	190.67 ± 22.61	266.67 ± 15.65
Minor elements		
Copper (Cu)	5.60 ± 0.4	4.12 ± 0.38
Iron (Fe)	2.17 ± 0.15	4.50 ± 0.49
Manganese (Mn)	32.17 ± 3.14	35.57 ± 2.26
Zinc (Zn)	46.37 ± 4.21	35.92 ± 4.24

Table 3. Total polyphenol and flavonoid content of silks from immature and mature corns

Extract	Immature silks (mean + SD)	Mature silks (mean + SD)
Total polyphenol (mg GAE/g extract)		
Water	35.35 ± 2.17	64.22 ± 2.55
Ethanol	92.21 ± 3.59	49.88 ± 2.87
Ethyl acetate	6.70 ± 0.51	4.96 ± 0.53
Total flavonoid (mg CAE/g extract)		
Water	8.40 ± 0.48	2.31 ± 0.12
Ethanol	7.55 ± 0.37	1.96 ± 0.20
Ethyl acetate	0.66 ± 0.02	2.10 ± 0.19

deoxyglucosyl-3'-methoxyluteolin, 6,4'-dihydroxy-3'-methoxyflavone-7-*O*-glucosides, ax-5"-methane-3'-methoxymaysin, ax-4"-OH-3'-methoxymaysin and 7,4'-dihidroxy-3'-methoxyflavone-2"-*O*-α-L-rhamnosyl-6-C-fucoside (Ren *et al.*, 2009). Ascorbic acid is required for a variety of physiological processes as well as acting as a powerful antioxidant in the battle against diseases caused by free radicals (Alam, 2011; Pisoschi *et al.*, 2009). The vitamin C content of corn silk powder was reported to be high as 270±0.57 mg/100 g, (Singh *et al.*, 2022) which is significantly higher than the 9.72 mg/100 g reported by El-Kewawy (2018). In addition to the above phytochemicals, corn silk contains saponins, which are characterized by their structure containing a triterpene or steroid aglycone and one or more sugar chains. Consumer demand for natural products coupled with their physicochemical (surfactant) properties and mounting evidence on their biological activity (such as anti-cancer and anti-cholesterol activity) has led to the emergence of saponins as commercially significant compounds with expanding applications in food, cosmetics, and pharmaceutical sectors (Güclü-Ustündag and Mazza, 2007). In the field of cosmetics, many different products are made up from corn silk including cream, powder, liquid, capsules, gel, tincture or tea. For instance, to make skin look and feel healthy, skin brightening powder of cornsilk used, this powder contains the unique bio-active complex formulated with vitamins and botanicals, excellent as a highlighter, brightens and minimize the appearance of pores.

Medicinal importance of corn silk in health benefits

Corn silk is used as a medicine for centuries and is categorized as medicinal herb by practitioners of traditional medicine in many countries. It has long been used for treatment of several health problems such as kidney stones, nephritis, blood pressure, diabetics, cystitis, edema, gout, urinary infection etc in several countries. In Dominican Republic it is used to treat fibroids and to reduce cramps when combined with other plants (Ososki *et al.*, 2002). In Jordan, cornsilk is prescribed by some herbalists for treating cold and constipation as well as moderately used to treat kidney stones, oedema and obesity (Abu-Irmaileh and Afifi, 2003). According to an ethnobotanical survey in certain parts of Iranian provinces, corn silk is used to treat infections of urinary system (Mosaddegh *et al.*, 2012). Corn silk is very well known as an important traditional Chinese medicine in treating several illnesses related to kidney. It has been used to treat oedema, cystitis, gout, prostatitis and as antimicrobial agent (Velazquez *et al.*, 2005). Cornsilk has also been used to treat rheumatism and rheumatoid arthritis ailments (Maksimovic and Kovacevic, 2003). India has large diversity of plant resources that are very useful in the early middle ages to treat various types of ailment (Middha *et al.*, 2012). Many researchers demonstrated its effectiveness and suggested for treatment of different diseases and metabolic disorders as follows.

Diuretic activity and in treatment of kidney diseases

The potential of corn silk as a diuretic agent is first reported by Caceres *et al.* (1987). It is observed that a combination of aqueous extract of corn silk with *T. terrestris* resulted in similar diuresis effect as in *T. terrestris* aqueous extract alone (Al-Ali *et al.*, 2003). Pinheiro et al (2011) conducted in-vivo experiment and demonstrated the diuretic effect of corn silk. Effectiveness of cornsilk as a cure for kidney-related problems in traditional medicine has been shown by several scientific findings which support the use of corn silk as a diuretic remedy. Corn silk treatment reduced lipid peroxidation there by attenuating kidney oxidative stress and increasing the activity of antioxidant enzymes like SOD and enhances renal function (Yulina *et al.*, 2013). Sukandar *et al.* (2013) reported that corn silk and binahong leaves could improve kidney function in rat model of kidney failure. Combination of the half dose of each extract found significant improvement in functioning of the kidney. Corn silk has been used as a diuretic agent for treatment of kidney stone and urinary tract diseases (Aukkanita *et al.*, 2015). The CKD (Chronic Kidney Disease) is basically a common kidney disease, where patients will have gradual reduction of kidney function and over time damage kidneys. In addition to the effects on kidneys, this disease also increases the risk of having heart and blood vessels diseases. For its treatment, corn silk is usually prescribed in the form of corn silk tea. Corn silk tea has the function of increasing the urine output and removes the excess fluid out, which can help remove the toxins and wastes out, hence reducing creatinine level and can help relieve the swelling. In addition, High blood pressure, being the most prominent symptom, is also reduced with the help of corn silk tea (Vijitha and Saranya, 2017).

Anti-hyperglycaemic and anti-diabetes effect

Diabetic mellitus (DM) is a leading chronic metabolic disease worldwide that is associated with the abnormal functioning of the hormone insulin and often induces many serious complications and diabetic nephropathy. It is a complex metabolic disease characterized by hyperglycemia resulting from defects in insulin secretion, insulin action, or both (Ibrahim *et al.,* 2016). As a folk medicine, Corn silk was used to treat DM due to its anti-diabetic potential. In 2009, Guo *et al.* reported that the corn silk extract causes reduction of blood glucose level in hyperglycaemic mice i.e. blood glucose level was decreased at higher doses of corn silk (4.0 g/kg body weight, BW). The level of serum insulin increased (9.8 ± 0.5 µU/mL) after being given 4.0 g/kg body weight of corn silk extract. After studied several parameters such as blood glucose, glycohaemoglobin (HbA1c), insulin secretion, pancreatic β-cells damage, hepatic glycogen and gluconeogenesis in the hyperglycaemic mice they concluded that the effect of cornsilk extract on glycaemic metabolism is via increasing insulin level and recovery of β-cells. Cornsilk polysaccharides exhibited anti-diabetic effect on streptozotocin (STZ)-induced diabetic rats (Zhao *et al.*, 2012). Corn silk inhibits α-amylase activity and slow down starch digestion rate and restrained the increase of post-meal blood sugar (Chen *et al.,* 2013). Chen and Guo (2018) reported that corn silk exhibit beneficial effect on glycemic metabolism through enhance insulin secretion whereby the augment of insulin level and recovery of â-cells possible through which corn silk control hyperglycemia. Pan *et al.* (2019) reported intake of corn silk polysaccharide increase serum insulin secretion and recover glucose intolerance in type 2 diabetics. Wang and Zhao (2019) suggested corn silk traditional use in the effective management of diabetic mellitus (DM) and diabetic nephropathy (DN). Thus, corn silk can be a potential bioactive agent for the effective management and treatment of diabetes mellitus.

Antihyperlipidemic, anti-obesity and antihypertensive effect

Obesity has become a major public health problem now a day which is associated with health conditions such as diabetes, cardiovascular disease, hypertension, cancer, reduced life expectancy, and poor cognition and motor control (Bray, 2004; Wang *et al.,* 2016). High-fat diets and frequent feeding of it contribute to elevating the triglycerides (TG) levels all day long, exposing the large quantities of atherogenic TG-rich lipoproteins that can penetrate and reside in the sub-endothelial space, contributing to foam cell formation and promoting lipid accumulation in the vessel wall which promotes endothelial cell (EC) activation and atherosclerosis (Yin *et al.,* 2015), one of the factors that triggered hypertension, cardiovascular disease, and stroke. Atherosclerotic cardiovascular disease (ASCVD) is the leading cause of death and it has been confirmed that increased low-density lipoprotein cholesterol (LDL-C) is an independent risk factor for atherosclerosis. Recently, evidence has shown that hypertriglyceridemia is associated with incremental ASCVD risk (Peng *et al.,* 2017). Yan *et al.* (2011) reported that flavonoids from cornsilk exhibit antihyperlipidemic effects and protect against atherosclerosis. High maysin corn silk extract inhibits adipocyte differentiation through inhibition of C/EBP-â and PPAR-ã AMPK expression in adipose tissue, inhibits expression of CD-36, AP-2, and LPL related to fat accumulation in adipose tissue, inhibits expression of ACC-1, GPAT-1, G6PDH, FAS, SCD-1, SREBP-1c, and PDK-4 related to fat synthesis, and increases expression of AMPK, CPT-1, and HSL related to lipolysis and fatty acid oxidation to reduce body fat, consequently reducing body weight in experimental animals (Lee *et al.* 2016). The Low-density lipoprotein (LDL) or the “bad” cholesterol, can gradually build up in the arteries (the blood vessels that carry blood throughout the body) and, over time, cause heart diseases and stroke. On the other hand, high levels of HDL (High-density lipoprotein), or “good” cholesterol, protect the heart by helping to remove the build-up of LDL from the arteries. The combination of high levels of triglycerides with low HDL and/or high LDL cholesterol levels can increase the risk of heart problems, such as heart attacks. Wu *et al.* (2017) reported that the flavonoid from corn silk extract reduces the serum total cholesterol (TC), triglyceride (TG), and low-density lipoprotein cholesterol (LDL-c) levels without any effect on High-density lipoprotein cholesterol (HDL-c) level. Cornsilk has been consumed regularly as a decoction in order to treat high blood pressure (Ong and Nordiana, 1999). George and Idu (2015) reported that corn silk aqueous extract exhibits an antihypertensive effect by lowering of blood pressure.

Anti-oxidative and anticancer effect

Corn silk has been used traditionally as a medicine for its antioxidant properties due to the presence of flavonoids, alkaloids, phenols, steroids, glycosides, and tannins in it. According to an experimental study, photochemical constituents, free radical scavenging activity and total antioxidant activity of various extracts of corn silk were carried out to test its anti-oxidant activity. Corn silk contains polyphenols that are responsible for free radical scavenging activities. The polyphenols content of corn silk varies from 6.70 to 101.99 mg GAE/g extract, depending on the solvent used and cornsilk extracts have shown strong antioxidant activities thus highly recommended to be implemented in the pharmaceutical and health related industries to treat oxidative stress related disease (Nurhanan and Wan Rosli, 2013). The antioxidant activities of all cornsilk extracts were determined via β-carotene bleaching method, 2,2-diphenyl-2-picrylhydrazyl (DPPH.) radical scavenging, superoxide anion (O_2^-) radical scavenging and ferric reducing power activity (FRAP). The highest polyphenol content was exhibited by the methanol extract (101.99 mg GAE/g) compared to that of ethanol (93.43 mg GAE/g), water (35.34 mg GAE/g) and ethyl acetate extract (6.70 mg GAE/g). The flavanoid content of cornsilk extracts was in the range of 0.66 to 9.26 mg catechin equivalent/g extract showing the highest content found in the methanol extract. In the antioxidant assays, the methanol extract exhibited the strongest free radical scavenging and reducing activity as compared to the other extracts. In the β-carotene assay, the methanol (66.05%) extract, showed highest bleaching activity compared to the ethanol (52.92%), water (38.65%) and ethyl acetate (26.33%) extract. In FRAP assay, the ferric reducing activity of methanol extract reached 56.41% at 1600 µg/ml while ethanol (51.16%), water (35.01%) and ethyl acetate extract (27.21%) exhibited lower reducing activity. methanol, water and ethyl acetate extracts of corn silk show a concentration-dependant manner based on DPPH, FRAP, XOD (xanthine oxidase) system and ABTS [2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate)] free radical scavenging capacity. Inhibition of free radicals increases when a higher concentration of extract is applied. The free radical scavenging capacities of corn silk obtained from DPPH, FRAP, XOD, and ABTS assays could be attributed to the phenolics and flavonoids present in cornsilk powder. The flavonoid maysin from corn silk extract contains luteolin, a biologically active substance known to have antioxidant and anticancer activities (Lee *et al.,* 1998). The antioxidative activity of flavones in corn silk is associated with the prevention of cancer and coronary heart disease which is also promising (Birt *et al.*, 2001). Antioxidant activity from matured corn silk is higher than from the immature corn silk (Maksimovic and Kovaèevic, 2003). The upper parts of corn silk showed higher antioxidant activity than from the lower parts of corn silk (Alam, 2011). Several studies on maysin of corn silk have demonstrated antioxidative, antiallergy, and anticancer effects (Bai *et al.,* 2010; Hu and Deng, 2011, Lee *et al.,* 2016). Many researchers reported the anti-oxidant properties and effects of corn silk in their in-vitro studies (Maksimovic, *et al.* 2005; Liu *et al.* 2011; El-Ghorab, 2007; Ebrahimzadeh 2008; Kan 2011). Corn silk polysaccharide treatment was shown to enhance antitumor activity through increased immune capability and anti-inflammatory effects (Yang *et al.,* 2014; Wang *et al.,* 2012). Guo *et al.* (2016) investigated the anticancer activity of corn silk extract in human colon cancer cells and human gastric cancer cells and reported that corn silk extract inhibited the proliferation of cancer cells and increased the level of apoptosis in a concentration dependent manner.

Neuroprotective effects

The *in-vitro* data suggesting that herbal medicines like corn silk inhibits cholinesterase, resulting in neuroprotective effects of Alzheimer’s disease, quoted by Natural Medicine Database. Alzheimer’s disease might be prevented by inhibition of acetylcholinesterase (AChE) and butrylcholinesterase (BChE) as both of these degrade the neurotransmitter acetylcholine through hydrolysis. The neuroprotective effects of corn silk ethyl acetate and ethanol extract from four corn varieties (var. *intendata*, *indurata*, *everta* and *saccharata*) was investigated by measuring AChE and BChE inhibition (Bump and Brown, 1990). Among these, the ethyl acetate extract of var. *intendata* (200 µg/mL) had the highest AChE inhibition (96.69%), while at the same concentration ethyl acetate extract of var. *everta* exhibited the highest BChE inhibition (41.46%). High inhibition of AChE by ethyl acetate extract of corn silk showed that the extracts of corn silks have the potential to be used in neuroprotective applications. Maysin isolated from corn silk exhibits neuroprotective effect via the antioxidative and anti-apoptotic mechanism (Kan *et al.,* 2011; Lee *et al.,* 2014).

Anti-depressant effect

In recent years, considerable attention has been directed towards the identification of plants with antioxidant and anti depressant ability that may be used in Human diet therapy. Ebrahimzadeh *et al.* (2009) studied the antidepressant activity of corn silk and reported corn silk has good anti-depressant potential. He also reported that the extract also had high levels of phenol and flavonoids and was so safe at least up to 4000 mg/kg.

Anti-inflammatory effect

Inflammation is part of the complex biological response of the vascular tissue system due to harmful stimuli, like infection by pathogens, damaged cells, or irritants. The classical signs of acute inflammation are pain, redness, swelling, and functions loss. Generally, two types of medicine are used to treat inflammation effects, steroidal and non-steroidal anti-inflammatory drugs but they have lots of side effects as well as many adverse effects on health so herbal medicines are now emphasized to use in the treatment of such diseases, because herbal medicines have little or no side effects. Corn silk is very well known for its anti-inflammatory properties. Traditional medicine followers are of the view that it can be used in reducing the pain caused by inflammatory ailments like gout and arthritis. Ethanol extract of corn silk inhibits the expression of ICAM-1 and adhesiveness of endothelial cells and causes anti-inflammatory effects (Stoecklin *et al.,* 2003). Kim *et al.* (2005) reported that corn silk stimulated COX-2 and secretion of PGE2. Anti-inflammation effects of corn silk were also observed by Wang *et al.* (2011) when carragenin-induced pleurisy rats were administered corn silk orally with corn silk for 6 hours. Pretreatment with corn silk extract also inhibited TNF-Î±, IL-1Î², VEGF-Î±, and IL-17A and blocked inflammation-related events (ICAM-1 and iNOS) by activation of NF-ÎºB. Supplementation with corn silk may be a promising treatment for inflammatory diseases that involve oxidative stress (Wang *et al.,* 2012). Corn silk polysaccharide Enhances antitumor activity through increased immune capability and anti-inflammatory effects (Yang, 2014).

Anti-microbial effect

Aqueous extract of corn silk possesses antimicrobial effects against *S. aureus*, *B. subtilis* and *Candida albicans* (Xing *et al.,* 2012). Petroleum ether (PECS) and methanol (MECS) extract and flavonoids were active against most of the gram-positive and gram-negative bacteria tested (Nessa *et al.,* 2012). Surjee and Zwain, (2015) reported that the ethanol and aqueous extracts of corn silk have inhibitory effects against bacteria. Corn silk can also be taken as a tea to treat the symptoms of UTI. Corn silk is best used in combination with other stronger antiseptic herbs to treat bladder infections and it will provide effective symptom relief from burning and pain associated with UTI (Vijitha and Saranya, 2017).

Present and future prospective

The interest in using corn silk in herbal medicines, food, and cosmetics has been increasing in the last few years. However, it is very important to carry out proper research on toxicity and determine the safety level before any use of it as food or in any herbal products. A recent study using male and female Wistar rats confirmed that corn silk is non-toxic in nature (Wang *et al.,* 2011). There were no histopathological and adverse effects observed at a corn silk concentration of 8.0% (w/w) consumed for 90 days. This content corresponds to a mean daily corn silk intake of approximately 9.354 and 10.308 g/day/kg body wt. for males and females, respectively. As such, the intake of corn silk has no adverse effects and this supports the safety of corn silk for human consumption. Researchers reported that acute and sub-acute toxicity studies of corn silk revealed no death or abnormal symptoms and no related toxic effect on body weight, water intake, food consumption, urine parameters, clinical chemistry, or organ weight in all treatment groups within the study period (Ha *et al.,* 2018). Because human research on corn silk is limited, official dosage recommendations haven't been established. A variety of factors could influence your body's reaction to this supplement, including age, health status, and medical history. Most available research suggests that corn silk is nontoxic and those daily doses as high as 4.5 grams per pound of body weight (10 grams per kg) are likely safe for most people (Hasanudin *et al.,* 2012). The therapeutic and health benefits exerted by corn silk may be linked with the presence of various phytochemicals such as sterols, polyphenols, flavonoids, and anthocyanins as well as minerals and other essential nutrients. These substances are able to scavenge free radicals and have shown some significant *in vitro* and *in vivo* antioxidative activities thus this corn silk is also being utilized as a hypoglycemic agent, diuretic agent, antioxidant, and other therapeutic functionalities. No doubt, the benefits of corn silk in improving pharma-nutritional functionalities can be very useful for future studies. Recently, a novel coronavirus, COVID-19 has been creating havoc with huge numbers of casualties the world over. Till now, although hundreds of years have passed, research in the entire world could not be able to eradicate the viral deaths and the pandemic issues in right earnest hence, children's health and safety are at risk (Das *et al.* 2021). Thus there are huge scopes for further research to study the effect of corn silk on viral pathogens of humans for all age groups as well as its role in immunity development against COVID-19 and other pathogenic viruses.

The processed dried corn silk has been successfully incorporated into food products to enhance nutritional values and physiological functionalities. Incorporation of corn silk powder results in increasing protein, cooking yield, moisture, and fat retention (Wan Rosli *et al.*, 2011). Food-derived bioactive peptides received growing attention by the researchers over the last two decades. These multifunctional peptides are used for the prevention of cardiovascular disease. Antioxidant peptides are recognized as potent, natural alternatives to synthetic antioxidants for application as food additives. Such peptides are also potential for the future development of functional food ingredients and therapeutic agents (Lammi *et al.* 2019). Recently, consumer demand for healthy snacks has increased. Crackers are popular healthy snacks with a high potential to enhance nutritional value by incorporating naturally available ingredients. Corn silk incorporated crackers are rich in calories, protein, fibre, and minerals. The pulverized dried corn silk can effectively use to prepare value-added food products (Priyadharshini, K. and Parameshwari, 2020). The value added by incorporating corn silk powder will enhance the nutritional quality. Hence, corn silk powder can be exploit as a mean of value addition in different novel products. Corn silk is considered as a good source of nutritional composition and potential antioxidant activity thus incorporation of corn silk powder resulted in increased protein, fibre, vitamin C, calcium, and magnesium in the crackers. Crackers with 10% corn silk added were highly acceptable by the consumers. This novel corn silk for incorporation in crackers could permit a reduction of formulation cost without affecting sensory attributes of the developed product with which the consumer is familiarized. The addition of corn silk powder in butter biscuits improves some essential nutrients and healthy functional properties. Considerable higher polyphenol content (60.4-86.8%) and antioxidative improvement are obtained by the incorporation of corn silk powder in butter biscuits. The corn silk powder-based biscuits have higher free radical scavenging capacity (24.45-62.73%) and ferric-reducing capacity (16.94-342 µmolTE/g) with higher levels of gallic acid and ferulic acid compared with all-wheat-based biscuits (Nurhanan and Wan Rosli, 2016). The addition of corn silk powder in traditional Indian snack laddoo of different blends like raw papaya, rice flour, and sesame seeds was found to be organoleptically acceptable. For laddoo of all three blends, corn silk powder can be added up to a level of 10% for value addition to increase the fiber, protein, and mainly the mineral content of the product as well as imparting curative effects to the products (Singh and Raghuvanshi, 2021). In addition to these, the processed corn silk shows some beneficial effects when it is applied to few other food items such as bread and patties. Incorporation of corn silk powder results in increased protein, total dietary fibre and firmness but decreases sensory acceptability of yeast bread. Addition of 2% corn silk powder to yeast bread also slightly increases protein, ash and TDF content, meanwhile their textural properties and sensory acceptability are unchanged compared to control yeast bread. On the other hand, yeast bread with 6% corn silk-added has the highest content of protein; ash and TDF content but adversely affects the textural and sensory acceptability (Ng and Wan Rosli, 2013). The utilization of corn silk, on one hand will promote value addition of the products and on the other hand, will provide low-cost nutritious alternatives, especially in poor developing countries for combating malnutrition among children and vulnerable sections of the society. Corn Silk is also having traditional use in cosmetic preparations to soften the skin tissues (Emollient) and overcome skin rashes. The application of corn silk extracts on faces with hyper pigmentation significantly reduced the skin pigmentation without abnormal reactions. It has good prospects for suppressing the skin pigmentation (Choi *et al.*, 2014). Thus the corn silk is a potential source of an extra income to the farmers and there is a vast scope for research and development of different value-added products by utilizing this corn silk and its extracts. This will lead to the valorization of agricultural residue via waste utilization which increases farmer income as well as reduce environmental pollution due to agricultural wastes, which will lead to the valorization of agricultural residue via waste utilization which increases farmer income as well as reduce environmental pollution due to agricultural wastes.

Conclusion

Corn silk could be potential health promoting agent in humans. Several studies have demonstrated the therapeutic potential of corn silk extract against several diseases including diabetes, hyperlipidemia, cancer, obesity, cardiovascular diseases, kidney disease, and microbial infections. In addition to that, the processed corn silk shows some beneficial effects when it is applied in some food items such as biscuit, bread, laddoo, cookies, crackers and patties. These products being inexpensive and highly nutritious as well as rich in fiber they can surely be a promising solution to improve defecation pattern by recommending these products to be supplemented through various dietary intervention program. However, further studies are needed to standardize the effective doses for different health purposes for different age groups and to investigate in detail the molecular mechanisms by which corn silk extract exhibits health-promoting effects. Thus, there is a great need to strengthen research, testing, and product development activities for proper, effective, and safe utilization of corn silk in development of nutritious food so that in near future, it can be utilized effectively to prevent malnutrition and health problems.

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REVIEW PAPER

Maize nutritional quality and value addition: a brief overview

Pratik Sanodiya · Krishna Prasad Bhusal · Neel Kamal Mishra

Abstract: Maize is a major cereal crop that is known as the "Queen of Cereals" due to its numerous uses and high productivity potential. Maize is not only one of the most significant cereal crops in India but the world as well. It is crucial for both human and animal nutrition in general and for fulfilling the calorie and protein needs of millions of people in emerging nations. Due to unhealthy life style and habits of the present generation, many health problems have been noticed in the last two decades. Multigrain concepts of nutrition can play a significant role to mitigate these health challenges. As we all know that maize has a lot of fiber, antioxidants, and other vitamins and minerals. Various value-added products prepared from maize have the potential to alleviate nutritional disorders. In view of above, the current article describes the nutritional quality along with the potential and opportunity for countless value-added products made from maize, which are crucial for dietary and economic stability.

Keywords: Maize · Nutritional quality · QPM · Value added products

Introduction

Southern Mexico and Mesoamerica saw the domestication of maize (*Zea mays* L., often known as corn) more than 9,000 years ago (Awika, 2011; Kennett *et al.*, 2020). Despite maize's later domestication and relative isolation until European settlement in the Americas, maize has rapidly spread throughout the world since then and has become the leading global staple cereal in terms of annual production exceeding 1 billion metric tonnes (Garcia-Lara *et al*., 2019). A significant portion of the human diet is made up of the three primary global staple cereals: wheat, rice, and maize, which together account for an estimated 42% of the world's food calories and 37% of the average protein intake (FAO STAT 2021).

The total area of maize (for dry grain) in the world is 197 M hectares, with significant regions in Asia, Latin America, and sub-Saharan Africa (SSA) (FAOStat, 2021). In many nations, particularly in SSA, Latin America, and a few nations in Asia, it is a well-established and significant crop for human consumption, accounting for more than 20% of food calories there (Shiferaw *et al*., 2011). In comparison to wheat and rice, maize is a more adaptable crop with a wider range of uses. It has a variety of roles as an industrial and energy crop in developed economies, where it is largely used as a crop for livestock feed. The demand for maize as feed is increasing along with economic development (including income growth and urbanization), which is driving the consumption of animal-source foods (Table 1).

Throughout the past ten years, there has been a rise in interest in agri-food systems (Brouwer *et al*., 2020; Fanzo *et al*., 2021; HLPE, 2017; IFAD, 2021). This partly reflects worries about How to effectively provide for the recent global food crisis the expanding global population within the parameters of the planet (Willett *et al.*, 2019) and in the setting of global warming (Jones and Yosef, 2015). It has an impact on a heightened curiosity about agri-food system results, whether it is concerning nutrition and food, environmental sustainability, livelihoods, inclusion, and the prospect for resilience to restructure agri-food systems to enhance these. Thus, agri-food systems are crucial for the 17 goals of the

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Table 1. Global cereals production statistics (annual averages for dry grain only)

		1993–95 (TE1995)	2017–19 (TE2019)	2021-2022 (TE2022)	Relative change (%)
Maize	Area (Million ha, M ha)	135	197	206.87	
	Production (Million ton, Mt)	521	1,137	1216.03	118%
	Yield (t/ha)	3.9	5.8	5.88	50%
Rice (Paddy)	Area (M ha)	148	164	165.92	11%
	Production (Mt)	538	757	513.97	41%
	Yield (t/ha)	3.6	4.6	4.63	26%
Wheat	Area (M ha)	218	216	221.74	-1%
	Production (Mt)	545	757	779.21	39%
	Yield (t/ha)	2.5	3.5	3.51	40%
Other cereals	Area (M ha)	191	149	147.8	-22%
	Production (Mt)	315	301	300.5	-4%
	Yield (t/ha)	1.6	2.0	2.12	23%
All cereals	Area (M ha)	692	727	735	5%
	Production (Mt)	1,919	2,952	3142	54%
	Yield (t/ha)	2.8	4.1	4.6	46%

Source: FAO Stat (2021). TE: triennium ending

2030 Agenda for Sustainable Development SDGs (Fanzo), Sustainable Development Goals.

Maize kernel composition and anatomy

In general maize kernel is a good source of proteins, carbohydrates, lipids, and some of the essential minerals and vitamins. Especially the large and small nutrients in the maize kernel importantly contributed to its improved food plus feed quality. Besides, Maize also has highest energy (ME 3350 kcal/kg) among cereal grains. As a result, maize is known as a nutritional cereal (Table 2).

The endosperm, germ, pericarp, and tip cap make up 83%, 11%, 5%, and 1%, respectively, of the maize kernel's four main structural components. Starch makes up the majority of the endosperm, which is encased in a protein matrix. The two primary forms of starch are opaque and hard or vitreous. Starch degradability and in vivo starch digestibility in ruminants are inversely correlated with the former (Gunaratna *et al*., 2010). The maize kernel's embryo, also known as the germ, contains nutrients and enzymes necessary for the growth and development of new maize. Its fat content is also significantly high (around 33.3%). The germ of the kernel has around 80% of the mineral content, but the endosperm only possesses 1%. The three most common minerals are phosphorus (in the form of phytate), potassium, and magnesium, which together account for almost 85% of the mineral composition of kernels. Sulfur, which is mostly found in organic form as a component of methionine and cystine, is the fourth most common element. Moreover, the germ includes anti-oxidants including vitamin E. Except for the tip cap, the endosperm, and germ are surrounded by a high-fiber (8.8% crude) semipermeable barrier called the pericarp. During kernel development and the kernel dry-down period, moisture and nutrients pass through the tip cap. On the tip cap, the black layer, or hilum, serves as a seal. Due to the genetics of the endosperm sink, maternal parent, and environment, maize kernels are amenable to changes that change their nutritional content (Nuss and Tanumihardjo, 2010).

Table 2. Status of macromolecules, nutrients, and minerals in maize (composition per 100 g of edible portion of maize)

Parameter	Quantity	Parameter	Quantity
Carbohydrate	71.88 g	Riboflavin	0.10 mg
Protein	8.84 g	Amino acid	1.78 mg
Fat	4.57 g	Mineral	1.5 g
Fibre	2.15 g	Calcium	10 mg
Ash	2.33 g	Iron	2.3 mg
Moisture	10.23 g	Potassium	286 mg
Phosphorus	348 mg	Thiamine	0.42 mg
Sodium	15.9 mg	Vitamin C	0.12 mg
Sulfur	114 mg	Magnesium	139 mg

Source: Tanumihardjo *et al.* (2020)

The maize varieties can be categorized based on their kernel textures such as dent, flint, waxy, flour, sweet, pop, and pod corn. Except for pod corn, these divisions are based on the quality, quantity, and pattern of endosperm composition, which defines the size of the kernel and is not indicative of natural relationships. As in the cases of floury (fl) versus flint (FI), sugary (su) versus starchy (Su), waxy (wx) versus nonwaxy (Wx), and other single recessive gene modifiers that have been used in breeding special-purpose maize, viz. sweet corn, popcorn, waxy maize, etc.

QPM and nutritional security

The biological value of QPM maize is nearly twice as high as that of normal maize (NM), greater than that of wheat and rice, and matches that of milk for real protein digestibility, which helps to reduce feed demand. In comparison to animal protein, the cost index for the manufacture of each unit of QPM protein is substantially lower (Gupta *et al*., 2009). Consequently, QPM can be used as food for the country's nutritionally undernourished people, especially in tribal and hilly areas where maize is the main crop. Besides this, QPM can be used as a nutritionally superior meal for children, pregnant and lactating mothers, adolescents, and the old age population of the country (Prasanna *et al*., 2001). In the future, India will likely host 50% of the world's hatcheries because QPM also provides low-cost, high-quality feed to support the growth of the chicken industry. QPM thereby ensures that India has access to food and nutrition (Table 3).

QPM has created a new possibility in the field of animal nutrition as well thanks to its well-balanced amino acid composition. Rising earnings and an increase in meat eating have led to a shift in the world's cereal demand that favors maize as a key feed crop. According to predictions, demand for monogastric animals like pork and poultry will rise by 30% globally. The poultry sector is looking for maize due to its higher levels of oil and amino acids (Hellin and Erenstein, 2009). Balanced meals are necessary for people to completely utilize their genetic potential (Ignjatovic-Micic *et al*., 2013). Oil added to nutritionally enriched QPM has the potential to take the place of more expensive dietary sources of fats and proteins. Since oil has a higher calorific value than starch, it is preferred that kernels should have a high oil concentration (Saleh *et al*., 1997; Yin *et al*., 2002). The study showing the dietary replacement of NM by QPM showed a considerable increase in broiler weight gain with much better feed efficiency (Table 4). The need for soybean meal and consequent expense is significantly reduced in broiler diets when QPM is substituted for NM at a rate of 60% (Subsuban *et al.*,1990). The use of QPM in place of normal maize resulted in savings of 2.8% on chicken feed and 3.4% on pig feed, according to calculations for a pig and poultry ration consisting of NM, QPM, sorghum, soybean meal, and synthetic lysine and tryptophan (Pereira *et al.*, 1992). Studies have also proven enhanced growth in pigs when QPM is substituted with normal maize, hence increasing the bio-available protein (Mbuya *et al.*, 2011; Ai and Jane, 2016). As a result, QPM can lower the cost of animal feed by spending less on more expensive sources of high protein.

Value-added products of maize

In India, maize is generally consumed in the form of chapati, popcorn, roasted fresh cob, etc. Different value-added products of maize are classified based on utility.

Table 3. Status of various protein fractions and amino acids in normal maize and QPM kernels of Indian genotypes

Protein / amino acid	Normal maize (%)	QPM (%)
Albumins	3.2	13.2
Globulins	1.5	3.9
Prolamines	47.2	22.8
Glutelins	35.1	50.0
Tryptophan	0.3 or less	0.6 or more
Lysine	1.2-1.5	2.4 or more

Source: Anonymous (2010)

Table 4. Protein quality in different types of maize *vis* other cereals

Cereal	Protein Quality (% casein)	Cereal	Protein Quality (% casein)
Rice	79.3	Sorghum	32.5
Wheat	38.7	Barley	58.0
Normal maize	32.1	Pearl millet	46.4
Opaque-2 maize	96.8	Finger millet	35.7
QPM	82.1	Teff	56.2
Oats	59.0	Rye	64.8

Source: FAO (2022)

Most common value-added products

1. *Corn oil*- The majority of refined maize oil is used in cooking, where its high smoke point makes it an excellent frying oil. It is also used as a biodiesel feedstock. Maize oil can also be used to make soap, paint, inks, textiles, nitroglycerin, and pesticides, as well as to protect metal surfaces from rust.

2. *Corn Syrup*- Corn syrup, a food syrup primarily composed of glucose, is derived from grain starch. Corn syrup is used in cooking to soften the texture, add volume, keep the sugar from crystallizing, and improve flavor.

3. *Corn flakes*- Corn flakes are one of the most nutritious foods and are consumed as breakfast food not only in India but elsewhere in the world. In addition to their delicious flavor, crispy cornflakes are also well-liked for their friable texture, flavorful blend, and, most importantly, their simplicity in preparation. This crucial agro-based food processing sector has a lot of room to grow, especially in regions where maize is grown, to meet the growing demand of urban and industrialized cities.

4. *Pop corn*- Popcorn is a common snack at sporting events and movie theatres. Traditions differ as to whether popcorn is consumed as a salty snack food (as it is in the United States) or as a sweet snack food with caramelized sugar (predominating in Germany). Popcorn is naturally low in calories, fat, sugar, and salt while being abundant in nutritional fiber and antioxidants. Those with dietary limits on their intake of calories, fat, or sodium may find it to be an alluring snack as a result. However, substantial amounts of fat, sugar, and sodium are frequently added for flavor to prepared popcorn, making it fast a very poor choice for persons on restricted diets.

5. *Roasted corn*- When corn is in season, masala butta, or spiced fire-roasted corn on the cob, is a popular street snack in India.

Some other value-added products of maize which are used directly or indirectly in human consumption are listed in Table 5. These products enhance the market value of maize.

Fermented products of maize

Maize can be prepared and consumed in a variety of ways. It’s typically ground and pounded. The dish can be cooked, baked, or fried. The whole grain can be boiled, roasted, or fermented. Cooking maize meal with water yields a thick mush or dough. It can be combined with water to make gruel, porridge, or soup. In this section, we demonstrate the variety, significance, and microbiological characteristics of some fermented maize products. Some globally fermented corn products and their nutritive value as shown in the Table 6.

a) Fermented Industrial products- Maize fermented products are mostly utilized for Industrial purposes some as described below.

i) Beverages- Corn starch grits are mostly used for beverages purpose, beer and distilled liquors are the major products with respect to the volume of production and utilization.

ii) Wines- High fructose corn syrup-sweetened “wine

Table 5. Different types of value added product by using QPM

Products	Types
Traditional products	Ladoo, halwa, kheer, chapati, sev, mathi, pakora and cheela
Baked products	Bread, nan khatai and cake
Extruded products	Vermicelli and pasta
Snacks and savoury items	QPM biscuit salted, QPM biscuit sweet, choco maize biscuit, honey maize chikki, maize matthi, namak para, sev, shakarpara, QPM burfi, QPM halwa, suji upma, suji kheer, sevian (sweet), sevian (upma), QPM chatni powder-I, QPM chatni powder-II and QPM chatni powder-III
Convenience foods	Instant idli mix, instant dhokla mix, and porridge mix; sprouted products– sprouted chat, QPM vada, QPMsevian and QPM flour
Specialty foods	High-quality protein mix,low-quality protein mix, quality protein mix for the elderly, QPM honey liquid, and honey maize water (Singh, 2006)

Source: Kawatra and Sehgal (2022)

Table 6. Fermented food products of maize.

Name of the fermented food	Description	Microorganism	Nutritive value	References
Chicha	Salivation and/ or malting	*Saccharomyces cerevisiae, S. Mycoderma vini Lactobacillus, Acetobacter, Aspergillus, Penicillium*	Vitamins B	Steinkraus (1996)
Tesguino	Malting and extraction juice of maize stalk followed by boiling of juice	*S. cerevisiae Lactobacillus Streptococcus, Leuconostoc, Pediococcus, Saccharomyces Candida Cryptococcus, Hansenula*	Rich in vitamins and enzymes & serves as a refreshing alcoholic drink.	Ulloa *et al.* (1987); Wacher-Rodarte (1995)
Umqombothi	Malting	Lactic acid, bacteria and yeast.	Vit B mild alcohol sour aroma	Bleiberg *et al.* (1979); Coetzee (1982)
Busaa (Nigeria, Ghana)	Opaque maize beer	*Pediococcus L. helveticus, L. salivarius* riboflavin *cerevisiae, Candida krusei*	Crude protein, thiamine	Farnworth (2003; Willis (2002)
Atole Hurtado (Mexico)	Steeping and milling of maize grains	Lactic acid and bacteria	Sour nonalcoholic porridge, diacetyl provides sensory properties	Escamilla-Hurta *et al.* (1993)
Pozol	Boiling of kernels	*Leuconostoc mesenteroides Lactobacillus plantarum, L. Confusus, Lactococcus, Trichosporon guillermondii, C. parapsilosis, S. Cerevisiae*	Control of diarrhoea; antagonistic to manypathogen-ic bacteria, yeast and moulds; acidic flavour.	Ulloa *et al.* (1987); Canas-Urbina *et al.* (1993); Nuraida *et al.* (1995)
Mahewu	Based on corn meal	*Streptococcus lactis, delbrueckii, Candida Guilliermondii*	Non-alcoholic sour and beverages	Gadaga *et al.* (1999); Odunfa *et al.* (2001); Steinkraus (1996)
Abati (Paraguy and Argentina)	Based on maize dough	Lactic acid, bacteria and yeast.	Alcoholic beverages	Haard *et al.* (1999)
Cachiri (Brazil)	Based on maize manihot or fruit and produced on clay pots	Lactic acid, bacteria and yeast.	Fermented non-alcoholic beverages	Haard *et al.* (1999)
Agua-agria (Mexico)	Grinding of maize with water	Lactic acid and bacteria	Non-alcoholic beverages	Haard *et al.* (1999)

coolers” and sweet “pop” both have a considerable market demand for wine production.

iii) *Distilled liquors*- Maize corn is the chief source of carbohydrates that helps the production of better quality liquors.

iv) *Fuel alcohol and chemicals*- By fermenting corn, dextrose, or molasses, ethanol, citric acid, glutamic acids, lysine, and food-grade lactic acid can be produced more cheaply. Riboflavin (vitamin B2) and cobalamine (vitamin B12) are two vitamins that are produced through fermentation utilizing dextrose and corn syrup liquor.

v) *Antibiotics*- For the commercial manufacturing of antibiotics, corn syrup, dextrose, corn starch, lactose, and sucrose are the primary carbohydrate sources. The most common antibiotics manufactured are tetracycline, penicillin, neomycin, bacitracin, and streptomycin. Penicillin, bacitracin, and neomycin, in particular, have been used in very large quantities as growth promoters in animal feeds.

vi) *Enzymes*- Because society is becoming increasingly prone to diseases as a result of nutrient deficiencies or excesses, it is classified as one of the vulnerable groups. Of course, they require the attention that the university has turned its attention. The goods created thus far are inexpensive in order to reach the targeted population, which is currently unable to afford the high cost of purchasing nutrient-dense food products. The requirement of customers seeking dietary diversity owing to shifting food habits in the age of globalization and urbanization will unquestionably be met by low-cost healthy food products in a variety of formats.

b) *Fermentations of maize residues to value-added coproducts*

i) *Ethanol*- Mixed sugars made from maize fiber and other biomass sources have the potential to be used as the starting material for the fermentation of a wide range of useful products, such as enzymes, organic acids, biopolymers, carotenoids, amino acids, and vitamins. Ethanol is very interesting. According to estimates, using the corn fiber fraction would result in a 10% increase in ethanol yields (Gulati *et al*., 1996)

ii) *Xylitol*- Xylose could also end up as xylitol. A valuable sugar alternative is xylitol, a sugar alcohol derivative of xylose (Pepper and Olinger, 1998). In terms of sweetness, xylitol is comparable to sucrose, but unlike sucrose, it has anti-cariogenic properties and is metabolized via an insulin-independent mechanism. Xylitol is particularly helpful in mints, sweets, and toothpaste because of its significant negative heat of solution. Xylitol is traditionally made from birch wood chips using a chemical procedure, and it costs around $7 per kilogram31. It has been proposed that a bioconversion procedure might provide a more cost-effective option.

iii) *Pullulan*- Much little study has been reported on the creation of value-added byproducts from maize-based fuel ethanol stillage, despite the fact that bioconversions of corn fiber and other lignocellulosic wastes have received a lot of attention. In order to create corn condensed distiller's solubles (CCDS), which is then combined with maize fiber to create corn gluten feed, the initial or thin sillage (TS) from ethanol distillation the process is concentrated by evaporation (Leathers, 1998).

Moreover, CCDS contains growth agents such as peptides and vitamins, which are well known. Hence, the stillage wastes mimic the ingredients for a fermentation medium. As a result, stillage wastes have been evaluated as production substrates for the valuable bioproducts of pullulan and astaxanthin (Leathers, 2002).

iv) *Astaxanthin*- The carotenoid pigment called astaxanthin is what gives salmon their distinctive color. The pigment is crucial for customer approval and may also have favorable effects on health. Salmon must eat this pigment since they are unable to produce it. Astaxanthin is a costly feed additive for salmon raised on farms. The astaxanthin-rich red yeast *Phaffia rhodozyma* has been commercially developed as an addition to aquaculture feed (Pepper and Olinger 1988).

Conclusion

Maize is used as a direct food source and an indirect feed source for meals derived from animals in a variety of global agri-food systems. It is a flexible, multipurpose crop that is mostly utilized for feed around the world. As maize has such a wide range of nutritional benefits, there are many opportunities to produce products with additional value. In addition to ensuring higher returns for farmers, the commercialization, promotion, and adoption of maize-based value-added products will also provide jobs for upcoming new generations and promote dietary diversity for consumers. Moreover, it guarantees nutritional and food security to India.

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REVIEW PAPER

A review of nitrogen management strategies and their implications on maize (*Zea mays* L.) performance

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Abstract: Maize (*Zea mays* L.) is one of the most versatile crops grown throughout the tropical as well as temperate regions of the world. These days, high external inputs required for high-yield goals largely depend on artificial sources and methods, among which nitrogen (N) is a source of worry worldwide. Crops need N for active growth and photosynthetic activity throughout the entire growth cycle. In Indian soils, N deficiency is a widespread problem, and correct management is crucial from an economic and environmental standpoint. Effective use depends on timing, technique, and optimal N application that is in tune with crop needs. Since maize has the largest yield potential of all the grains, it drastically depletes soils of N and water. Among other methods, maize's response to high N fertilisation levels is a way to determine maximal productivity. Not only is crop productivity affected by N supply, but also crop quality. Employing inorganic fertiliser can boost crop output, but protecting the environment for future generations is burdensome, especially given the ongoing rise in the global population. It is possible to achieve sustainable agricultural yield by using fertilisers, both organic and inorganic, strategically.

Keywords: Nitrogen, Organic, Efficiency, Sustainable, Crop productivity

Introduction

Globally, maize is cultivated on 201.98 million ha in more than 150 countries, having wide variations in soil, climate, biodiversity and management practices. Maize provides a staple diet for more than 900 million people in developing nations. It served as a fuel source as well as a source of raw materials for the manufacturing of food sweeteners, alcoholic drinks, protein, oil, and starch. Because of its greater adaptability, the crop is flourishing in a variety of global climatic conditions (Hartkamp, 2001; Amanullah *et al.*, 2007). The total production of maize in the world is 1162.35 million tonnes, with a yield of 5.75 tonnes /ha. India occupied 4th place in area and 7th in production of maize among the cereal crops. It ranks 3rd among the cereals in India after wheat and rice. It is cultivated on 9.86 million ha with a production of 31.51 million tonnes and a productivity of 3.19 tonnes/ha under a wide range of agro-ecological situations (Anonymous, 2022). Maize is a nutrient-exhaustive crop that demands high nutrition for its growth and development. The productivity of the crop depends on the nutrient management. Nitrogen and phosphorus are more important for the development of maize than other essential elements. A sufficient amount of essential nutrients must be supplied to ensure a good yield and maintain soil fertility. It has been demonstrated that increasing maize yield and soil fertility requires balanced

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nutrient application through the incorporation of organic and inorganic fertilisers (Almaz *et al.*, 2017; Manjunath *et al.*, 2021). Efficient use of N is important for maize production as it increases the yield and maximizes economic return and minimizes NO_3 leaching. Nitrogen is an essential nutrient for crop production. It is part of every cell, a component of amino acids and nucleic acids, and especially, it is a major constituent of chlorophyll. When a plant is nitrogen deficient, it normally shows symptoms like chlorosis or yellowing, mainly in older leaves since it is a mobile nutrient in the plant. In corn, if the deficiency is severe, it is common to observe an inverted V-shaped necrosis in the lower leaves starting at the leaf tip. Several organic and inorganic nitrogen sources can be used to supply the nitrogen required for optimum crop growth.

Adequate nitrogen not only affects maize yield but also grain quality. The application of nitrogen at low rates reduced the grain yield of maize by 43-74 per cent and the number of grains per plant up to 33-65 per cent (D’Andrea *et al.*, 2006). With the increase in nitrogen dose, yield and protein concentration in maize seed increased. The yield of maize grain produced per unit of nitrogenous fertilizer applied depends upon the uptake from fertilizer and soil N and its utilization. Nitrogen is absorbed by maize plants throughout their growth period. The plant has the greatest need for nutrients during the tasseling, silking, and grain formation stages. However, a relatively high nutrient concentration is necessary for maximum growth during the vegetative growth period. Application of nitrogen at the initial stage of the crop enhances the growth rate of leaf and root and ultimately it increases the yield of the crop. Nitrogen is important for plant metabolism as it participates in proteins and chlorophyll biosynthesis. The goal of this review study was to understand the effects of various nitrogen management practices on maize growth, yield, quality, and nutrient uptake.

Materials and methods

Identification, Screening, and selection processes were followed in this systematic review. Based on identification and screening, Literature on various aspects of nitrogen management in maize were gathered. During the screening process, more than 20 documents were identified. Only those who focused on nitrogen management in maize crop with full text available in English were kept for the selection process. The main objectives and criteria in nitrogen application methods in maize crop are:-

- *Foliar application:* Either water-soluble solid fertilizers or liquid fertilizers are mixed with water in the right proportion and sprayed on the foliage of plants for direct absorption of nutrients.
- *Fertigation:* Fertigation is the technique of supplying dissolved fertiliser to crops through an irrigation system.
- *Broadcasting:* It refers to spreading fertilizers uniformly all over the field.
- *Band placement:* It refers to the placement of fertilizers in the soil at a specific place with or without reference to the position of the seed.

Results and discussion

Effect of N management on growth parameters

Thakur *et al.* (2022) carried out research at Indore (Madhya Pradesh) and reported that [40 kg N as basal followed by (fb) 2 splits of 40 kg N and 38.8 kg at 30 and 52 days after sowing (DAS) and 1% N foliar spray at 40 DAS was found to be promising under rainfed conditions. According to Begam *et al.* (2018), plant height increased when N levels rose from 75 to 150 kg ha^{-1}. The harvest index, LAI and dry matter accumulation were considerably higher with 125 kg of N per hectare and lower at 75 kg N application. Regarding the timing of the application of N, treatment S1(½ as basal + ½ at 25 DAS) initially showed higher plant height, while treatment S3(½ as basal + ¼ at 25 DAS + ¼ at 45 DAS) ultimately produced better results. According to Verma (2011), the application of 150 kg of N_2O per hectare was much more effective for maize growth and grain yield than applications of 100 kg and 50 kg of N_2O per hectare in both years. And among organic sources, FYM @ 7.5 t/ha was proven to be the best treatment. Khadtare *et al.* (2006) conducted research at the college farm of the Anand Agricultural University in Anand (Gujarat) during the rabi season of 2005-2006. They reported that significantly higher values were obtained for cob girth, cob length, and green cob weight in treatment having recommended dose of fertiliser (RDF) (150-50-0 kg N-P-K/ha), followed by 75% recommended dose of nitrogen

(RDN) + 25% N through vermicompost (VC) made from *Parthenium hysterophorus* and 75% RDN + 25 %N through VC prepared from *Amaranthus spinosus*. According to Sharifi *et al.* (2021) observed that potassium fertilization effects on growth of hybrid maize under semi-arid conditions of Kandahar province of Afghanistan.

The application of 100 kg N/ha and 7.5 t FYM/ha significantly affected the plants' height, leaf area index, and length of time until maturity and silking (Verma *et al.*, 2012). In the spring of 2007, research was conducted at the University of Agriculture, Faisalabad's Agronomic Research Area. The treatment of urea and poultry manure had a substantial impact on all of the measured parameters, including plant height, cob length, number of grains per cob, grain weight per cob, 1000-grain weight, grain yield, biological yield, and harvest index. While the application of 50% N from urea + 50% N from poultry manure resulted in the observation of the highest grain yield (5.6 t ha^{-1}) (Cheema *et al.*, 2010). According to Meena *et al.* (2021) reported that growth and physiological indices changes in maize with differential residue and nitrogen management under conservation agriculture practices.

Effects of N management on yield parameters

In an experiment conducted by Singh *et al.* (2017), it was found that applying 300 kg N ha^{-1} was more profitable than applying nitrogen at other levels. With 300 kg N ha^{-1}, the highest values of cobs per plot (136), cob length (19.2 cm), grains per row (34.2), grain row/cobs (20.0), cobs girth (13.2 cm), test weight (244.7 g), grain yield (9.5 t ha^{-1}), and stover yield (10.1 t ha^{-1}) were measured. The maximum values of cobs/plot (129.0), cobs length (19.8 cm), grains/row (30.7), grains row/cobs (18.8), cob girth (12.2), test weight (238.7g), grain yield (8.4 t ha^{-1}), and stover yield (9.5 t ha^{-1}) were all recorded with five nitrogen splits (Table 1). The maize variety JM 218 and nitrogen scheduling, according to Thakur *et al.* (2022), were found to be promising because they generated higher grain yields (6139 kg/ha and 6197 kg/ha), stover yields (11,107 kg/ha and 11,207 kg/ha), and cob attributes (cob length, number of grain rows, and test weight). A greater cob/plant, grain/cob, and seed index were also reached with 125 kg N ha^{-1} in addition to a better grain yield (5.99 t ha^{-1}). Begam *et al.* (2018) found that the combination of N applied three times (12 as a base application + 14 at 25 DAS + 14 at 45 DAS) and applied subsequently resulted in a greater grain yield of 5.63 t ha^{-1}. Meena

In Rajasthan, Golada *et al.* (2013) found that the maize yield attributes, yields, and net returns were significantly enhanced by increasing N levels up to 90 kg ha^{-1}. Green cob production increased significantly when N applications of 90 and 120 kg N ha^{-1} were given, increasing over 60 kg N ha^{-1}. The findings showed that applying nitrogen up to 90 kg ha^{-1} considerably improved the production of green cobs and baby corn by 20.5 and 23.6 per cent, respectively as compared to applying 60 kg ha^{-1}. Srivastava *et al.* (2017) reported that maximum total dry matter, grain yield (t/ha), kernel number/cob and cob number/ m^2 was found with early sowing date and nitrogen level at 125 kg/ha. According to Neupane *et*

Table 1. Effect of nitrogen and its scheduling on yield and economics of *rabi* maize (Mean of 2 years)

Treatments	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Total profit (Rs X 10^3)	Net profit (Rs X 10^3)	Benefit cost ratio
Nitrogen (kg ha^{-1})					
150	6.9	8.1	104.4	69.6	2.9
200	7.9	8.7	118.7	83.2	3.3
250	8.8	9.3	131.8	95.5	3.6
300	9.5	10.1	143.2	106.3	3.9
CD (P=0.05)	0.5	0.5	14.5	8.5	0.1
Nitrogen scheduling					
3 Split	6.7	7.9	101.2	65.3	2.8
4 Split	7.4	8.5	111.3	75.5	3.1
5 Split	8.4	9.5	127.3	91.4	3.5
CD (P=0.05)	0.4	0.5	13.4	7.5	0.1

Source: Singh *et al*. (2017)

al. (2017), genotype HM-4 generated 4.6 and 4.1 per cent greater maize weight and cobs than HQPM-1. In comparison to 3 splits (50% B), in 4 splits with a higher basal (B) dose, RDN increased cob and maize output by 4.8 and 5.1 per cent, respectively. According to the results, RDN should be used to grow HM-4 at a rate of 50 per cent as B, 25 per cent at knee height, 20 per cent at tassel emergence, and 5 per cent foliar spray after first picking as urea solution (3%) to increase yield. According to research by Gomaa *et al.* (2017), the foliar application of nano and the soil application of mineral fertilisation (K and P) had a significant impact on biological, grain, and straw yields in both growth seasons. The highest values of biological, grain, and straw yields (18.76 and 17.93 tons/ha), (8.68 and 8.35 tons/ha), and (10.08 and 9.58 tons/ha), respectively, were obtained with the application of mineral fertiliser in the soil + foliar application of nano fertiliser followed by foliar nano-fertilization treatment. Sharma *et al.* (2021) also reported that maize yield was increased by 10-25% under new stabilized urea fertilizer (AGROTAIN incorporated urea) in maize-wheat system compared to control method.

Effect of N management on economics

According to Kalhapure *et al.* (2013), using 25% RDF plus biofertilizers (Azotobacter + PSB) + green manuring with sunhemp + compost resulted in the highest gross return (Rs 95.9x10^3/ha), net return (Rs 54.2x10^3/ha), and B:C ratio (1.30). However, Singh *et al*. (2017) reported that maximum net returns and benefit-cost ratio were achieved with 300 kg N ha^{-1} and 5 splits of nitrogen and Golada *et al.* (2013) also reported that increasing nitrogen levels up to 90 kg ha^{-1} markably improved the net returns and benefit cost ratio of maize crops. The pooled data of two years experiment inferred that nitrogen level of 125 kg ha^{-1} and applied in three growth stages (½ as basal + ¼ at 25 DAS + ¼ at 45 DAS) in maize can be used for yield increase and higher profit as per the reportings of Begam *et al.* (2018).

Effect of N management on nutrient content, uptake and quality parameters

Neupane *et al*. (2017) reported that the combined approach resulted in higher N uptake and protein content. According to the results, 50 per cent RDN should be supplied as the basal dose. The rest of 25 per cent at knee height, 20 per cent at tassel emergence, and 5 per cent as a foliar spray after first picking as urea solution (3%) to increase nitrogen and protein content in corn and fodder (Manikandan and Subramanian, 2016).

During the rabi season of the year 2005-2006, a field experiment was carried out on the medium calcareous soil of the Instructional Farm at the Junagadh Agricultural University in Junagadh (Gujarat) to examine how rabi maize (*Zea mays* L.) responded to vermicompost and nitrogen levels. The application of 120 kg N/ha + 1.5 t vermicompost/ha produced noticeably better nutrient content and absorption as compared to the application of 80 kg N/ha + 1.5 t vermicompost/ha and control treatments (Meena *et al.*, 2007).

In a field experiment conducted by Shinde *et al.* (2014) in Parbhani (Maharastra) during the rabi seasons of 2004-2005 and 2005-2006, it was discovered that the application of 100% RDF (120-60-40 kg N-P-K/ha) + 10 t FYM/ha led to the highest maize protein content. According to Manikandan and Subramanian (2016), treatment with nano-zeourea consistently resulted in higher maize growth, yield, quality, and nutrient uptake than treatment with traditional urea (Manikandan and Subramanian, 2016).

Conclusion

Results showed that integrated nitrogen management techniques on maize crops provide multiple benefits for increasing soil fertility and agricultural yield in environmentally friendly methods. The data presented in this review paper allow for the conclusion that varied nitrogen treatment rates and timing considerably affect growth metrics *i.e.*, plant height, aerial dry matter accumulation, leaf area index (LAI) and grain yield.

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RESEARCH PAPER

Surveillance of major maize diseases and their distribution scenario in different agroclimatic zones of India

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Abstract: The maize is third most significant cereal crop after rice and wheat. To know changes in the pattern of disease distribution under global climate change, hence surveying is a crucial activity. The five maize-growing zones of India *viz*. Northern Hill Zone (NHZ), North West Plain Zone (NWPZ), North East Plain Zone (NEPZ), Peninsular Zone (PZ), and Central Western Zone (CWZ) were surveyed from 2013 to 2018 for major maize diseases. Two to three talukas were chosen in each district for the roaming survey, two to three villages per taluka were chosen, and three fields on either side of the road were chosen at random in each hamlet. In four zones (NHZ, NWPZ, NEPZ, and PZ), the maydis leaf blight severity was high (67.7%) in NEPZ. Further, NHZ showed the highest severity of turcicum leaf blight (55.5%) and banded leaf and sheath blight (77.7%). Moreover, *Curvularia* leaf spot prevalence (53.3%) and post flowering stalk rot (74%) was highest in CWZ, and bacterial stalk rot in NWPZ (56%). PZ was the only region where sorghum downy mildew was common. In India, a significant maize disease is now being assessed and banded leaf and sheath blight, maydis leaf blight, Turcicum leaf blight, and others were the most prevalent diseases. This study will help to develop management strategies, identify the races of the pathogens, and recommend the resistant varieties.

Keywords: Diseases · Distribution · Maize · Surveillance

Introduction

Maize (*Zea mays* L.) is the most versatile crop grown under diversity of environments unmatched by any other crop (Ahangar *et al*., 2022). Among major cereal crops in production, maize is the world's third leading crop after wheat and rice. It has highest genetic yield potential amongst the cereal crops (Debnath *et al*., 2020; Rathore *et al*., 2021). Use of maize as feed, food, fodder and specialty corn as pop-corn, sweet corn, baby corns make it one of the main crops par excellences for industrial use adapted to different agro-ecological and climatic conditions (Vardhan *et al*., 2020; Gul et al.,2021). In

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India, maize is planted on a 9.02 mha plot with a 27.71 mt yield and a productivity of 3.1 t/ha (FAOSTAT, 2021). About 112 diseases of maize have been documented from various regions of the world; 65 of them are known to occur in India (Saxena, 2002). Out of 65, 11 significant maize diseases, including one cyst nematode, are of national significance (AICRPM, 2018).

Diseases are the main biotic constraints that restrict maize productivity. Major diseases are maydis leaf blight (MLB) caused by *Bipolaris maydis*, Turcicum leaf blight (TLB) caused by *Exserohilum turcicum*, Banded leaf and sheath blight (BLSB) caused by *Rhizoctonia solani*, and Curvularia leaf spot (CLS) caused by *Curvularia lunata*. Other disease like post flowering stalk rot (PFSR- charcoal rot-*caused by Macrophomina phaseolina* and Fusarium stalk rot caused by *Fusarium verticillioides*, bacterial stalk rot (BSR) caused by *Dickeya zeae* and sorghum downy mildew (SDM) caused by *Pernosclespora* sorghi. The *Bipolaris maydis* is a necrotrophic plant pathogen that actively kills tissues of the host, colonizing and thriving on the contents of dried and dead cells. The pathogen allows penetration and colonization by producing a range of toxins and secondary metabolites. Race 2 *O2* (Old race) and Race 2 *T*2 (Virulent on corn containing T-CMS) produce phytotoxins, which were designated as Hm-O and Hm-T toxins, respectively, by Lim & Hooker (1972). The *Exserohilum turcicum* is heterothallic ascomycete and act as a facultative parasite of maize (Zhang *et al.*, 2012; Ahangar *et al.*, 2022). The *Rhozoctonia solani* pathogen is soilborne as it survives in the soil and on diseased crop debris in the form of sclerotia or mycelium. Sclerotia can survive for several years in the soil. The fungi proliferate by irrigation and by the motion of affected soil and debris (Kaur *et al.*, 2021). The *Curvularia lunata* This pathogen is seed and soil borne causing disease prevalent in the hot, humid maize growing areas and causes approximately 10-60% yield losses due to loss of photosynthetic region of the crop and up to 33.4% losses in grain number (DingFa *et al.*, 1999). The *Marcophomina phaseolina* is a primarily soil-borne and seed-borne pathogen (Babu *et al.*, 2010). *Fusarium verticillioides* survives on crop residue in the soil or on the soil surface (Nyvall and Kommedahl, 1970). Under favorable condition, it may infect roots as well as stalk (Lipps and Deep, 1991). The soil represents a favorable habitat for microorganisms and is inhabited by a wide range of microorganisms, including bacteria, fungi and proto-zoa. *D. zeae* survives in plant debris but the survival period varies from different environmental conditions (Anil Kumar and Chakravarti, 1971; Prasad and Sinha, 1977; Saxena and Lal, 1982). *P. sorghi* can produce symptoms on both maize and sorghum, it typically does not complete sexual reproduction on maize, so no oospores are formed (Jegera *et al.*, 1998). Understanding how prevalent some serious diseases are around the globe is crucial. Consequently, a regular study was conducted for eight significant diseases to determine the severity and current pattern of dispersion. Due to global climate change and co-evolution of pathogen with their host, the occurrence of diseases for any crop may be changed. Therefore, survey from 2013-2018 was done to know the current patterns of maize disease in India.

Materials and methods

Methods of survey

A systematic and intensive survey was carried out in series to measure disease severity and know prevalence of important naturally occurring diseases of maize. These surveyed areas covered the maize growing regions by involving All India Coordinated Research Project (AICRP) Centers (Figure 1 and Table 1). The *roving* survey was conducted in five zones for six years (*kharif* 2013-18) in India. In this survey, 2-3 taluka were selected in each district. In each taluka, 2-3 villages were identified and, in each village, three fields were randomly selected on both sides of the road. From each field, 100 plants were randomly selected when crop was flowering to grain filling stage.

Scoring of the diseases

The severity of the disease was recorded by following 1 to 9 rating scale (Table 2) given by Chung *et al.* (2010) and Mitiku *et al.* (2014), and later the percent disease index (PDI) was calculated by the formula given by Wheeler (1969). Individual scoring and PDI was calculated was done as prescribed by Hooda *et al.* (2018); Aggarwal *et al.* (2021).

$$\text{PDI} = \frac{\text{Sum of numerical rating}}{\text{Total No. of plants observed x Maximum rating}} \text{ x } 100$$

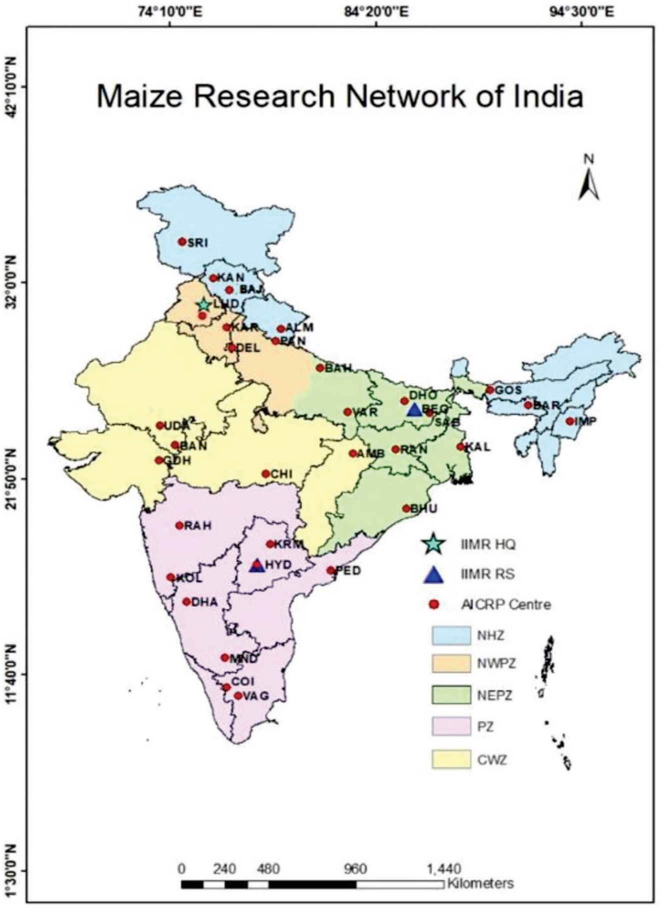


Figure 1. Maize growing zones of India (*Source:* https://iimr.icar.gov.in)

Results and discussion

During the *kharif* season 2013-18, disease survey was carried out in the all-maize growing zones of India. The purpose of keep monitoring disease severity in places where maize is grown in order to detect any outbreaks and gauge any changes in disease severity. Symptoms of major maize diseases have been depicted in Figure 3. The severity of MLB was highest (67.7%) in NEPZ during year 2016. The TLB disease severity was highest (55.5%) in NHZ during year 2015. The BLSB disease severity was highest (77.70%) in NHZ during year 2013. The CLS disease severity was highest (53.30%) in CWZ during year 2016. The BSR disease severity was highest (56%) in NWPZ during year 2016. The PFSR disease severity was highest (74%) in CWZ during year 2015. The SDM disease severity was highest (50%) in PZ during year 2016.

The MLB and CLS diseases were observed to be widespread in practically every zone based on observation data. However, NWPZ and NEPZ had the highest severity, followed by NHZ and PZ (Figure 2; Table 3). Previously thought to be minor, both diseases are now responsible for yield losses that can be avoided that range from 19–24% (AICRPM, 2018). Hulagappa *et al.* (2011) noted a

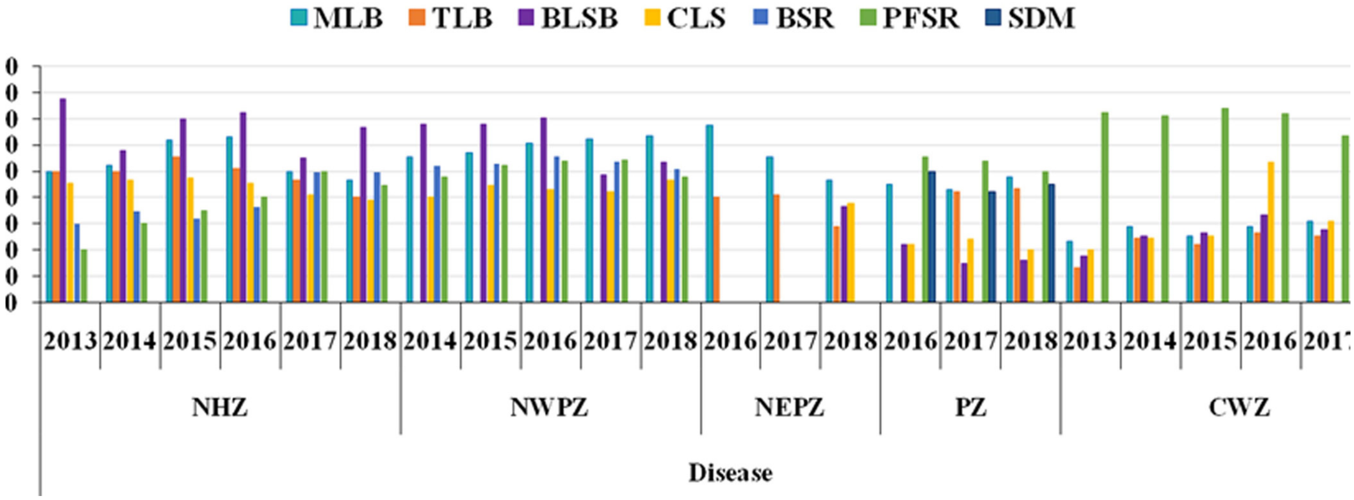


Figure 2. Severity of different maize diseases recorded from 2013 to 2018

Table 1. Zone-wise location of the AICRP centers in India

Zone code	Zone name	Maize growing centre
I	Northern Hill Zones (NHZ)	Bajaura, Almora, Dhaulakuan, Barapani and Imphal
II	North West Plain Zone (NWPZ)	Ludhiana, Karnal, Pantnagar and Delhi
III	North East Plain Zone (NEPZ)	Dholi, Sabour and Kalyani
IV	Peninsular Zone (PZ)	Hyderabad, Dharwad, Mandya and Coimbatore
V	Central Western Zone (CWZ)	Udaipur and Godhra

Table 2. Disease scoring scale for foliar diseases of maize (MLB, TLB, BLSB, CLS, PFSR (charcoal rot and *Fusarium* stalk rot) and BSR)

Rating scale	Degree of infection (% Diseased leaf area)	Disease reaction
1	Nil to very slight infection (≤10%)	Resistant (R)
2	Slight infection, a few lesions scattered on two lower leaves (10.1-20%)	(Score: ≤ 3.0)
3	Light infection, moderate number of lesions scattered on four lower leaves (20.1-30%).	(PDI: ≤ 33.33)
4	Light infection, moderate number of lesions scattered on lower leaves, a few lesions scattered on middle leaves below the cob (30.1-40%).	Moderately resistant (MR) (Score: 3.1–5.0)
5	Moderate infection, abundant number of lesions scattered on lower leaves, moderate number of lesions scattered on middle leaves below the cob (40.1-50%).	PDI: 33.3455.55)
6	Heavy infection, abundant number of lesions scattered on lower leaves, moderate infection on middle leaves & a few lesions on two leaves above the cob (50.1-60%)	Mod. susceptible (MS) (Score: 5.1-7.0)
7	Heavy infection, abundant number of lesions scattered on lower and middle leaves and moderate number of lesions on two to four leaves above the cob (60.1-70%).	(PDI: 55.5677.77)
8	Very heavy infection, lesions abundant scattered on lower and middle leaves and spreading up to the flag leaf (70.1-80%).	Susceptible (S) (Score: >7.0)
9	Very infection, lesions abundant scattered on almost all the leave plant prematurely dried and killed (>80%).	PDI: >77.77)

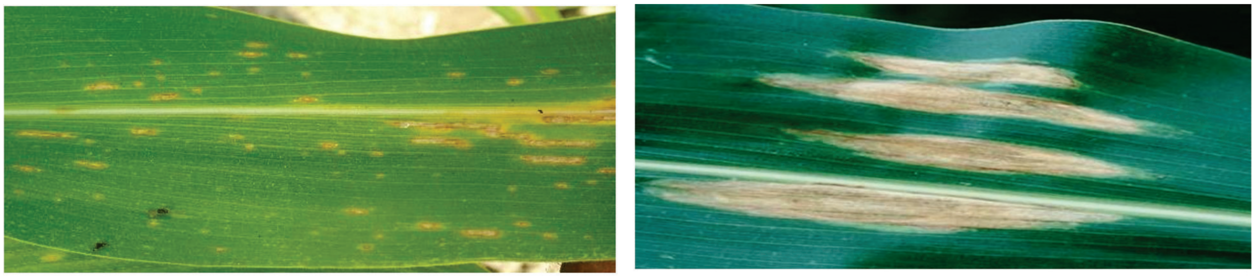
Main disease score recorded was converted to percent disease index (PDI). For BSR (percent basis) while for SDM the PDI was calculated as described by Lal and Singh (1984) using the formula PDI = (Number of plants infected / Total number of plants) × 100(percent disease index) = MDS X 100/9(MDS= Mean disease severity)

broad range of MLB disease severity during *kharif* and *rabi* crop from several areas in Northern Karnataka, while the *kharif* season showed the highest disease severity. The cropping season is the main element to affect an increase or reduction in the disease severity of TLB, according to Geeta *et al.* (2018), the high turcicum leaf blight severity was noticed in Eastern Karnataka during *kharif* 2016. Except NWPZ, all four zones had a high TLB prevalence.

As previously mentioned, CLS is a new maize disease that is now prevalent in all of India's maize-growing regions. In places with frequent excessive rainfall or even on prolonged wet days, the disease is reported to be more severe. The severity of the CLS disease also worsens with the crop's maturation. The maize crop's grain filling stage is when the disease severity peaks. Although the CWZ has the highest disease severity of CLS, this disease is currently reemerging in all areas of maize. Additionally, it was shown that the pattern of disease prevalence varied according to the crop season, with MLB being more common at 35–40 DAS and CLS being more severe at 55–75 DAS. Akinbode *et al.* (2014) discovered during their investigation on the recurrence of maize diseases in the southwest and Kwara states of Nigeria that the entire farm was entirely infected by the CLS disease, which posed a possible danger to maize output owing to its direct impact on photosynthesis.

Except for PZ, all the zones were affected by BLSB disease. Most of the survey locations in PZ had the lowest severity of this disease. According to Sharma and Saxena (2002), one of the most significant diseases affecting maize in South and South-East Asia is the BLSB disease. This disease has been reported to occur in Indian states like Haryana, Himachal Pradesh, Punjab, Uttar Pradesh, Rajasthan, Madhya Pradesh, Meghalaya, Orissa, West Bengal, and Assam (Payak and Sharma, 1985; Rani *et al.*, 2013). The various areas appear to have endemic BLSB disease. According to a survey, BLSB is common in north Karnataka's main maize-growing regions and ranges in severity from low to severe (Rajput *et al.*, 2014). In West Bengal, the disease is also seen at the pre-flowering stages (Patra, 2007).

The incidence of bacterial stalk rot (BSR), which ranged from 30 to 56%, was higher in NHZ and NWPZ. In India, the Northern Hill Zone (NHZ) and North Western Plain Zone (NWPZ) both exhibit BSR prevalence. In comparison to NHZ, the severity of BSR is substantially higher (56%) in NWPZ during year 2016. BSR disease has become one of the most significant diseases affecting the kharif-sown maize crop in India in recent years (Kumar *et al.*, 2015). These findings suggest that BSR may soon affect all the maize growing regions in India, and if



(a) MLB (b) TLB

(d) CLS

(c) BLSB (e) ChR (f) FSR

(g) BSR (h) SDM

Figure 3. Symptoms of major maize diseases (a to h)

suitable precautions are not done, it might become a terrible disease that spreads across the whole country. Mandya and Chikkabalapura districts of Karnataka experienced moderate to severe stalk rot incidence. However, NWPZ, PZ, and CWZ had higher rates of PFSR disease.

Conclusion

Our research showed that MLB, TLB, BLSB, and CLS were found in all of India's maize-growing regions due to varietal differences, susceptibility with variable disease responses, increased relative humidity, and frequent and

Table 3. Severity of maize diseases (percentage) in different maize growing zones of India (2013-18)

Diseases	Disease severity (%) and maize growing zones																						
	NHZ						NWPZ					NEPZ			PZ			CWZ					
	2013	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2016	2017	2018	2016	2017	2018	2013	2014	2015	2016	2017	2018
MLB	50	52.2	62	63.2	50	46.6	55.5	57	60.5	62.2	63.3	67.7	55.5	46.6	45	43	47.7	23.3	28.8	25.5	28.8	31.1	34.4
TLB	50	50	55.5	51.1	46.6	40	*					40	41.1	28.8	*	42.2	43.3	13.3	24.4	22.2	26.6	25.5	38.8
BLSB	77.7	57.7	70	72.2	55	66.6	67.9	68	70.5	48.8	53.3	*		36.6	22.2	15	16	17.7	25.5	26.6	33.3	27.7	30
CLS	45.5	46.5	47.5	45.5	41.1	38.8	40	44.4	43	42.2	46.6	*		37.7	22.2	24	20	20	24.4	25.5	53.3	31.1	35.5
BSR	30	35	32	36.6	50	50	52.2	53	56	54	51.1	*			*			*					
PFSR	20	30	35	40	50	44.4	47.7	52.2	53.9	54.4	47.7	*			55.5	53.9	50	72.2	71	74	72	63.3	66.6
SDM	*	*	*	*	*	*	*	*	*	*	*	*			50	42.2	45	*	*	*	*	*	*

*The particular disease not prevalent in the zone
MLB– Maydis leaf blight, TLB– Turcicum leaf blight, BLSB– Banded leaf and sheath blight, CLS– Curvularia leaf spot, BSR– Bacterial stalk rot, PFSR (Charcoal rot and FSR), SDM– Sorghum downy mildew

heavy rainfall, which created favorable environmental conditions for the development of the foliar diseases. These diseases have been widely distributed, and because of their great degree of diversity, if any isolate becomes more virulent, an epidemic might develop.

Future research

The present study will support in to make decision and experiment according to status of important disease of maize in India.

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RESEARCH PAPER

Genetic analysis of yield and its components traits in diallel cross of maize (*Zea mays* L.) under rainfed condition

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Abstract: Maize is one of the oldest domesticated crops and the world's third most important cereal crop, with a high yield potential. It is currently farmed in most parts of the world, across a wide variety of environmental conditions spanning 50 degrees north and south of the equator. In many regions of the world, it is widely utilized for food, feed, fuel, and fiber. Because of its cross-pollinated nature, maize has a wide range of morphological variability and geographic adaptation. A diallel mating design excluding reciprocals was practised among 8 diverse parents to generate 28 crosses for assessing genetic parameters in maize during *kharif* 2021. Analysis of variance revealed significant variability in the parents for all the characters under study except cob length, cob girth, number of kernel row per cob and 100 grain weight. The ratio of σ^2 gca and σ^2 sca was found less than unity for most the characters, which revealed prime role of non-additive gene action for expression of the characters under study. Among the traits, grain yield was positively ($P < 0.01$) correlated with plant height, cob length, cob girth, kernel row per cob, hundred grain weight (test weight) and cob weight under rainfed conditions. High broad-sense heritability was observed for days to tasselling, days to silking, kernel per row, grain yield and, kernel row per cob indicating that additive or genetic factors influenced the expression of these traits and they are less influenced by environmental factors.

Keywords: Maize · Correlation · Heritability · Non-additive · Variance

Introduction

Maize (*Zea mays* L.) is one of the most important strategic and economic crops in the world. It is the third most important food grain in India after wheat and rice. It accounts for around 10 per cent of total food grain production in the country. In India, maize is principally grown in two seasons, rainy (*kharif*) and winter (*rabi*). *Kharif* maize represents around 78-80 per cent of maize area in India, while *rabi* maize correspond to 20-22 per cent maize area. Globally, maize is known as queen of cereals because of its highest genetic yield potential. Maize is the only cereal crop that can be grown in diverse seasons. Being a C4 plant, it is physiologically more efficient and resilient to changing climatic conditions with wider genetic variability and also able to grow successfully throughout the world over a wide range of environmental conditions covering tropical, subtropical and temperate agro-climatic conditions. The method of diallel-crossing is one of the widely used methods of hybridization, because it is possible to determine the performance of the different genotypes in the offspring by calculating general and specific combining ability and their effects. A breeder will be able to determine to what extent the environment impacts yield by determining genotypic and phenotypic variance in yield and its components of diverse

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crop genotypes (Ullah *et al*., 2012). Heritability assumes that individuals who are closely connected are more likely to resemble one another than those who are distantly related (Falconer and Mackay, 1996). Heritability estimate helps breeders to allocate resources effectively to select desired traits and to achieve maximum genetic gain with little time and resources (Smalley *et al*., 2004). Characters having a high heritability can be quickly progressed by using simple selection. Grain yield is the polygenic trait that is influenced by a number of morphological and physiological traits. Information on the correlations between traits is crucial in maize breeding to aid the identification of superior genotypes with higher grain yield through indirect selection, of secondary traits. Grain yield can be enhanced by understanding the correlation between yield and its components and influencing the kind of relationship between them (Kalla *et al*., 2001). Present study was therefore under taken to investigate the trend of the genetic parameters for yield and its attributing traits as well as their correlation under rainfed condition.

Materials and methods

Experimentation

Half diallel crosses were made to generate 28 F_1 crosses during rabi 2020-21. The 28 F_1 crosses and the eight parents were evaluated in a randomized complete-block design (RCBD), with three replications in *kharif* 2021 cropping season at Maize Research Station, Sardarkrushinagar Dantiwada Agricultural University, Bhiloda. Due to limited F_1 seed each entry was grown in 1 row with 4 m in length at one location only. The spacing of 60 cm between the rows and 20 cm between the plants was maintained. All recommended agronomic practices were followed for raising a good maize crop. Twelve phenotypic traits were recorded i.e., days to tasseling, days to silking, anthesis-silking interval, primary ear height (cm), plant height (cm), cob length (cm), cob girth (cm), number of kernel row per cob, number of kernels per row, cob weight per plant (g), grain weight per plant (g) and test weight (g). The mean performance of each parent and hybrids was subjected to statistical analysis.

Statistical analysis

Analysis of variance to test the significance for each character was carried out as per methodology given by Panse and Sukhatme (1985). The correlation coefficients were calculated to determine the degree of association of characters with yield and also among the yield components themselves. Genotypic correlations were computed by using the formula given by Webber and Moorthy (1952) and Singh and Chaudhary (1985). The significance of '*r*' value was tested according to t-test at n-2 degree of freedom. Heritability in broad and narrow sense was estimated depending on the variance of general and specific combining abilities, and on the variance of experimental error according to Singh and Chaudhary (1985). In AGD-R (Analysis of Genetic Designs with R software the proportion of additive and dominance variance components for grain yield and other secondary traits was computed using the Baker's ratio (Baker, 1978), considering that the genetic variance between single-cross progeny is $2\sigma^2A + \sigma^2D$ which is equivalent to addition of the mean squares contribution from the GCA and SCA (Rukundo *et al*., 2017). The Baker's ratio formula used to generate variance components was: GCA/SCA = $2\sigma^2$ GCA / ($2\sigma^2$ GCA + σ^2 SCA).

Results and discussion

The results of analysis of variance (Table 1) revealed that mean square values due to genotypes were found significant for all the characters, indicating the presence of sufficient amount of genetic variability in the material under study. The variance due to parents was found significant for the characters like; days to tasseling, days to silking, anthesis-silking interval, plant height, number of kernels per row and grain weight per plant. The mean square due to hybrids indicated significant difference for all the characters under study except cob girth. Mean sum of squares due to parents vs hybrids showed significant differences for characters under study *viz*., day to tasseling, days to silking, plant height, cob length, cob girth, number of kernel rows per cob, number of kernels per row, grain yield, 100 grain weight suggesting the existence of differences between parents and hybrids leading to manifestation of heterosis.

The ratio of *gca/ sca* variance for all the characters under study was found less than unity (Table 2) Therefore, prime role of non-additive gene action was observed for inheritance of most the traits. So, exploitation of these traits for improvement of yield through heterosis breeding may be beneficial. Baker's ratio close to zero

Table 2. Estimates of variance, heritability and bakers ratio for different traits

Character	DT	DS	ASI	PEH	PH	CL	CG	KR	KPR	CW	GY	TW
s^2gca	0.08	0.1093	0.0148	9.1544	19	0.2504	0.0191	0.025	1.1093	8.4892	4.7988	-0.0168
s^2 sca	1.17	0.9475	0.06	38.165	65.69	1.3129	0.0909	0.3277	5.54	65.63	44.845	1.9641
Ems	0.18	0.27	0.18	42.07	155.56	3.05	0.34	0.37	5.16	67.784	38.489	2.26
s^2 gca / s^2 sca	0.07	0.1154	0.2463	0.2399	0.2893	0.1907	0.2097	0.0763	0.2002	0.1293	0.107	-0.008
H^2 bs	95.68	92.83	59.89	80.11	66.66	64.08	53.25	75.38	81.85	78.52	80.93	71.93
H^2 ns	11.51	17.40	19.79	25.97	24.43	17.69	15.76	9.98	23.41	16.14	14.27	-1.25
Bakers ratio	0.12	0.19	0.33	0.32	0.37	0.28	0.30	0.13	0.29	0.21	0.18	-0.02

for flowering traits and kernel yields and its attributing traits implies that SCA estimates were more important. Estimates of Baker's ratio for these traits (grain yields) confirmed the importance of nonadditive gene action. Thus, predicting hybrid performance based on GCA values alone will be ineffective. The predominance of nonadditive gene effects for these traits also suggests that genetic gain could only be achieved through hybridization followed by selection at advanced generations, where the genes are fully fixed and expressed, dominance is dispersed, and undesirable linkage is broken. Estakhr and Heidari (2012) also reported the same results for yield and attributing traits.

For individual traits, the highest heritability (b.s) was observed for DT (95.68%) and the lowest for cob girth (53.25%), (Table 2). High broad-sense heritability observed for DT (95.68%), DS (92.83), KPR (81.85%), GWPP (80.93%) and KRPC (75.38%) indicates that additive or genetic factors influenced the expression of the traits and that the traits were less influenced by environmental factors. Similar results have been reported by Ilyas *et al.* (2019). The high broad-sense heritability estimates mean that the phenotypes were true reflection of the genotypes for the measured traits and that selection based on the phenotypic value could be reliable. On the contrary, cob girth (53.25%) showed moderately low broad-sense heritability estimates. This indicates that the environment influenced the expression of the traits and that there is little scope for advancement and/or improvement of these traits than the maturity traits.

Information on narrow-sense heritability is of prime importance to the breeder as a measure of efficiency in selection and as an index of transmissibility of favourable additive genes from parents to their offspring's (Falconer *et al.*, 1996). Narrow-sense heritability was moderate for PEH (25.97%), PH (24.43%) followed by KPR (23.41%) and DS (17.40%) suggesting that both additive and non-additive gene effects were primarily responsible for the genetic variation in these traits and improvement of these traits cannot rely upon only through selection. These results are in consonance with findings of Reddy and Jabeen (2016). The variation in the magnitude between broad-sense and narrow-sense heritability of the different traits indicates their levels of environmental influence. The wider difference between the broad- and narrow-sense heritability for all the traits studied suggests a higher environmental influence and therefore leads to difficulty in selection.

The correlation studies were carried out for grain yield per plant and other yield attributing traits (Table 3).

Table 1. Analysis of variance for morphological traits

Source of variation	d.f.	DT	DS	ASI	PEH	PH	CL	CG	KR	KPR	CW	GY	TW
Replications	2	0.108	0.27	0.33	85.20	374.81	6.94	0.823	0.03	10.63	21.41	47.27	0.87
Genotypes (G)	36	3.53*	3.16*	0.41*	185.92*	415.83*	7.65*	0.66*	1.29*	24.70*	273.40*	175.67*	6.821*
Parents (P)	7	3.31*	4.64*	0.66*	201.79*	573.45*	4.14	0.632	0.43	16.02*	185.73*	145.25*	0.94
Hybrids (H)	27	2.05*	1.58*	0.35*	167.78*	318.96*	8.51*	0.515	1.50*	25.19*	226.86*	125.72*	6.77*
Parents vs. Hybrids	1	44.70*	37.46*	0.32	671.06*	2312.76*	13.26*	5.63*	2.60*	91.62*	2229.42*	1717.33*	52.22*
Error	72	0.18	0.27	0.18	42.07	155.56	3.05	0.34	0.48	5.46	187.59	195.38*	3.91

*, ** indicate level of significance at 5% and 1%, respectively.

DT = Days to 50% taselling, DS = Days to 50% silking, ASI = Anthesis silking interval PEH = Plant ear height PH = Plant height CL = Cob length, CG = Cob girth, KR = No. of row per cobs, KPR = No. of kernels per row NGPR = No. of grains per row, CW = Cob weight, TGW = 1000 grain weight and GY = Grain yield

Table 3. Genotypic correlation coefficient values among all pairs of traits in maize

Character	DT	DS	ASI	PEH	PH	CL	CG	KRPC	KPR	CW	HGW	GY
DT	1											
DS	0.939**	1										
ASI	-0.299^{NS}	0.047^{NS}	1									
PEH	-0.254^{NS}	-0.218^{NS}	0.135^{NS}	1								
PH	-0.340*	-0.320^{NS}	0.101^{NS}	0.878**	1							
CL	-0.128^{NS}	-0.147^{NS}	-0.037^{NS}	0.274^{NS}	0.386*	1						
CG	-0.331*	-0.362*	-0.044^{NS}	0.230^{NS}	0.160^{NS}	0.392*	1					
KRPC	-0.068^{NS}	-0.078^{NS}	-0.018^{NS}	0.392*	0.292^{NS}	0.338*	0.493**	1				
KPR	-0.219^{NS}	-0.217^{NS}	0.035^{NS}	0.298^{NS}	0.433**	0.922**	0.332*	0.333*	1			
CW	-0.326^{NS}	-0.289^{NS}	0.147^{NS}	0.296^{NS}	0.435**	0.826**	0.400*	0.395*	0.919**	1		
HGW	-0.287^{NS}	-0.251^{NS}	0.135^{NS}	0.328^{NS}	0.421*	0.620**	0.434**	0.354*	0.575**	0.639**	1	
GY	-0.335*	-0.297^{NS}	0.149^{NS}	0.296^{NS}	0.427**	0.780**	0.455**	0.420*	0.882**	0.985**	0.630**	1

*, ** indicate level of significance at 5% and 1%, respectively.

Table 4. Weather data year (2021-22)

Standard Week No.	Dates	Maximum Temp. (^{o}C)	Minimum Temp. (^{o}C)	R H (%)	Rain fall (mm)	Days
14	02 April – 08 April	39.5	30.2	92.3	0.0	0
15	09 April – 15 April	42.5	30.5	89.7	0.0	0
16	16 April – 22 April	41.3	29.0	91.3	0.0	0
17	23 April – 29 April	41.5	29.5	91.3	0.0	0
18	30 April – 06 May	43.5	27.5	90.1	0.0	0
19	07 May – 13 May	43.0	28.5	88.6	0.0	0
20	14 May – 20 May	41.7	30.3	91.7	0.0	0
21	21 May – 27 May	43.5	31.5	90.3	0.0	0
22	28 May – 03 June	42.5	31.9	88.2	0.0	0
23	04 June – 10 June	39.6	28.3	83.3	72.2	3
24	11 June – 17 June	38.2	26.6	89.6	0.0	0
25	18 June – 24 June	36.9	27.3	90.0	16.5	1
26	25 June – 01 July	35.1	24.3	90.7	0.0	0
27	02 July – 08 July	37.6	27.2	88.5	0.0	0
28	09 July – 15 July	32.8	27.0	89.0	46.5	4
29	16 July – 22 July	32.3	26.3	90.1	0.0	0
30	23 July – 29 July	30.6	25.7	85.4	44.2	4
31	30 July – 05 August	33.3	26.8	93.5	15.0	4
32	06 August – 12 August	34.3	27.2	87.1	0.0	0
33	13 August – 19 August	34.5	27.1	89.1	3.0	1
34	20 August – 26 August	36.8	25.7	91.4	31.4	2
35	27 August – 02 September	37.4	27.2	88.9	58.8	3
36	03 September – 09 September	36.9	25.3	87.5	24.6	3
37	10 September – 16 September	35.4	24.0	88.7	201.2	6
38	17 September – 23 September	35.5	25.7	89.5	44.6	5
39	24 September – 30 September	34.4	27.1	92.5	48.6	3
40	01 October – 07 October	35.6	24.7	90.7	1.1	1
41	08 October – 14 October	35.8	26.8	90.5	1.0	1
42	15 October – 21 October	36.1	24.5	88.4	0.0	0
43	22 October – 28 October	34.3	22.4	87.3	0.0	0
		37.4	27.2		608.7	41

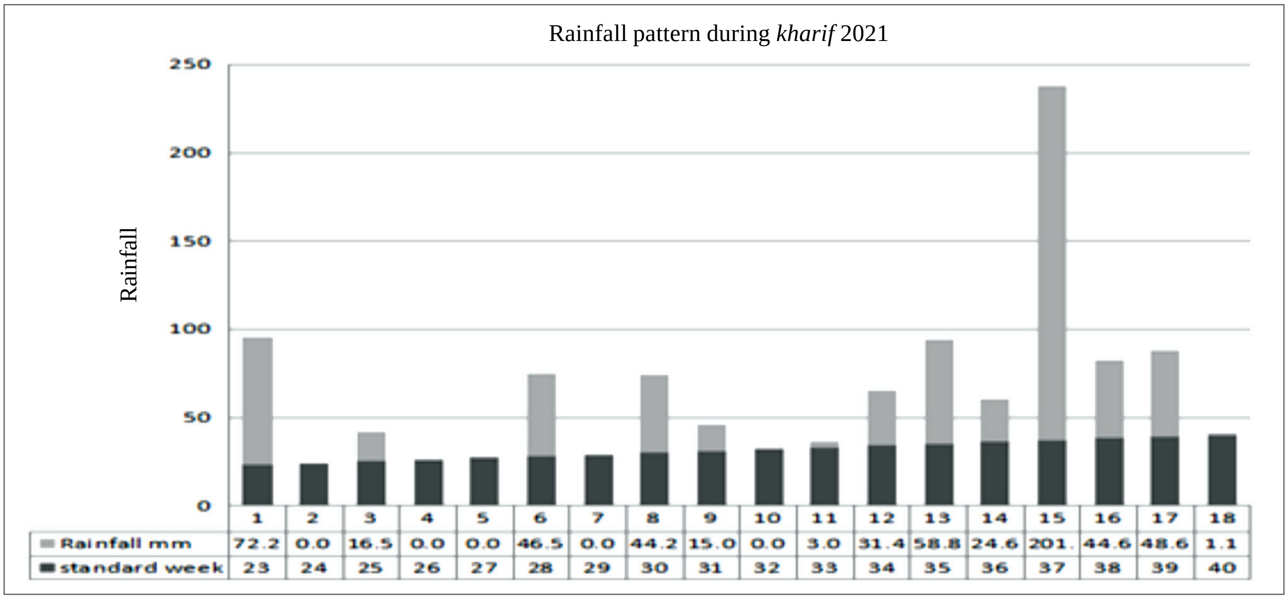

Figure 1. Rainfall pattern during cropping season (*kharif* 2021) at Maize Research Station Bhlioda

The association between two variables which can be directly observed is termed as phenotypic correlation, whereas the inherent or heritable association is known as genotypic correlation (Table 4). Among the traits, GY was highly significant and positively correlated with PH (r = 0.42**), CL (0.78**), CG (0.45**), KPR (0.88**), HGW (0.98**) and CW (r = 0.63**) under rainfed conditions. Days to 50% tasseling showed positive significant association with days to 50% silking (0.93**) and negative significant association with PH (-34*), CG (-0.33*) and GY (-0.33*) (Figure 1). Days to 50% silking also followed the same trend for yield attributing traits and seed yield per plant. This clearly indicates that as the number days taken for tasselling and silking increase, most of the assimilates are diverted towards vegetative growth of the plant as a result of which the ear characters, plant height and ultimately grain yield are reduced significantly. Similar results were also reported by earlier workers viz., Nataraj *et al*. (2014); Talabi *et al*. (2017) and Matongera *et al*. (2023). In the present study, plant height showed positive significant association with cob length, number of kernels per row, cob weight and grain yield. In the present material under study, increased plant height contributed for increase in the length of ear thereby accommodating more kernel rows and more number of kernels per row ultimately resulting in more seed yield per plant. Ear height showed positive significant association with kernel rows. Positive significant association of cob characters with number of kernel rows, number of kernels per row, test weight and grain yield were observed indicating that increase in length and girth of ears will lead to simultaneous increase in kernel rows as longer and broader kernels can accommodate more number of kernel rows and consequently more number of kernels per row. These are the important yield attributing traits which can be aimed for simultaneous improvement in yield. Similar results were reported by earlier workers viz., Jemal *et al*. (2020) and Shivani and Prasad (2017).

Conclusion

Genotypic correlation coefficients showed that all the traits considered in the study have positive correlation with grain yield except days to 50% tasseling, days to 50% silking, Anthesis silking interval and primary ear height. Plant height, cob length and girth, number of kernels per row, number of kernels row and100-grain weight showed highly significant and positive correlations with grain yield. Genotypic correlations among traits affecting grain yield explain the true association as they exclude any environmental influences. High broad-sense heritability observed for flowering and yield attributing traits along with grain yield. However, further evaluation of these genotypes at more locations and over years is advisable to confirm the promising results observed in present study. Hence, it can be concluded that cob length, kernel per row, and100-grain weight were the most effective traits for selection to improve grain yield of the maize genotypes tested in rainfed condition.

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RESEARCH PAPER

Heritability and genetic variance for grain yield and its component characters in single cross hybrids of maize (*Zea mays* L.)

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Abstract: Estimates of genetic variability and heritability in selection of desirable characters could assist the plant breeder in ascertaining criteria to be used for the breeding programmes. Twelve inbred lines and 66 F_1s generated by crossing these twelve genetically diverse parents in a half diallel mating design were evaluated at the two agricultural research stations of Kashmir in 2018 cropping season to estimate genetic variability, and heritability for, grain yield and its component characters. The estimates related to genetic components of variance revealed that estimates of additive component (D) significant for all the traits except for ear height and cob length, whereas the two measures of dominance component (H_1 and H_2) were significant for all the traits. This suggested the involvement of both these components in the inheritance of these traits, however greater magnitude of dominance component than its corresponding additive component of variance demonstrated greater role of dominance component in the inheritance of traits studied. Estimation of h^2 was significant and positive for all characters. The estimate of h^2/H_2 was less than unity for days to maturity, number of ear plant^{-1} and protein percentage indicating greater proportion of recessive group of genes for these two traits and for rest of traits h^2/H_2 was more than unity indicating greater proportion of dominance group of gene. The genetic ratio KD/KR was greater than unity for all characters under study except for plant height, ear height, cob length and kernel rows cob^{-1} where it was less than unity. The narrow sense heritability was high for days to maturity and protein percentage and low for rest of traits in the present study which indicate that additive genetic variance for these traits was relatively less pronounced than non-additive and more ever suggested importance of dominance component.

Keywords: Heritability · Diallel · Grain Yield · Dominance

Introduction

Maize (*Zea mays* L.) belongs to the tribe *Maydeae*, of the grass family, *Poaceae*. *Zea mays* is the only cultivated species in the genus Zea with chromosome number 2n=20. It contributes nearly 9 per cent to the National food basket, 5 per cent to the world dietary energy supply and more than 100 billion to the agricultural GDP at current prices (Malhotra, 2017). Globally maize is cultivated over an area of 197 million hectare with a production of 1137 million metric tonnes and productivity of 5.85 tonnes per hectare (FAOSTAT, 2022). In In India, maize is cultivated on 10.2 million hectare with a production of 27.8 million metric tonnes and productivity of 2.97 tonnes per hectare (DACNET, 2022). Textile, foundry, corn starch, corn syrup, corn oil dextrose, corn flakes, gluten, grain cake, lactic acid and acetone are

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among main products of maize. It is the third most important cereal in India after wheat and rice. The major maize growing states are Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Andhra Pradesh, Himachal Pradesh, West Bengal, Karnataka and Jammu and Kashmir. Heritability is an important property of quantitative traits because it is a measure of the relationship between phenotypic values and breeding values (Falconer, 1981). A successful breeding programme not only depends on the amount of genetic variability present in the population but also on the extent to which it is heritable, which sets the limit of progress that can be achieved through selection (Najeeb, 2009 and Wang, 2011). Genetic variability for agronomic characters therefore is a key component of breeding programmes for broadening the gene pool of crops (Ahmad 2011). Heritability is a measure of the phenotypic variance attributable to genetic causes and has predictive function in plant breeding. It provides information on the extent to which a particular morphogenetic character can be transmitted to successive generations. Knowledge of heritability influences the choice of selection procedures used by the plant breeder to decide which selection methods would be most useful to improve the character, to predict gain from selection and to determine the relative importance of genetic effects (Kashiani, 2010 and Laghari, 2010). The most important function of heritability in genetic studies of quantitative characters is its predictive role to indicate the reliability of phenotypic value as a guide to breeding value (Falconer, 1996). Diallel analysis provides good information on the genetic identity of genotypes especially on dominance-recessive relations and some other genetic interactions. Diallel crosses have been used in genetic research to determinate the inheritance of a trait among a set of genotypes and to identify superior parents for hybrid or cultivar development (Yan and Kang, 2003). The importance of estimation of the genetic component variances that have been found to be a useful tool for selection of parents which when used meticulously in a hybridization programme is likely to yield successful results. Thus present study was conducted to assess genetic variability and heritability for grain yield and its component characters in twelve maize inbred lines to provide necessary information that could be useful in maize improvement programmes aimed at improving grain yield.

Materials and methods

The experimental material for the present study comprised of 12 genetically diverse inbred lines/parents developed and maintained at Dryland Agriculture Research Station, Budgam, Jammu & Kashmir were crossed in January at experimental farm of Winter Nursery Centre, ICAR-Indian Institute of Maize Research, Hyderabad, Telangana in half-diallel mating design to generate sixty-six F_1s cross combinations. Detailed description of the germplasm is presented in Table 1.

The cross progenies were developed through controlled hand pollination at WNC, Hyderabad during *rabi* 2018. The 66 progenies so developed were evaluated along with their parents (12 inbred lines) and one check

Table 1. Description of maize inbred lines under evaluation

S.No.	Inbred line	Colour	Pedigree	
1.	KDM-340A	Yellow	(DMR) PRO-349 (Trial No. = 71 of 2001)	Hyderabad
2.	KDM-895A	Yellow	DMR (Z. T. No. = 102 of 2003)	Pantnagar
3.	KDM-914A	Yellow	(AH-1139) DMR (Trial No. = 63 of 2000)	Delhi
4.	KDM-445A	Yellow	SSFX-9919 (Trial No. = 71 of 2001) DMR	New Delhi
5.	KDM-916A	Yellow	DMR (Tr. No. = 68) 2001 Hyd. 00RIBK114	Hyderabad
6.	KDM-926B	Yellow	Tr. No. = 62B of (Navjot) 2001 (DMR)	Ludhiana
7.	KDM-362A	Yellow	DMR (Trial No. = 69 of 2001, E. No. = 6520)	New Delhi
8.	KDM-439	Yellow	DMR (Tr. No. = 71 of 2001) E. No. = 6127	Hyderabad
9.	KDM-969	Yellow	FH-3209 (Z. Trial 102 of 2002 DMR)	Almora
10.	KDM-1095	Yellow	Tr. No. = 47A of 2002 from WNC	Hyderabad
11.	KDM-1156	Yellow	Pop-446C1F2-110-1 x Pop-445C1F2	
12.	V-351	Yellow	Shakti (So) SN25≠CCBf≠ x -1-F-4≠ x b	Almora

*KDM: Karewa Dryland Maize

i.e., SMH-2 at two diverse locations of Kashmir valley i.e., Dryland Agricultural Research Station (DARS), Old Airport, Budgam (E_1) and Experimental Farm of the Division of Plant Breeding and Genetics, SKUAST-K, Shalimar Srinagar (E_2) during *kharif* 2019. The material was evaluated separately in a complete randomized block design using two replications over two environments. The standard check was randomized along with F_1's while as parents were randomized separately. Each genotype was represented by single row of five meters. The intra and inter row spacing was maintained at 20 and 60 cm respectively. Two seeds were planted per hill and later thinned to one seedling per hill at 4 leaf stage. One row of non-experimental material was planted on either side of each replication as border row to avoid the border effect. Recommended package of practices were adopted to raise a good crop. Data was recorded on yield and different yield contributing traits viz., days to tasseling, days to silking, days to maturity, plant height, ear height, number of ears per plant, cob length, cob diameter, kernel rows per plant, kernels per row, hundred grain weight, yield per plot, shelling percentage and protein content. The narrow sense heritability as low (10-30), medium (30-60) and high (>60) was estimated for all the traits.

Statistical analysis

The specific combining ability effect of ij^th^ and ji^th^ (reciprocal) cross was calculated as:

$S_{ij}= (X_{ij}./l) - [(X_{i}.. + X_{ii}. + X_{j}.. + X_{jj}.)/(P + 2)\ 1] + 2_{X\ldots}/ (P+1)\ (P+2)\ 1$

$S_{ji}= (X_{ji}./l) - [(X_{j}.. + X_{jj}. + X_{i}.. + X_{ii}.)/(P +2)/l] + 2_{X}\ldots/ (P+1)\ (P+2)\ 1$

Where, P = number pf parents, l = number of environments, $X_{i}..$ = total of arrays of i^th^ parents over environments, $X_{ii.}$= mean value of i^th^ parents over environments, X… = grand total of P (P +1)/2 progenies and P is parental value over environments, $X_{ij}.$ = progeny mean value in diallel table (crosses) over environments, $X_{j}..$= total of arrays of j^th^ parents over environments, and $X_{jj}.$= mean value of j^th^ parents over environments.

Heritability was estimated in both single and pooled over environments as per the procedure presented by Burton and Dewane (1953); Johnson *et al*. (1955) and Hanson *et al*. (1956).

Using Hayman's (1954a) least square estimates, the following genetic components of variations in F_1 were calculated:

1) $D = 4\ \Sigma uvd^2$ = components of variation due to additive effect of genes arising from differences between a pair of corresponding homozygotes.

   If u = v = 0.5 then $D = d^2$. Where, u = proportion of positive genes in the parents, v = proportion of negative genes in the parents, d = additive effect, and u + v = 1

2) $H_1 = \Sigma\ uvh^2$= component of variation due to dominance effect of genes arising from the departure of heterozygotes from the mean of the corresponding pair of homozygotes.

3) $H_2 = H_1\ [1 - (u-v)^2] = 16\ \Sigma\ u^2 v^2 h^2$ = proportion of dominance variance due to positive (u) and negative (v) effects of genes.

4) h^2 = net dominance effect (algebraic sum over all loci in heterozygous phase in all crosses)

5) Fr = Proportion of dominant and recessive alleles of genes in j^th^ parent

6) F = relative frequency of dominant and recessive alleles in parents

7) The average degree of dominance was calculated as positive square root of ratio between components of variation due to dominance effects of the genes to component of variation due to additive effects of genes i.e.

   Degree of dominance (a) $\left[\frac{H_1}{D}\right]^{1/2}$

Where, H= dominance component of variance, and D= additive component of dominance.

The proportion of positive and negative alleles at loci exhibiting dominance was calculated by formulae: $UV = H_2/4H_1$

The ratio has maximum value of 0.25 signifying thereby that there is symmetrical distribution of positive and negative alleles. The value less than 0.25 indicates that positive and negative alleles are not in equal proportion in parents. The prevalence of dominant and recessive genes was calculated by ratio:

$$\frac{(4\ DH_1)^{1/2} + F}{(4\ DH_1)^{1/2} - F} = \frac{KD}{KR}$$

Where, positive and negative sign of F indicated dominant and recessive genes respectively. If the ratio was 1 dominant and recessive genes in parents were indicated to be in equal proportion. If it was less than 1, it indicated an excess of recessive genes and if it was more than 1, it indicated an excess of dominant genes.

In addition, estimation of genetic variance components was also carried out according to model as suggested by Kempthorne (1957) using statistical software package Windostat version 9.1.

Results and discussion

Analysis of variance for the traits under study in pooled analysis is presented in Table 2. The Table revealed highly significant mean sum of squares for the parents under study for all the traits thus indicating significant difference amongst the maize lines for all the traits. Mean sum of squares due to hybrids showed significant differences among replications for all the traits except cob length and shelling percentage, suggesting that the spectrum of genetic variability created after hybridization in the present material was significantly different from mean of parents. This was in conformation of the results reported by Choudhary *et al.* (2000). Parents vs hybrids was also highly significant in both environments and pooled analysis indicating presence of heterosis. Highly significant differences due to environment were observed in parents as well as hybrids for all the traits studied. This confirmed that each of target locations were unique and desired.

The estimates of components of genetic variance and their corresponding standard errors were estimated for fourteen traits in E_1, E_2 and pooled analysis. Results for pooled analysis are presented in Table 3. The proportional values of these components of genetic variances together with estimates of average degree of dominance and heritability in narrow sense are given in Table 4.

The genetic components of variance and other components like D, H_1, H_2, h^2, F are important to obtain sound genetic information about the materials used for generating new variability. The estimates related to genetic components of variance revealed that estimates of additive component (D) significant for all the traits except for ear height and cob length, whereas the two measures of dominance component (H_1 and H_2) were significant for all the traits. This suggested the involvement of both

Table 2. Analysis of variance for different characters in maize (*Zea mays* L.)

Source of variation	d.f	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows Cob^{-1}	Kernels row^{-1}	100-grains weight (g)	Grain yield (q/ha)	Shelling (%)	Protein (%)
Environments	1	119.388*	70.885*	195.926**	846.782**	257.388**	0.206**	148.767*	1.712**	6.321*	205.157**	9.131**	600.013*	81.027**	0.693*
Block within Environments	2	4.888	9.263	265.862**	948.314**	251.234**	0.120*	52.044	0.094	8.321**	41.978**	15.951**	95.929**	4.344	0.419
Treatments	77	60.617**	82.240**	304.418**	2715.526**	1729.368**	0.138**	188.584**	4.902**	15.457**	116.533**	41.971**	1507.108**	72.096**	2.359**
Parents	11	121.538**	24.188	507.475**	669.748*	328.203**	0.047	4.629	0.128**	9.455**	36.112**	19.194**	158.385**	23.464	3.375**
Hybrids	65	125.748**	112.950**	337.522**	1214.972**	833.108**	0.209**	88.325	0.571**	10.254**	57.082**	12.625**	360.722**	12.042	1.848**
Parents vs. Hybrids	1	192.002**	274.640**	318.986**	12055.100**	77599.100**	0.850**	5648.934**	338.904**	669.688**	4865.507**	2200.029**	90858.200**	3630.545**	24.418**
Treatment x Environments	77	24.037	26.956	474.978**	631.730*	488.602*	0.564**	75.990	0.489	8.879**	22.592**	6.375*	60.805*	23.600	1.399**
Parent x Environments.	11	124.811**	136.748**	470.839**	946.794**	306.339*	0.574**	155.380*	0.320**	7.242*	54.460**	30.961**	128.869**	139.387**	2.074**
Hybrids x Environments.	65	81.500**	65.950*	463.279**	985.806**	284.041*	0.358**	87.266	0.518**	9.408**	15.238**	2.152	33.735	3.935	0.082
Parent x Hybrids x Environments	1	380.457**	444.640**	380.928*	1251.091**	369.966**	0.322**	109.771	0.423**	21.483**	150.091**	20.433**	301.679**	28.205	2.608**
Error	154	23.050	25.471	78.388	273.892	121.000	0.054	71.347	0.058	3.048	6.510	3.260	28.468	18.674	0.287
Total	311	25.361	27.685	83.964	868.365	544.655	0.077	91.294	1.369	6.795	38.406	13.623	400.178	32.972	0.831

*,** significant at 5 and 1 per cent level, respectively

Table 3. Estimates of components of genetic variation for maturity, morphological and yield attributing traits in Maize (*Zea mays* L.)

Components	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows cob^{-1}	Kernels row^{-1}	100-grains weight (g)	Grain yield (q/ha)	Shelling (%)	Protein (%)
$\hat{D}$	2.814* ±0.932	3.023** ±1.122	22.169** ±2.816	22.411** ±5.006	4.0132 ±88.250	0.037* ±0.016	26.976 ±50.458	0.165* ±0.074	2.202* ±0.828	6.399* ±3.120	3.720** ±1.378	31.311* ±13.200	2.437* ±1.266	0.836* ±0.062
$\hat{F}$	3.859 ±2.113	4.686 ±2.544	5.825 ±6.384	14.104 ±215.326	16.894 ±200.013	0.013 ±0.036	44.140 ±114.359	0.110 ±0.168	0.111 ±1.877	2.660 ±9.338	4.664 ±3.124	7.098 ±36.716	2.335 ±2.870	0.473 ±0.367
$\hat{H}_1$	14.273** ±1.865	16.572** ±2.245	34.106** ±5.634	1609.550** ±190.064	1067.780** ±176.547	0.137** ±0.031	86.9836** ±10.942	2.983** ±0.148	11.188** ±1.656	76.842** ±8.243	23.621** ±2.758	810.345** ±32.408	28.291** ±2.533	2.333** ±0.324
$\hat{H}_2$	12.181** ±1.551	14.065** ±1.868	23.124** ±4.687	1532.470** ±158.100	988.210** ±146.857	0.092* ±0.026	98.741** ±8.967	2.876** ±0.123	10.746** ±1.378	75.157** ±6.856	21.272** ±2.294	790.650** ±26.958	26.218** ±2.107	1.535* ±0.269
$\hat{h}^2$	43.745** ±1.037	55.816** ±1.249	15.524** ±3.134	7377.981** ±105.707	4717.457** ±98.190	0.050* ±0.017	363.600** ±56.141	21.765** ±0.082	39.326** ±0.921	300.778** ±4.584	127.162** ±1.534	5817.051** ±18.024	169.110** ±1.408	0.928** ±0.180
$\hat{E}$	1.130** ±0.258	1.284* ±0.311	1.675 ±1.781	67.942* ±26.350	41.330 ±24.476	0.019** ±0.004	28.358* ±13.994	0.019 ±0.020	1.082** ±0.229	1.489 ±1.142	0.716 ±0.382	9.978* ±4.493	0.643 ±0.351	0.017 ±0.044

*,** Significant at 5 and 1 per cent levels, respectively

$\hat{D}$ = additive component of variance; $\hat{F}$ = covariance of additive and dominance effects; $\hat{H}_1$ = Variance due to dominance effect of genes arising from the departure of heterozygotes from the mean of the corresponding pair of homozygotes; $\hat{H}_2$ = proportion of dominance variance due to positive (u) and negative (v) effects of genes; $\hat{h}^2$ = Estimate of heritability in broad sense; $\hat{E}$ = environmental component of variance

these components in the inheritance of these traits, however greater magnitude of dominance component than its corresponding additive component of variance demonstrated greater role of dominance component in the inheritance of traits studied, which was also found while estimating variance arising due to dominance deviation through combining ability analysis by Griffing (1956a, b) approach. The distribution of alleles in the parents revealed that positive and negative alleles at these loci are not in equal proportion in parents since H_1 exceeds H_2 and dominance gene action resulted mainly from positive gene action. Similar results have been reported by Rakesh *et al.* (2005) and Lata *et al.* (2006).

Estimation of h^2 was significant and positive for all characters revealing that net dominance effect over all the loci in heterozygote was significantly more and exhibited the positive direction of dominance. The value of F estimate was positive and non significant for all traits under study thus revealing contribution of more recessive alleles towards dominance deviation. The study of proportions of various genetic components of variance revealed that the proportion of $(H_2/4H_1)$ was less than 0.25 for all the traits under study indicating asymmetrical gene distribution in the parents. The estimate of h^2/H_2 was less than unity for days to maturity, number of ear plant^{-1} and protein percentage indicating greater proportion of recessive group of genes for these two traits and for rest of traits h^2/H_2 was more than unity indicating greater proportion of dominance group of gene. The genetic ratio KD/KR which gives the proportion of dominant and recessive alleles in the parent was greater than unity for all characters under study except for plant height, ear height, cob length and kernel rows cob^{-1} where it was less than unity. This suggested that barring these characters there was higher proportion of dominant alleles in the parents for all the characters. The study of proportion of average degree of dominance measured form genetic components of variance $(H_1/D)^{0.5}$ was more than unity thus revealing over dominance range for all traits under study. Similar results have been reported by Kumar and Gupta (2004); Rakesh (2005) and Lata *et al.* (2006).

This dominance was due to high heterozygosity in F_1 indicating that parents selected were diverse and from different source population. However, the discrepancy in the degree of dominance estimated from genetic components resulted mostly from G x E interaction or

Table 4. Proportion of genetic components of variation for yield attributing traits in Maize *(Zea mays* L.)

Components	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Cob length (cm)	Cob diameter (cm)	Kernel rows cob^{-1}	Kernels row^{-1}	100-grains weight (g)	Grain yield (q/ha)	Shelling (%)	Protein (%)
$[\frac{\hat{H}_1}{\hat{D}}]^{½}$	1.902	2.537	1.034	4.826	8.606	1.530	2.719	5.413	4.059	2.726	2.059	4.152	3.902	1.376
$\frac{\hat{H}_2}{4\hat{H}_1}$	0.164	0.162	0.136	0.191	0.185	0.138	0.252	0.193	0.191	0.196	0.180	0.195	0.184	0.132
$(\frac{KD}{KR})$	1.748	1.859	2.263	0.863	0.854	2.426	0.666	1.026	0.854	1.500	1.324	1.434	1.159	2.577
$\frac{\hat{h}^2}{\hat{H}_2}$	2.494	2.761	0.551	3.852	3.819	0.383	3.824	6.063	2.882	3.024	4.782	5.878	5.135	0.487
Heritability (n.s)	0.092	0.069	0.758	0.148	0.275	0.075	0.064	0.032	0.054	0.102	0.084	0.076	0.063	0.134
B	0.470	0.325	0.266	0.072	0.088	0.265	0.082	0.365	0.247	0.119	0.272	0.514	0.227	-0.144
	±0.505	±0.392	±0.232	±0.214	±0.374	±0.227	±0.145	±0.658	±0.460	±0.231	±0.425	±0.688	±0.483	±0.196
b-0/SE(b)	-1.031	-0.989	-1.212	-0.736	-1.374	-1.092	-1.122	-3.682	-1.786	-0.774	-1.593	-4.270	-2.313	-0.985
b-1/S.E (b)	1.445	2.114	1.478	6.816	10.913	4.529	34.124	42.947	4.105	4.754	3.103	2.371	-2.006	-0.723
t^2	0.069	0.431	0.594	13.984	42.394	0.498	10.702	9.881	6.142	5.853	2.438	2.699	4.139	3.944

$[\frac{\hat{H}_1}{\hat{D}}]^{½}$ = average degree of dominance; $\frac{\hat{H}_2}{4\hat{H}_1}$ = proportion of genes with positive and negative effects

$(\frac{KD}{KR})$ = The proportion of dominant and recessive alleles; $\frac{\hat{h}^2}{\hat{H}_2}$ = approximation of groups of genes exhibiting dominance

Table 5. Mean performance of traits

Characters	Mean
Days to tasseling	78.257
Days to silking	81.938
Cob length (cm)	19.68
Plant height (cm)	155.061
Ear height	74.55
Days to maturity	147.855
Cob diameter (cm)	4.567
No. of kernel rows/cob	14.623
Ear plant^{-1}	1.229
No. of kernels/row	21.849
100 grain weight	20.674
Grain yield/plant (g)	511.077
Shelling percentage	79.089
Protein content (%)	7.994

from sampling error, which subsequently had an influence on the estimation of dominance components. Over dominance in most cases may result from a particular combination of positive and negative genes or complementary type of gene action due to correlated gene distribution, which may seriously inflate mean degree of dominance and convert partial dominance into apparent over dominance (Hayman, 1954a; Comstock and Robinson, 1952).

Success of breeder in changing the characters of population depends upon the degree of correspondence between genotype and phenotypic values. This degree when measures in terms of heritability in narrow sense has been used as a direct selection parameter to improve the efficiency of the process. The variation in the estimates of heritability usually arises because of the choice of reference population, plot size, planting density, number of replications and method of estimation. Thus the comparison of estimates obtained by different workers must be treated with caution (Robinson, 1963).

The narrow sense heritability was high for days to maturity and protein percentage and low for rest of traits in the present study. The results are compatible with those of genetic analysis which indicate that additive genetic variance for these traits was relatively less pronounced than non-additive and more ever suggested importance of dominance component. The result also inferred that though these characters are amenable for improvement through selection but these characters would be influenced much by the environment. Low narrow sense heritability estimates for most traits indicated that in the present set of materials, the genes were showing non additive gene action and isolation of high yielding inbreeds would not be feasible unless the non allelic interactions and / or linkage are not dissipated through a selection procedure, which can slow down the rate of homozygosity in the segregating generation.

Conclusion

From the study it can be concluded that there is prevalence of greater magnitude of non-additive genetic component of variance relative to additive component individuals. Therefore, for these traits hybridization followed by selection is expected to result in some promising hybrids and thus favors the hybrid production. Wide range of variability existed in the maize inbreeds under study as indicated by the magnitude of their variability parameters implying considerable scope for maize improvement through phenotypic selection and development of transgressive segregates in the population. High estimates of heritability are useful in predicting the resultant effect of selecting the best individuals.

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RESEARCH PAPER

Gene action studies of quantitative and qualitative traits in maize (*Zea mays* L.)

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Abstract: The present study was undertaken to determine the type of gene action, genetic parameters of yield and other quantitative traits by crossing eight diverse maize inbred lines in half diallel mating fashion. Seed of 28 F_1 population along with their parents and a standard check was planted during *rabi*, 2019-20 in randomized complete block design and replicated thrice at the Main Maize Research Station, Anand Agricultural University, Godhra. The observations were recorded on different quantitative characters and protein content. The results revealed that mean squares due to parents and hybrids were significant for all the characters indicating that parents and hybrids differed significantly in their combining ability effects and importance of both additive as well as non-additive gene effects for their inheritance.The analysis of variance revealed significant differences among genotypes for all the characters. The estimates of components of genetic variation revealed the pre-ponderance of non-additive genetic variance for all the characters under study. The significance of both gca and sca variance indicated the involvement of both additive and non-additive gene effects for the inheritance of days to 50% tasselling, days to 50% silking, cob weight, number of kernels per row, shelling %, 100 kernels weight, kernel yield per plant and protein content. The predominance of non-additive gene action resulted in enormous heterotic response in kernel yield and its attributes including quality traits and thus heterosis breeding would be the best approach for yield improvement.

Keywords: Gene action · Diallel · Additive · Dominance · Heterosis

Introduction

Maize is the most important cereal crop in the world after wheat and rice. It has great yield potential and attained the leading position among cereals in term of production as well as productivity. With the introduction of hybrids in maize, the inclinations of acreage and production have been increasing due to its high yield potential. Maize is the most important crop, being grown in over 166 nations throughout the world, in tropical, subtropical and temperate climates and at elevations ranging from sea level to 3000 meters above sea level. Worldwide maize grown on 207.25 million hectare (MH) with total production of 1217.31 million metric tonnes (MMT) and productivity is 5.87 metric tonnes (MT), with a greater range of soil, climate, biodiversity and management approaches, accounting for 37 per cent of global kernel production (Anonymous,2023). The United States of America (USA) is the world's largest producer of maize, accounting for 30 per cent of global production and maize is recognized as the foundation of the US economy. In the year 2021-2022 in INDIA maize is grown on 10.04 MH with 33.62 MT production and productivity is 3349 kg/ha (Anonymous, 2023). Gujarat contributes approximately 5 per cent of India's total production, with a total production of 6.67 lakh tonnes in the year 2020–

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21. The total area under cultivation was 3.88 lakh ha. giving productivity of 1716.32 kg/ha. It is grown primarily in the Panchmahal, Dahod, Chhotaudepur, Mahisagar and Arvalli district of Gujarat (Directorate of Agriculture, 2022).

Planning and execution of a breeding programme requires information on the genetic systems controlling the character of the interest, so that the expected gain can be maximized with the selection process (Viana *et al*., 1999). A mating design frequently employed by plant breeders to ascertain genetic basis of variation in various attributes is diallel analysis. This approach has been effectively used by Singh and Roy (2007) in maize. Diallel analysis is commonly used for estimation of genetic variances from single crosses. Knowledge of gene action helps in the selection of parents for use in the hybridization programs and also in the choice of appropriate breeding procedure for the genetic improvement of various quantitative characters. The present study was conducted to determine the gene action and genetic variation for kernel yield per plant and other quantitative characters in maize germplasm.

Materials and methods

The study was conducted at Main Maize Research Station, Anand Agricultural University, Godhra. The experimental material comprises of eight parents, their 28 hybrids develop using half diallel mating design and one standard check. Eight inbred lines i.e. HKI 163, GYL-11, CM-500, I-07-57-3-3, I-07-54-3-1, I-07-6-4-5, LM-16 and IL-14-53 were obtained from Godhra station. The crossing program was undertaken using half diallel (excluding reciprocal) method during *rabi* 2019-20. The seeds of all the crosses and parental lines were harvested separately. The experiment was conducted during rabi 2020-21 in replicated trial by planting of F_1 hybrid along with the parents at sowing distance of 60 × 20 cm. Each treatment comprised of two rows of four-meter length.

Dose of fertilizer @ 160 kg N and 20 kg P per hectare was applied. Data pertaining to plant height, days to 50% tasseling, days to 50% silking, ear height and kernel yield per plant were recorded. The data was statistically analyzed following Panse and Sukhatme (1978). Genetic analysis was done according to the diallel technique as described by Hayman (1954) and Jinks (1954). Genetic components of variation, D (additive effects of genes), H1 and H2 (dominance effects of genes) and F were computed from estimates of variances and covariances. The observation on days to 50% tasseling, days to 50% silking and days to maturity were noted on a plot basis. For remaining traits, five competitive plants were randomly selected and tagged at in each plot on which observation was recorded from each genotype at different crop growth stages and the average value calculated.

Results and discussion

Mean sum of squares obtained from analysis of variance indicated significant differences among the parents and derived F_1 hybrids for all the characters (Table 1) and thus allowed to use of Hayman-Jinks model for genetic analysis of these characters.

Gene action

Days to 50% tasselling: The significance of both gca and sca variance (Table 2) indicated the involvement of both additive and non-additive gene effects for the inheritance of this trait. But the σ^2gca/σ^2sca ratio less than unity for the character suggested the predominant role of non-additive gene effect. These findings are in agreement with the results of Suneetha *et al.* (2000); Lal *et al.* (2011); Sundararajan and Kumar (2011); Vaghela (2012) and Nanavati (2015) as they reported the significance of both σ^2gca and σ^2sca, while Premlatha and Kalamani (2010) observed preponderance of σ^2sca. Shete *et al.* (2011b) also reported a preponderance of additive gene action for this trait. Kumar *et al.* (2021) also reported effect of environment on stability.

Days to 50% silking: The significance of both gca and sca variance (Table 2) indicated the involvement of both additive and non-additive gene effects for the inheritance of this trait. But The (σ^2gca/σ^2sca) ratio below unity in present investigation had suggested the predominant role of non-additive gene action. This results are substantiated by Srivastava and Singh (2003); Lal and Kumar (2012); Kumar and Kumar (2014); Aminu *et al*. (2014); Rajesh *et al*. (2018); Gami *et al*. (2018).

Days to maturity: The ratio σ^2gca/σ^2sca was found to be less than unity (Table 2) indicated the pre-ponderance of

Table 1. Analysis of variances (mean squares) and variance components for various characters

S.No.		Mean Sum of Square						
	Characters ↓	Replication	Genotypes	Parents	Hybrids	Parents *vs.* Hybrids	Check *vs.* Hybrids	Error
	df →	2	36	7	27	1	1	72
1.	Days to 50% tasseling	7.31	15.16**	16.23**	11.96**	95.00**	14.18	2.41
2.	Days to 50% silking	5.14	14.22**	17.24**	11.65**	72.90**	3.72	2.55
3.	Days to maturity	2.74	19.33**	36.04**	15.46**	25.15**	0.81	2.74
4.	Plant height	214.71*	723.00**	379.99**	747.73**	3163.34**	15.89	52.52
5.	Ear height	103.17*	305.68**	145.57**	368.71**	2.00	28.42	27.90
6.	Cob length	2.13	11.82**	9.64**	13.01**	5.59	1.27	1.29
7.	Cob weight	396.25*	2412.90**	1054.65**	2829.46**	2003.07**	1083.20**	93.20
8.	Kernel rows per cob	0.13	1.96**	2.64**	1.88**	0.38733	0.90*	0.13
9.	Kernels per row	15.88	60.69**	48.98**	65.72**	50.09*	17.39	7.17
10.	Shelling percentage	13.12	115.94**	46.55	140.18**	61.93	1.30	23.97
11.	100 kernels weight	15.20*	47.10**	80.57**	39.34**	68.15**	1.41	3.10
12.	Kernel yield per plant	3833.31	17430.22**	12967.14**	17753.41**	46212.22**	11163.42*	1975.66
13.	Protein content	0.2768	1.72**	0.82**	1.52**	2.01**	13.29**	0.13

*, ** Significant at P = 0.05 and P = 0.01 probability levels

Table 2. Mean squares due to general and specific combining ability for different characters in maize

Source of variation	d.f.	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Ear height	Cob length	Cob weight
Replication	2	7.31	5.14	2.74	214.71	103.17	2.13	396.25
GCA	7	15.40**	11.99**	17.02**	406.77**	173.07**	7.03**	1146.38**
SCA	28	2.48**	3.05**	4.02**	207.97**	87.40**	3.29**	734.61**
σ^2gca	-	1.29	0.89	1.30	19.88	8.57	0.37	41.18
σ^2sca	-	1.67	2.20	3.10	190.47	78.11	2.86	703.54
σ^2 A	-	2.58	1.79	2.60	39.76	17.13	0.75	82.35
σ^2 D	-	1.67	2.20	3.11	190.47	78.10	2.86	703.54
σ^2gca/σ^2sca	-	0.77	0.40	0.42	0.10	0.12	0.13	0.10
Error	72	0.80	0.85	0.91	17.51	9.30	0.43	31.07
Average degree of dominance	-	0.81	1.11	1.09	2.19	2.14	1.96	2.92
Predictability ratio	-	0.61	0.45	0.46	0.17	0.18	0.21	0.10

*, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively. “-” indicate negative estimate

non-additive gene action in expression of this character. These results are in accordance with Lal and Kumar (2012); Kumar and Kumar (2014); Ahmed *et al.* (2016) and Haydar and Paul (2014).

Plant height (cm): A perusal of the data indicated the involvement of both additive and non-additive gene effects for the inheritance of this trait. The ratio σ^2gca/σ^2sca was found to be less than unity (Table 2) indicated the pre-ponderance of non-additive gene action in the inheritance of the character. The results of present finding are in agreement with result of Reddy *et al.* (2011); Lal and Kumar (2012); Kumar and Kumar (2014); Haydar and Paul (2014); Gami *et al.* (2018); Rajesh *et al.* (2018) and Akula *et al.* (2018).

Ear height (cm): The estimate of σ^2gca/σ^2sca (0.14) was found to be less than unity (Table 2) narrated the pre-ponderance of non-additive gene action in the inheritance of the character. These results were in concordance with Reddy *et al*. (2011); Lal and Kumar (2012); Haydar and Paul (2014); Ahmed (2016) and Rajesh *et al.* (2018) reported non-additive gene action.

Cob length (cm): The proportion of additive and non-additive genes estimated by σ^2gca/σ^2sca was 0.13, (Table 2) which indicated pre-ponderance of non-additive gene action in the inheritance of the character. These results were in similarity with Reddy *et al*. (2011); Kambe *et al.* (2013); Kumar and Kumar (2014); Ahmed *et al*. (2016); Rajesh *et al.* (2018) and Gami *et al*. (2018).

Cob weight (g): The significance of sca variance and gca variance (Table 2) indicated the involvement of both additive and non-additive type of gene effects in the expression cob weight. However, the ratio σ^2gca/σ^2sca below the unity suggested the pre-ponderance of non-additive gene action in the inheritance of this trait. These results were in accordance with Rajesh *et al.* (2018) and Aminu *et al*. (2014).

Number of kernel rows per cob: The ratio σ^2gca/σ^2sca was displayed to be less than unity (Table 3) indicated the pre-ponderance of non-additive gene action in the inheritance of the character. The results are in conformity with the finding of Premlatha *et al*. (2011); Kambe *et al.* (2013); Haydar and Paul (2014); Aminu *et al*. (2014); Rajesh *et al.* (2018); Gami *et al*. (2018); Akula *et al.* (2018) and Dar *et al*. (2018) observed non-additive gene action.

Number of kernels per row: The gca and sca variance were significant (Table 3) indicated the involvement of both additive and non-additive gene action in the expression of trait. However, the ratio σ^2gca/σ^2sca (0.07) was found to be less than unity indicating the pre-ponderance of non-additive gene action in the inheritance of the character. These results were in concordance with Reddy *et al.* (2011); Kambe *et al.* (2013); Kumar and Kumar (2014) and Rajesh *et al.* (2018).

Shelling percentage (%): The gca and sca variance were significant (Table 3) indicated the involvement of both additive and non-additive gene action in the expression of trait, However the significance of sca variance (Table 3) indicating the pre-ponderance of non-additive gene action in the inheritance of the character. This result was in close agreement with Kumar and Kumar (2014).

100 kernel weight (g): The gca and sca variance were significant (Table 3) indicated the involvement of both additive and non-additive gene action in the expression of trait. Similar gene action was also reported by Reddy *et al.* (2011); Premlatha *et al.* (2011); Kambe *et al.* (2013); Kumar and Kumar (2014); Aminu *et al.* (2014); Rajesh *et al.* (2018) and Gami *et al.* (2018).

Kernel yield per plant (g): The gca and sca variance were significant (Table 3) indicated the involvement of both additive and non-additive gene action in the expression of kernel yield per plant. But the ratio σ^2gca/σ^2sca (0.08) was found to be less than unity indicated the pre-ponderance of non-additive gene action in the inheritance of the character. This result was in concordance with Reddy *et al.* (2011); Premlatha *et al.* (2011); Lal and Kumar (2012); Kambe *et al.* (2013); Kumar and Kumar (2014); Aminu *et al.* (2014); Kuselan *et al.* (2017) and Rajesh *et al.* (2018).

Table 3. Mean squares due to general and specific combining ability for different characters in maize

Source of variation	d.f.	Kernels row per cob	Numbers of kernals per row	Shelling percentage	100 kernels weight	Kernel yield per plant	Protein content
Replication	2	0.13	15.88	13.12	15.20	3833.31	0.28
GCA	7	1.18**	27.64**	41.82**	19.74**	8917.21**	0.83**
SCA	28	0.53**	18.89**	39.22**	15.23**	5107.89**	0.37**
σ^2gca	-	0.07	0.88	0.26	0.45	380.93	0.05
σ^2sca	-	0.49	16.50	31.23	14.20	4449.34	0.33
σ^2 A	-	0.13	1.75	0.52	0.90	761.86	0.09
σ^2 D	-	0.49	16.50	31.23	14.20	4449.34	0.33
σ^2gca/σ^2sca	-	0.14	0.05	0.08	0.03	0.08	0.15
Error	72	0.04	2.39	7.99	1.03	658.55	0.04
Average degree of dominance	-	1.93	3.07	7.76	3.79	2.42	1.88
Predictability ratio	-	0.21	0.10	0.02	0.06	0.15	0.22

*, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively. ; "-" indicate negative estimate

Protein content (%): The gca and sca variance were significant (Table 3) indicated the involvement of both additive and non-additive gene action in the expression of trait. However, the ratio σ^2gca/σ^2sca was found to be less than unity indicating the pre-ponderance of non-additive gene action in the inheritance of the character. Similar results were reported by Premlatha *et al*. (2011).

Combining ability analysis

The magnitude of GCA and SCA variances revealed that the SCA variances were higher than their respective GCA variances for all the characters except protein content. The GCA and SCA ratio (σ^2GCA/σ^2SCA) was less than unity for the traits plant height, cob weight, shelling percentage, kernel yield per plant, 50% tasseling, 50% silking, days to maturity, cob length, kernel rows per cob, kernels per row, 100 kernels weight, protein content indicated that non-additive components play relatively greater role in the inheritance. If GCA and SCA ratio (σ^2GCA/σ^2SCA) was more than unity for the traits in which additive components play relatively greater role in the inheritance of these traits. These results are in concordance with Kumar *et al*. (2019) (Table 1).

An overall appraisal of gca effects revealed that among the eight parents, GYL 11, CM 500 and I 07-6-4-5 were found to be good general combiners for kernel yield per plant. The parent is a good combiner for one or more component characters and was thus noted as a source of favourable/desirable genes for accumulating higher yield directly or indirectly through various component characters.

The parents, HKI 193, I 07-54-3-1, I 07-6-4-5 and IL 14-53 were good general combiners for days to 50% silking and tasseling. Whereas, as same parents were good general combiners for days to maturity (Table 4). Therefore, these genotypes were found to be relatively more promising for their utility as donors in breeding program for early flowering and early maturity in maize. Whereas, for plant height and ear height, parents HKI 193, GYL 11, CM 500 and I 07-6-4-5 were good general combiners. For average cob weight HKI 193, CM 500, I 07-57-3-3 and LM 16 these genotypes are more promising for their utility as donor in generating fruit/cob having more weight. The parents HKI 193 and CM 500 were good combiners for 100 kernel weight. Whereas, parent CM 500 and I 07-57-3-3 were good combiners

Table 4. Estimation of GCA effects of parents for various characters in maize

S.No.	Parents	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Ear height (cm)	Cob length	Cob weight	Kernel rows per cob	Kernels per row	Shelling percentage	100 kernels weight	Kernel yield per plant	Protein content
1.	HKI 193	-1.38**	-1.28**	-2.12**	4.97**	4.32**	0.04	11.52**	-0.57**	-0.2	-4.27**	2.36**	-43.04**	0.09
2.	GYL 11	088**	0.65**	-0.52**	4.63**	2.66**	-0.03	-3.69*	0.2**	0.82	-0.17	-0.34	19.23*	0.19**
3.	CM 500	2.42*	1.78*	1.94*	7.30**	1.89*	0.47*	10.73**	0.49**	0.13	-0.4	1.46**	24.46**	0.48**
4.	I 07-57-3-3	-0.18	-0.35	0.18	-5.93**	-0.94	1.43**	5.41**	-0.09	1.24**	-0.03	-0.74*	-11.74	-0.40**
5.	I 07-54-3-1	-0.05**	-0.42*	-0.96**	-10.00**	-2.81**	-0.80**	-3.43*	-0.12*	0.29	2.03*	-0.94**	3.73	-0.37**
6.	I 07-6-4-5	-1.12**	-1.12**	-0.26**	4.37**	5.09**	-0.13	-10.92**	-0.001	1.00*	2.27**	-2.04**	48.96**	0.08
7	LM 16	0.35**	1.18**	1.51**	0.23	-3.54**	0.37	8.12**	0.36**	-3.94**	1.13	0.56	-22.84**	-0.10
8	IL 14-53	-0.92**	-0.45**	0.24**	-5.57**	-6.68**	-1.36**	-17.75**	-0.26**	0.66	-0.57	-0.31	-18.74*	0.02
Range	Max.	2.42	1.78	1.94	7.30	5.09	1.43	11.52	0.49	1.24	2.27	2.36	48.96	0.48
	Min.	-1.38	-1.28	-2.12	-10.00	-6.68	-1.36	-17.75	-0.57	-3.94	-4.27	-2.04	-43.04	-0.40
Significant	Positive	3	3	3	4	4	2	4	3	2	2	2	3	2
	Negative	4	4	4	3	3	2	4	3	1	1	3	3	2
	Total	7	7	7	7	7	4	8	6	3	3	5	6	4
S.E. ±		0.27	0.27	0.28	1.24	0.90	0.19	1.65	0.06	0.46	0.84	0.30	7.59	0.06
C.D. at 5%		0.52	0.53	0.55	2.43	1.77	0.38	3.23	0.12	0.90	1.64	0.59	14.88	0.12

* and **, significant at 5 % and 1 % levels of probability, respectively.

for cob length. The parents GYL 11, CM 500 and LM 16 were good general combiners for number of Kernel rows per cob, while parents like I 07-57-3-3 and I 07-6-4-5 were good general combiner for kernel per row. As these parents possessed high concentration of genes governing more number of kernel yield per plant, they are likely to be produced desirable segregants when used in crossing programme.

Parents showed differences in their general combining ability effects for the same trait e.g., GYL 11, CM 500 and I 07-6-4-5 were good general combiner. Whereas, I 07-57-3-3 and I 07-54-3-1 is average combiner and HKI 193, LM 16 and IL 14-53 were poor combiners for the kernel yield and several yield components (Table 4). Thus, it was evident that each parent has its specific genetic constitution and capacity to transmit its characteristics to the progenies.

Table 5. Estimation of specific combining ability (sca) effects of hybrids for various characters in maize

S.No	Hybrid	Plant height	Ear height	Cob length	Cob weight	Shelling (%)	Kernel yield per plant
1	HKI 193 × GYL 11	9.40*	13.23**	0.72	-16.47**	10.43**	-64.01**
2	HKI 193 × CM 500	0.40	-1.00	-2.31**	52.79**	-3.67	-5.91
3	HKI 193 × I 07-57-3-3	-7.70*	-4.17	2.39**	21.67**	-3.03	-25.71
4	HKI 193 × I 07-54-3-1	1.37	-4.30	-3.64**	-71.79**	5.90*	34.83
5	HKI 193 × I 07-6-5-4	13.33**	5.13	1.39*	5.40	-8.00**	13.59
6	HKI 193 × LM 16	27.80**	8.76**	0.59	27.53**	-2.20	8.39
7	HKI 193 × IL 14-53	17.27**	-0.10	0.22	3.16	-3.17	112.29**
8	GYL 11 × IL 14-53	20.07**	22.66**	4.86**	62.89**	8.23**	97.83**
9	GYL 11 × I 07-57-3-3	-2.03	0.50	-2.90**	0.61	2.87	-3.31
10	GYL 11 × I 07-54-3-1	-8.30*	-3.97	1.14	3.74	4.47	33.89
11	GYL 11 × I 07-6-5-4	24.0**	-12.8**	-1.02*	7.43	-9.43**	-73.34**
12	GYL 11 × LM 16	-10.2**	1.43	-1.20	-13.07**	7.70**	128.46**
13	GYL 11 × CM 500	-9.73*	-11.44**	-0.41**	-12.00*	-14.27**	-102.31**
14	IL 14-53 × I 07-57-3-3	3.97	1.93	-1.90**	-15.14**	-6.23*	-39.21
15	IL 14-53 ×I 07-54-3-1	-17.3**	12.80**	2.23	6.26	-3.97	-71.34**
16	IL 14-53 × I 07-6-4-5	4.33	-5.44*	-0.53	-2.91	7.47**	63.09**
17	IL 14-53 × LM 16	6.47	-22.80**	-0.67	-14.82**	0.60	-54.44*
18	IL 14-53 × CM 500	-8.73*	2.33	-1.74**	6.19	-4.03	62.79**
19	I 07-57-3-3 × I 07-54-3-1	14.60**	2.63	-1.39*	8.38	-0.33	36.86
20	I 07-57-3-3 × I 07-6-4-5	5.90	4.06	-1.57**	-9.86	6.10*	-3.37
21	I 07-57-3-3 × LM 16	-9.30*	-7.30**	0.94	-15.93**	1.23	64.43**
22	I 07-57-3-3 × CM 500	18.17**	4.83	2.07	22.94**	1.93	10.99
23	I 07-54-3-1 × I 07-6-4-5	-0.70	-1.07	1.27**	11.47*	6.70**	29.49
24	I 07-54-3-1 × LM 16	3.10	2.90	0.43*	37.37**	1.17	21.29
25	I 07-54-3-1 × CM 500	-9.43*	-10.6**	-1.13	-22.99**	2.87	75.53**
26	I 07-6-4-5 × LM 16	-13.9**	-4.67	-0.57	-2.07	-4.40	20.06**
27	I 07-6-4-5 × CM 500	3.20	5.46*	-0.44	-2.24	3.30	-32.04
28	LM 16 × CM 500	5.00	-0.90	-0.27	-14.04**	3.10	-129.24**
Range	Min.	-17.30	-22.80	-3.64	-71.79	-14.27	-129.24
	Max.	27.80	22.66	4.86	62.89	10.43	128.46
No. of significant	Positive	8	5	5	7	7	8
crosses	Negative	9	6	9	9	4	6
	Total crosses	17	11	14	16	11	14
	S. E. ±	3.79	2.77	0.59	5.05	2.56	23.27
	C.D. at 5%	7.44	5.42	1.17	9.91	5.02	45.61

*, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively

The crosses, GYL 11 × IL 14-53 (good × poor) and I 07-6-4-5 × LM 16 (good × poor), has highly significant and sca effect for kernel yield along with heterosis (Table 5). The high sca effects in this cross might be due to additive gene interaction. This indicated good chances of isolating desirable genotypes from this cross in segregating generation because of fixable nature of gene action. This cross also manifested desirable sca effects for component traits viz., plant height, ear height, cob length, cob weight, shelling percentage. This appeared appropriate as yield being a complex character depends on a number of its component traits. The estimates of sca effects (Table 5) revealed that none of the hybrid was consistently significantly superior for all the traits. Out of 28 hybrids evaluated, 8 hybrids had registered significant positive sca effects for kernel yield per plant. The best three hybrid combinations on the basis of significant and positive sca effects for this trait were GYL 11 × LM 16, I 07-6-4-5 × LM 16 and HKI 193 × IL 14-53.

Conclusion

The significance of both gca and sca variance indicated the involvement of both additive and non-additive gene effects for the inheritance of the traits like days to 50% tasselling, days to 50% silking, cob weight, number of kernels per row, shelling %, 100 kernels weight, kernel yield per plant and protein content. Therefore, desirable character improvement could be achieved through the exploitation of heterosis. The parents vs. hybrids comparison was significant for all the characters except ear height, cob length, kernel row per cob, shelling percentage and protein content (%) suggesting that parents and hybrids differed statistically for given traits, which indicates involvement of non-additive gene effect and potential exploitation of heterosis for yield improvement.

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RESEARCH PAPER

Genetic analysis of variability and trait association in tropical field corn (*Zea mays* L.)

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Abstract: Grain yield is a complex trait influenced by environment and yield components. Hence, the information on the extent of variability in different traits and on association of yield with its components is useful for breeding for higher yield. Present study was carried out to investigate the nature and magnitude of genetic variability, heritability, genotypic and phenotypic correlations among grain yield components and their direct and indirect effects on grain yield of maize in two seasons- *kharif* and *rabi*. In *kharif*, a total of 170 genotypes (54 lines, 2 testers, 108 single cross hybrids and 6 checks) and in *rabi* 110 genotypes (34 lines, 2 testers, 68 single cross hybrids and 6 checks) were evaluated in latice design. The analysis of variance revealed significant mean sum squares due to genotypes for all the traits implying the existence of sufficient genetic variability among the inbreds. The presence of variability for various traits was also revealed by Phenotypic and Genotypic Coefficient of Variation (GCV and PCV) for different traits. Grain yield recorded GCV and PCV of 39.81 & 25.89% and 40.41 & 28.72% during *kharif* and *rabi*, respectively. Hence, there is possibility of selection of inbreds with higher performance for various traits. Correlation analysis revealed significant positive genotypic correlation (p = 0.01) of yield with plant height (rg = 0.97 and 0.83), ear height (rg = 0.98 and 0.82), cob length (rg = 0.91 and 0.71) and number of kernels per row (rg = 0.94 and 0.73) during *kharif* and *rabi*, respectively. The results of path coefficient analysis revealed that most of the characters studied had positive direct effects on grain yield. During *kharif* cob length (2.028), kernel row number (0.341) and hundred seed weight (0.126) had positive direct effect on grain yield. In *rabi*, cob width (0.578) had maximum direct effect on grain yield followed by ear height (0.461), cob length (0.412), and plant height (0.146). The results of variability analysis read with the results of trait association implied that there is possibility of improvement of yield and yield components in the material studied and the significant positive association meant that combination of traits could be improved simultaneously.

Keywords: Maize · PCV · GCV · Heritability · Correlation · Path analysis

Introduction

Maize (*Zea mays* L.) ranks third in India after wheat and rice among the food crops. It is the most versatile, photo-insensitive and widely adapted crop. It is the only food cereal crop that can be grown in diverse seasons, ecologies and with diverse uses. Maize can be used as food, feed and industrial raw material. Despite the efforts to improve productivity of maize, its average productivity in India (3.20 t ha^{-1}) is far below the world average (5.81 t ha^{-1}) (Anonymous, 2021). Therefore, there is lot of scope for enhancement of maize productivity in India through appropriate breeding strategies.

Breeding is a continuous process as the ever burgeoning population demands progressive genetic gain in the traits of economic importance. Therefore, the main goal of any breeding programme is to develop new genotypes that outperform the existing ones with respect

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to the target traits. Plant breeding programmes lay special emphasis on grain yield as it is one of the most essential trait for national food security. However, yield is a complex quantitative trait influenced by many component traits and environmental factors and hence, breeding for grain yield becomes a challenge. Moreover, the maize yield levels have attained a kind of plateau as a result of previous breeding efforts that have exploited major chunk of genetic variability in developing the excellent cultivars. Now there is a need to devise new strategies and to find the most important contributing traits (Belay, 2018). It is been long reported that the improvement in most significant component traits lead to increase in grain yield. Hence, There is an urgent need to focus on component traits along with grain yield in maize to achieve greater genetic gain in maize (Mohammadi *et al*., 2003). Therefore it is vital to identify the traits that have predominant role in enhancing grain yield through analysis of interrelationships, which will help in practicing direct and indirect selections to boost maize productivity.

Genetic improvement in economically important traits along with maintaining sufficient amount of variability is always the desired objective in maize breeding programme (Ahmed *et al*., 2011). Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are useful is determining the amount of variability present in a given character. Heritability and genetic advance (GA) of individual trait helps to find the efficiency with which genotypic variability can be exploited by selection (Bilgin *et al*., 2010). The estimates of genetic parameters like heritability and genetic advance provides the information on the nature of the gene action involved in the control of quantitative traits and help to evaluate the efficiency of different breeding strategies to obtain genetic gains (Vashistha *et al*., 2013). Heritability is a measure of the phenotypic variance attributable to genetic causes and it aids in determining the breeding scheme for the trait improvement. Genetic advance shows the degree of gain obtained for the characters under a particular selection pressure (Niji, 2018).

The knowledge of interrelationships between grain yield and its components improves the efficiency of breeding programs through the use of appropriate selection indices (Belay, 2018). Correlation coefficient quantifies the mutual association between a pair of variables independent of other variables to be considered. If there is positive association of yield with one or more component traits, indirect selection for such traits can be practised and simultaneous selection of yield and component traits would be effective (Prasad and Shivani, 2017). However, negative association would make it difficult to exercise simultaneous selection for such characters for varietal development (Prasad and Shivani, 2017). It must be noted that the correlation provides an over all association of a component trait with the grain yield. This association consists of direct and indirect effects of component traits. Therefore, partitioning of correlation into direct and indirect effects would help in better understanding of the interrelationships, This can be done through path analysis which portions the correlation coefficient into direct and indirect effects of various traits on dependent variable. This helps in determining the cause- effect relationship and to identify the traits with significant effects on yield to be used as selection criteria. Keeping these in mind, present study was undertaken to investigate genetic variability, heritability, genetic advance, phenotypic and genotypic correlations between grain yield and other traits and determining the direct and indirect effects of morphological traits on grain yield.

Materials and methods

The basic material for the study included 54 inbred lines of maize selected from the newly developed tropical germplasm lines of ICAR-IARI’s Regional Research Centre, Dharwad and 2 testers (LM-13 and LM-14) (Table 1). One hundred and eight single cross hybrids obtained from line × tester design (54 lines × 2 testers) were evaluated along with 56 (54 lines and 2 testers) parents and six checks viz., Bio-605 (National check), Bio-9544 (National check), NK-6240 (national check), 900M Gold (popular check), PMH-1 (hybrid between testers) and DKC-9178 (private check), using alpha lattice design.

The study was conducted in two seasons, *kharif* 2021 and *rabi* 2021. In *rabi*, 34 best lines were selected based on *kharif* performance and their crosses along with 6 checks (total of 110 genotypes) were evaluated using alpha lattice design with two rows of 3mlength in two replications. The field was divided into 11 blocks and each block had 10 entries. The plot size was 3.6 m^2 with spacing of 60cm x 20cm.

After thorough land preparation, sowing was done by hand dibbling of seeds with one seed per hill. The

Table 1. List of of the genotypes used in the experiment*

S.No.	Inbred	Source
1	BGD-48Y	IARI RRC, Dharwad
2	BLSB-7	
3	C-12	
4	C-14	
5	C-23	
6	C-2760	
7	C-2765	
8	C-67	
9	C-74	
10	C-78	
11	C-79	
12	C-83	
13	CDM-105	
14	CML-435	CIMMYT
15	CML-582	
16	D-2282_1	IARI RRC, Dharwad
17	DIM-204 B	
18	DT-2	
19	DT-5 _1	
20	GC-3	
21	JK-1553	
22	JK-1800	
23	JK-370	
24	MG-22	
25	PDM-10	IARI, New Delhi
26	PDM-6554	
27	PML-18 B	
28	PML-25	
29	PML-54	
30	TC-12	
31	UMI-1210	
32	BLSB-2 B	
33	PDM-6552	
34	PRJ-37	
35	C-11	IARI RRC, Dharwad
36	C-25	
37	C-30	
38	C-62	
39	C-8	
40	CML-565	CIMMYT
41	DDM-313	IARI RRC, Dharwad
42	DIM-316	
43	G-40	
44	KRN-114	
45	MG-50	IARI, New Delhi
46	PDM-134	
47	PDM-59	
48	PDM-6555	
49	PML-102 _1	
50	PML-45	
51	PML-46 _1	
52	PML-50	
53	PML-54-3	
54	PML-73	
55	LM-13	Tester1
56	LM-14	Tester2
Check		
C1	900M GOLD	Private check
C2	Bio-605	Early Check
C3	Bio-9544	Medium Check
C4	DKC-9178	Private check
C5	NK-6240	Late check
C6	PMH-1	Late check

*Also 108 hybrids derived from 54 x 2, L x T crosses were included. (listed in mean performance Table 2)

recommended dose of fertilizers (150 N, 75 P_2O_5 and 37.5 K_2O kg/ha) was given to the crop. The entire dose of P_2O_5, K_2O and one third of nitrogen was applied as basal dose and remaining two third of nitrogen was top dressed in two equal splits at fourth and seventh week after planting. Weeding, irrigation and other recommended cultural practices were followed to raise a healthy crop.

The observations were recorded from four randomly selected plants for plant height, ear height, number of kernel rows per cob (KRN), number of kernels per row (NK), cob girth (CG) and cob length (CL). Days to 50% flowering was recorded on whole plot basis. Hundred seed weight (HSW) was recorded in grams by weighing hundred seeds which were randomly selected. Grain yield (GY) was calculated using the whole plot yield and was converted to tonnes per hectare.

The various genetic parameters were estimated following the standard procedures reported earlier. The phenotypic and genotypic coefficients of variation (Burton and De Vane 1953), heritability (in the broad sense) (Lush, 1949 and Hanson *et al.*, 1956), genetic advance and genetic advance as per cent of mean (Johnson *et al.*, 1955) were computed.

Data from each season was subjected to ANOVA separately to know the significant genotypic differences. Correlation coefficients between different traits were determined as described by Singh and Chaudhary (1979). Path coefficients were determined following the method suggested by Dewey and Lu (1957). Data were analyzed using statistical packages *viz*., INDOSTAT (version 9.2) and MS-excel at the Department of Genetics and Plant Breeding, UAS, Dharwad.

Results

Mean performance of parents, hybrids and checks during *kharif* and *rabi* are presented in Table 2 and 3 respectively. During *kharif*, grain yield of the hybrids ranged from 5.6 to 12.85 t ha^{-1}. Out of 108 single cross hybrids, DDM-313 x LM-14 recorded highest yield of 12.85 t ha^{-1} followed by PML-25 x LM-14 (12.7 t ha^{-1}), PML-54-3 x LM-13 (12.55 t ha^{-1}). Inbred line PDM-134 recorded highest yield of 10.4 t ha^{-1} and TC-6 recorded lowest yield of 1.8 t ha^{-1}. Among checks, DKC-9178 recorded highest yield of 10.43 t ha^{-1}.

During *rabi*, among the sixty-eight cross combinations evaluated for grain yield, the test hybrid C-79 x LM-13 (10.06 t ha^{-1}) recorded the highest grain yield followed by C-78 x LM-13 (9.67 t ha^{-1}) and DT-2 x LM-13 (9.1 t ha^{-1}). However, the range varied from 4.23 to 10.06 t ha^{-1} and overall mean was 6.88 t ha^{-1}. JK-1553 recorded lowest (3.17 t ha^{-1}) and C-78 recorded highest (5.48 t ha^{-1}) yield among the lines. Similarly, in the checks; NK-6240 recorded the highest grain yield with mean of 7.46 t ha^{-1}.

The analysis of variance for all the 11 characters during *kharif* and *rabi* is presented in Table 4. The variance among genotypes was highly significant for all the traits *viz*., days to 50 per cent tasseling, days to 50 per cent silking, plant height (cm), cob girth (cm), number of kernel rows per cob, number of kernels per row, ear height (cm), cob length (cm), shelling percentage, hundred grain weight (g) and grain yield (t ha^{-1}).

Genetic variability

The ANOVA for *kharif* and *rabi* revealed significant sum of squares due to genotype (Table 4). The GCV values were lower than PCV values for all the traits during both the seasons (Table 5). The GCV and PCV values ranged from less than 10% to more than 20% for different traits. Grain yield recorded GCV and PCV of 39.81 & 25.89% and 40.41 & 28.72% during *kharif* and *rabi*, respectively. However, GCV and PCV were low for characters like shelling percentage (5.44, 3.08 and 7.00, 4.46), days to 50% tasseling (5.61, 4.21 and 6.25, 7.20) and days to 50% silking (5.36, 4.50 and 6.11, 7.29) during *kharif* and *rabi*, respectively. Hundred seed weight and kernels per row showed higher GCV and PCV during kharif and moderate during rabi. Whereas, cob width showed higher GCV and PCV during *kharif* and during *rabi*. The remaining traits had either lower GCV and moderate PCV or moderate GCV and higher PCV.

Heritability and genetic advance

The heritability of more than 66% was recorded for grain yield (97.07 & 81.29) and hundred seed weight (93.66 & 66.75) during *kharif* and *rabi*, respectively. The rest of the traits showed intermediate to higher values of heritability (Table 5). The least genetic advance as percent of mean (GAM) was observed for shelling percentage (8.70, 4.39) followed by days to 50% silking (9.71, 5.71) during *kharif* and *rabi*, respectively. Kernel row number showed intermediate (10.82, 17.32) and other traits like grain yield (80.81, 48.09), hundred seed weight (43.67, 23.41), plant height (24.99, 33.48), ear height (33.39, 41.17) recorded higher estimates of GAM in both seasons while kernels per row (35.40, 16.43), cob width (34.25, 14.55) and cob length (21.84, 15.88) showed variation in GAM between the season.

ANOVA for Line x Tester analysis during kharif and rabi 2021

Results of ANOVA of L x T for yield and yield related traits during *kharif* and *rabi* are presented in Table 6, which showed significant mean sum of squares due to lines, testers and crosses. During *kharif*, mean sum of squares (MSS) due to lines were significant for days to 50% flowering, ear height, kernel row number, hundred seed weight and grain yield and MSS due to testers was significant for most of the traits except days to 50% flowering, cob length, shelling percentage and hundred seed weight. The MSS due to crosses was significant for all traits except plant and ear height, cob length and kernel row number. During *rabi*, MSS due to lines and cross were significant for all

Table 2. Mean performance of Top 10 parents and hybrids during *kharif* 2021

S.No.	Genotype	DFT	DFS	PH	EH	CL	CW	KRN	KPR	HSW	SP	GY
	Parent											
1	PDM-134	58	60	205.3	96.5	16.7	4.5	13.6	31.6	37.0	73.7	6.4
2	PML-18 B	57	56	229.6	105.4	16.2	4.4	15.1	33.4	38.0	74.0	6.3
3	PML-46 _1	62	65	183.1	79.4	12.8	4.0	12.0	19.5	33.5	70.1	5.9
4	C-25	54	56	130.0	50.0	12.8	3.7	12.7	17.3	25.0	64.6	5.6
5	C-79	61	63	148.1	82.0	12.7	4.6	14.7	23.0	26.5	64.8	5.5
6	BGD-48Y	55	57	181.9	69.4	16.8	3.7	12.7	31.0	22.0	76.5	5.1
7	C-78	61	61	153.8	69.8	14.2	3.7	13.0	23.8	22.0	71.4	5.0
8	PML-73	62	64	134.4	64.4	10.8	4.2	16.0	20.7	23.5	68.3	4.9
9	PML-102 _1	53	55	174.6	78.8	12.0	4.2	12.0	20.8	41.5	74.5	4.8
10	LM-14	57	59	174.4	75.0	14.0	4.0	12.0	20.5	28.0	79.4	4.7
	Hybrid											
1	DDM-313 x LM-14	57	59	207.5	85.6	18.8	4.9	15.3	36.0	36.0	78.2	12.9
2	PML-25 x LM-14	59	62	228.8	103.1	16.9	4.5	13.7	31.7	40.0	76.1	12.7
3	PML-54-3 x LM-13	54	56	228.8	107.5	18.3	4.9	15.7	35.7	32.0	77.0	12.6
4	PML-45 x LM-13	58	60	224.4	98.1	18.9	4.6	13.3	36.0	37.5	75.9	12.4
5	PML-54-3 x LM-14	54	57	209.1	116.9	17.6	4.9	15.3	39.5	32.0	75.2	12.4
6	C-78 x LM-14	57	59	216.3	103.1	19.5	4.8	14.7	40.0	37.0	75.3	12.2
7	GC-3 x LM-14	54	57	211.3	91.3	17.9	5.0	14.0	32.8	39.5	70.3	12.2
8	PML-46 _1 x LM-14	54	56	211.3	97.5	19.9	4.7	13.3	39.8	34.5	75.5	12.2
9	PML-45 x LM-14	56	59	210.9	103.8	19.0	4.8	14.0	35.7	37.5	76.0	12.1
10	CML-582 x LM-14	57	59	223.8	100.6	14.6	4.8	14.3	24.7	36.5	76.5	11.9
	Checks											
1	900M GOLD	57	59	202.3	88.6	16.6	4.6	14.0	33.8	33.0	76.0	9.4
2	Bio-605	53	56	203.8	93.1	18.4	4.7	15.3	36.4	33.3	71.2	8.8
3	Bio-9544	56	58	190.8	86.3	17.3	4.5	13.9	34.0	34.8	79.6	8.2
4	DKC-9178	57	59	213.6	92.8	17.4	4.6	13.8	33.5	35.1	74.1	10.4
5	NK-6240	63	65	158.1	68.8	10.8	4.3	17.0	21.3	21.0	71.9	4.8
6	PMH-1	53	55	166.9	68.1	14.7	4.8	15.7	27.5	26.5	70.7	3.7
	CD (5 %)	9.54	9.61	17.6	9.7	3.08	0.48	1.78	8.72	5.23	4.83	1.19
	CD (1 %)	12.8	12.89	23.62	13.01	4.13	0.64	2.38	11.69	7.01	6.49	1.6
	CV (%)	6.46	6.32	6.08	6.61	11.29	6.47	6.2	17.43	3.52	11.26	12.96

DFT: Days to 50% tasseling
DFS: Days to 50% silking
PH: Plant height
CG: Cob girth
KRN: Kernel row number
NK: Number of kernels per row
GY: Grain yield
HSW: Hundred seed weight
Shelling %: Shelling percentage
CL: Cob length
EH: Ear height

the characters studied and MSS due to testers was significant for traits like cob width, kernel row number, hundred seed weight and grain yield.

Correlation among grain yield and other traits during kharif and rabi

The genotypic and phenotypic correlation for the traits considered during *kharif* and *rabi* are represented in Table 7 and Table 8, respectively. The results indicated that genotypic correlation was higher than phenotypic correlation for all the traits in both the seasons. In *kharif*, significant positive correlation coefficients were recorded for grain yield with plant height (rg = 0.972), ear height (rg = 0.98), cob length (rg = 0.91), number of kernels per row (rg = 0.937), hundred seed weight (rg = 0.835) and shelling percentage (rg = 0.684). While significant negative correlation was observed between grain yield

Table 3. Mean performance of genotypes for different traits during *rabi* 2021

S.No.	Parent	DFT	DFS	PH (cm)	EH (cm)	CL (cm)	CG (cm)	KRN	NK (per row)	Shelling (%)	HSW (g)	GY
1	LM-14	67	71	164.06	87.97	12.85	3.71	15.08	23.46	74.31	21.25	5.49
2	C-78	67	69	168.75	88.13	16.08	4.08	15	29.33	73.08	24.5	5.48
3	BGD-48Y	70	72	150	80.63	18.15	3.22	12.67	32.67	70.78	17.5	5.3
4	C-14	78	80	162.5	85.63	14.08	3.67	13.33	27.83	74.19	22.5	5.26
5	LM-13	77	79	164.22	79.06	13.4	3.65	13.33	22.71	74.4	29.25	4.94
6	PDM-6554	71	73	131.88	67.5	13.58	3.73	14.33	27.5	72.12	20.5	4.78
7	PDM-10	71	73	135.63	66.88	15.42	3.77	16.33	31.67	79.03	15	4.72
8	DT-2	70	68	126.88	53.75	16	3.48	13.33	31.17	71.29	23	4.69
9	GC-3	76	79	128.13	54.38	15.17	3.48	12.67	22.67	74.68	23.5	4.62
10	JK-1800	63	64	117.5	56.25	14	3.7	11.67	29.17	76.53	25.5	4.61
	Hybrid											
1	C-79 x LM-13	66	68	219.4	123.8	15.8	4.6	15.0	26.3	73.1	33.0	10.1
2	C-78 x LM-13	65	66	217.5	123.1	18.5	4.4	14.3	34.0	75.4	30.5	9.7
3	DT-2 x LM-13	69	69	198.8	105.6	16.2	4.2	15.0	30.0	79.7	23.5	9.1
4	PDM-10 x LM-13	70	72	199.4	115.6	17.3	4.2	15.3	34.2	80.0	24.5	9.1
5	C-2765 x LM-13	64	66	213.8	108.8	16.4	4.2	13.0	35.0	77.8	29.5	8.9
6	PDM-6554 x LM-14	65	67	208.8	116.3	16.5	4.3	15.7	28.2	71.2	24.5	8.9
7	C-14 x LM-13	72	75	218.1	120.0	17.2	4.1	13.0	33.2	77.2	28.5	8.6
8	C-67 x LM-13	70	72	216.9	118.1	14.7	3.7	14.3	28.8	75.5	25.5	8.5
9	C-78 x LM-14	72	74	204.4	119.4	18.7	4.5	16.0	35.2	76.5	25.5	8.2
10	C-2760 x LM-14	70	72	197.5	123.1	15.2	4.3	15.3	29.0	78.0	26.0	8.1
	Checks											
1	Bio-605	63	65	210.0	112.5	15.2	4.3	15.8	30.2	80.2	25.5	5.8
2	Bio-9544	70	72	186.6	116.3	14.5	4.0	14.7	32.1	78.1	22.5	6.6
3	NK-6240	73	74	194.1	116.3	15.5	4.3	15.0	27.6	77.2	26.5	7.5
4	900M-gold	72	75	203.8	119.1	14.1	4.5	16.3	29.5	77.1	22.5	6.8
5	PMH-1	71	73	203.44	115	14.58	4.01	16	25.33	74.57	24.75	5.83
6	GH-150125	73	77	203.13	98.13	16.92	4.42	14	27.68	74.26	25	5.89
	CD (5 %)	7.07	7.33	24.23	20.51	2.85	0.34	1.6	7.77	4.33	4.43	1.59
	CD (1 %)	9.4	9.74	32.19	27.24	3.78	0.45	2.13	10.32	5.75	5.89	2.12
	CV (%)	5.12	5.13	6.05	9.28	9.37	4.14	5.48	13.72	2.84	8.63	11.6

DFT: Days to 50% tasseling
DFS: Days to 50% silking
PH: Plant height
CG: Cob girth
KRN: Kernel row number
NK: Number of kernels per row
GY: Grain yield
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Shelling %: Shelling percentage
CL: Cob length
EH: Ear height

and days to 50% tasseling (rg= -0.328) and days to 50% silking (rg = -0.365).

In *rabi*, all the traits showed significant positive genotypic correlation ($p < 0.01$) in the desirable direction except number of kernels row number (KRN). The genotypic correlation coefficient was positive but not significant for KRN. The genotypic correlation of grain yield was highest with plant height (rg = 0.833) followed by ear height (rg = 0.817), number of kernels per row (rg = 0.727), Cob length (rg = 0.706), cob width (rg =0.691), shelling percentage (rg = 0.658) and hundred seed weight (rg = 0.591). Negative genotypic correlation was seen for days to 50% flowering.

Path coefficients for grain yield and related traits during kharif and rabi

The path coefficients of grain yield (dependent) with

Table 4. Mean sum of squares for different traits of maize

Traits	*Kharif* (2021)		*Rabi* (2021)	
	Genotypes (df = 169)	Error (df = 169)	Genotypes (df = 109)	Error (df = 109)
Days to 50% tasseling	22.52**	2.43	34.52**	16.90
Days to 50% silking	22.51**	2.90	38.82**	49.88
Plant height	2970.74**	945.69	2085.65**	122.75
Ear height	789.79**	189.99	986.14**	79.42
Cob length	19.39**	7.39	7.04**	2.19
Cob width	2.09**	0.46	0.26**	0.04
KRN	3.55**	1.30	4.65**	0.67
Kernels per row	100.33**	22.99	39.06**	16.28
Shelling percentage	42.96**	10.64	16.74**	2.83
Hundred seed weight	99.89**	3.27	28.23**	5.63
Yield	20.99**	0.31	5.34**	0.55

** = Significant at 1% level of significance

Table 5. Estimates of variances, PCV, GCV, heritability, genetic gain and GAM for yield and its components in maize

Traits	σ^2g	σ^2p	Mean	GCV	PCV	H^2	GA	GAM (%)
Days to 50% tasseling	10.05	28.48	56.48	5.61	6.25	80.52	5.86	10.37
(*kharif* /*rabi*)	8.81	25.71	70.43	4.21	7.20	34.27	3.58	5.08
Days to 50% silking	9.81	12.71	58.38	5.36	6.11	77.17	5.67	9.71
(*kharif* /*rabi*)	10.69	28.12	72.74	4.50	7.29	38.03	4.15	5.71
Plant height	1012.53	1958.21	188.58	16.87	23.47	51.71	47.14	24.99
(*kharif* /*rabi*)	981.45	1104.20	181.70	17.24	18.29	88.88	60.84	33.48
Ear height	299.90	489.89	83.59	20.72	26.48	61.22	27.91	33.39
(*kharif* /*rabi*)	453.36	532.78	98.28	21.67	23.49	85.09	40.46	41.17
Cob length	6.00	13.39	15.47	15.84	23.66	44.81	3.38	21.84
(*kharif* /*rabi*)	2.42	4.61	14.64	10.64	14.67	52.55	2.32	15.88
Cob width	0.82	1.28	4.35	20.78	25.96	64.05	1.49	34.25
(*kharif* /*rabi*)	0.11	0.15	3.95	8.31	9.77	72.26	0.58	14.55
KRN	1.13	2.43	13.78	7.71	11.31	46.43	1.49	10.82
(*kharif* /*rabi*)	1.99	2.66	14.51	9.72	11.24	74.76	2.51	17.32
Kernels per row	38.67	61.66	28.66	21.70	27.40	62.72	10.14	35.40
(*kharif* /*rabi*)	11.39	27.67	27.16	12.43	19.37	41.17	4.46	16.43
Shelling percentage	16.16	26.80	73.92	5.44	7.00	60.31	6.43	8.70
(*kharif* /*rabi*)	5.41	11.33	75.41	3.08	4.46	47.73	3.31	4.39
Hundred seed weight	48.31	51.58	31.73	21.90	22.63	93.66	13.86	43.67
(*kharif* /*rabi*)	11.30	16.93	24.17	13.91	17.03	66.75	5.66	23.41
Yield	10.34	10.65	8.08	39.81	40.41	97.07	6.53	80.81
(*kharif* /*rabi*)	2.39	2.95	5.98	25.89	28.72	81.29	2.87	48.09

σ^2g- genotypic variance PCV- genotypic coefficient of variation GCV- genotypic coefficient of variation
σ^2p- phenotypic variance H^2- heritability (bs) GA- genetic advance GAM(%)- Genetic advance as per cent of mean

independent variables are presented in Table 9 and Table 10 for *kharif* and *rabi*, respectively. The residual effects for *kharif* and *rabi* were 0.32 and 0.14, respectively. This reveled that during *kharif* cob length (2.028), kernel row number (0.341) and hundred seed weight (0.126) had positive direct effect on grain yield. Plant height (-1.038), cob width (-0.113), number of kernels per row (1.627) and days to 50% silking (-0.430) showed negative direct effect with grain yield. Hundred seed weight (0.126) and shelling percentage (0.089) showed positive direct effects on grain yield and it also showed positive indirect effects through all other traits except days to 50% flowering.

Table 6. ANOVA for Line x Tester for grain yield and its component traits in hybrids of maize (*Zea mays* L.)

Sources	d.f.	DFT	DFS	PH	EH	CL	CW	KRN	K/R	SP	HSW	GY
Kharif												
Replication	1	22.04**	81.89**	230992.8*	45573.64**	677.13*	1.95**	0.13	3069.53*	101.42*	532.04**	34.90**
Crosses	107	10.37**	9.23**	367.52	164.89	9.95	0.19**	1.4	33.67*	14.27*	25.57**	3.25**
Lines	53	15.89**	13.85**	391.93	176.54*	10.29	0.12	1.65**	34.27	15.57	33.56*	4.24**
Tester	1	3.37	0.782	1313.94*	3708.45**	5.74	7.68**	18.94**	425.04**	35.91	2.45	16.57**
Line x Tester	53	4.97**	4.76**	325.25	86.37	9.69	0.11	0.82	25.7	12.56	18.01**	2.01**
Error	107	2.28	2.69	433.7	127.95	9.94	0.09	1.33	23.03	9.36	2.97	0.38
Total	215	6.4	6.32	1473.13	357.7	13.05	0.15	1.36	42.5	12.23	16.67	1.97
Rabi												
Replication	1	14.24	7.07	21.24	9.01	1.73	0.04	0.26	120.13**	4.66	74.23**	0.82
Crosses	67	23.35**	28.30**	445.46**	351.45**	5.68**	0.13**	3.15**	36.19**	10.40**	16.52**	3.12**
Lines	33	26.12**	30.82**	686.20**	516.72**	7.38*	0.22**	4.15**	47.34*	12.15*	18.83**	3.55**
Tester	1	3.56	87.36	75.38	1819.90*	10.35	0.33**	12.16*	2.09	22.71	43.47*	18.39**
Line x Tester	33	21.18	23.98	215.93	141.75	3.84	0.04	1.88**	26.063	8.28	13.13*	2.22**
Error	67	12.56	13.48	147.41	105.58	2.04	0.03	0.643	15.14	4.71	4.93	0.64
Total	135	17.93	20.79	294.4	226.91	3.84	0.08	1.89	26.36	7.53	12.32	1..87

Table 7. Estimation of genotypic and phenotypic correlation for maize grain yield and related traits during *kharif* 2021

		DFT	DFS	PH	EH	CL	CW	KRN	NK	HSW	SP	GY
DFT	G	1										
	P	1										
DFS	G	0.998**	1									
	P	0.961**	1									
PH	G	-0.284**	-0.315**	1								
	P	-0.317**	-0.345**	1								
EH	G	-0.275**	-0.288**	0.961**	1							
	P	-0.305**	-0.329**	0.847**	1							
CL	G	-0.420**	-0.484**	0.921**	0.864**	1						
	P	-0.288**	-0.297**	0.539**	0.557**	1						
CW	G	-0.091	-0.080	0.312**	0.401**	0.360**	1					
	P	0.050	-0.031	0.183**	0.264**	0.278**	1					
KRN	G	-0.027	-0.008	0.550**	0.588**	0.345**	0.098	1				
	P	-0.023	-0.018	0.267**	0.361**	0.225**	0.176**	1				
NK	G	-0.399**	-0.449**	0.900**	0.894**	0.977**	0.393**	0.524**	1			
	P	-0.353**	-0.376**	0.663**	0.702**	0.765**	0.283**	0.352**	1			
HSW	G	-0.392**	-0.434	0.921**	0.852**	0.840**	0.330**	0.153*	0.779**	1		
	P	-0.368**	-0.391**	0.661**	0.670**	0.586**	0.261**	0.110*	0.619**	1		
SP	G	-0.543**	-0.568**	0.731**	0.724**	0.742**	0.414**	0.191**	0.748**	0.618**	1	
	P	-0.376**	-0.392**	0.388**	0.436**	0.457**	0.262**	0.125*	0.525**	0.462**	1	
GY	G	-0.328**	-0.365**	0.972**	0.980**	0.914**	0.300**	0.432**	0.937**	0.835**	0.684**	1
	P	-0.306**	-0.336**	0.739**	0.784**	0.627**	0.236**	0.306**	0.746**	0.798**	0.539**	1

Table 8. Estimation of genotypic and phenotypic correlation for maize grain yield and related traits during *rabi* 2021

		DFT	DFS	PH	EH	CL	CW	KRN	NK	HSW	SP	GY
DFT	G	1										
	P	1										
DFS	G	0.961**	1									
	P	0.962**	1									
PH	G	-0.389 **	-0.294 **	1								
	P	-0.191 **	-0.154 *	1								
EH	G	-0.423 **	-0.308 **	0.938 **	1							
	P	-0.197 **	-0.154 *	0.915 **	1							
CL	G	-0.366 **	-0.383 **	0.657 **	0.611 **	1						
	P	-0.295 **	-0.330 **	0.395 **	0.373 **	1						
CW	G	-0.443 **	-0.346 **	0.677 **	0.677 **	0.333 **	1					
	P	-0.316 **	-0.282 **	0.519 **	0.528 **	0.458**	1					
KRN	G	-0.267 **	-0.176	0.262 **	0.361 **	-0.038	0.510 **	1				
	P	-0.067	-0.035	0.141 *	0.204 **	0.033	0.395 **	1				
NK	G	-0.558 **	-0.520 **	0.657 **	0.670 **	0.854 **	0.379 **	0.051	1			
	P	-0.305 **	-0.338 **	0.309 **	0.339 **	0.805 **	0.433 **	0.079	1			
SP	G	-0.797 **	-0.617 **	0.566 **	0.588 **	0.454 **	0.583 **	0.332 **	0.656 **	1		
	P	-0.291 **	-0.251 **	0.357 **	0.362 **	0.329 **	0.398 **	0.194 **	0.458 **	1		
HSW	G	-0.276 **	-0.272 **	0.646 **	0.551 **	0.539 **	0.503 **	-0.189 *	0.274 **	0.368 **	1	
	P	-0.246 **	-0.248 **	0.488 **	0.415 **	0.479 **	0.484 **	-0.137 *	0.260 **	0.197 **	1	
GY	G	-0.545 **	-0.494 **	0.833 **	0.817 **	0.706 **	0.691 **	0.160	0.727 **	0.591 **	0.658 **	1
	P	-0.335 **	-0.348 **	0.705 **	0.684 **	0.647 **	0.642 **	0.111	0.607 **	0.394 **	0.567 **	1

Table 9. Direct (bold face) and indirect effects of different traits on grain yield during *kharif* 2021

	DFT	DFS	PH	EH	CL	CW	KRN	NK	HSW	SP
DFT	**0.481**	0.480	-0.136	-0.132	-0.202	-0.044	-0.013	-0.192	-0.188	-0.261
DFS	-0.430	**-0.430**	0.135	0.124	0.208	0.035	0.003	0.193	0.187	0.245
PH	0.295	0.327	**-1.038**	-0.997	-0.956	-0.324	-0.571	-0.935	-0.956	-0.759
EH	-0.373	-0.392	1.306	**1.360**	1.175	0.545	0.799	1.216	1.158	0.985
CL	-0.852	-0.981	1.868	1.752	**2.028**	0.730	0.699	1.981	1.704	1.505
CW	0.010	0.009	-0.035	-0.045	-0.041	**-0.113**	-0.011	-0.045	-0.037	-0.047
KRN	-0.009	-0.003	0.188	0.201	0.118	0.033	**0.341**	0.179	0.052	0.065
NK	0.649	0.731	-1.464	-1.454	-1.589	-0.640	-0.853	**-1.627**	-1.266	-1.217
HSW	-0.049	-0.055	0.116	0.107	0.106	0.042	0.019	0.098	**0.126**	0.078
SP	-0.048	-0.051	0.065	0.065	0.066	0.037	0.017	0.067	0.055	**0.089**

Residual effect = 0.3185

During *rabi*, cob width (0.578) had maximum direct effect on grain yield followed by ear height (0.461), cob length (0.412), and plant height (0.146). Cob width had highest direct effect but it showed negative indirect effects through kernel row number (KRN) (-0.273), number of kernels per row (NK) (-0.101), hundred seed weight (-0.034) and shelling percentage (-0.138). Though KRN and NK showed negative direct effects (-0.456 and -0.266 respectively), it possessed positive indirect on grain yield through cob length (0.016/0.352) and cob width (0.347/0.219). Hundred seed weight showed negative direct effect (-0.021) on grain yield but it has positive indirect effect through all other traits except NK (-0.073) and shelling percentage (-0.27). Shelling percentage had

Table 10. Direct (bold face) and indirect effects of different traits on grain yield *rabi* 2021

	DFT	DFS	PH	EH	CL	CW	KRN	NK	HSW	SP
DFT	**-0.121**	-0.156	-0.057	-0.195	-0.151	-0.256	0.122	0.149	0.046	0.076
DFS	-0.117	**-0.163**	-0.043	-0.142	-0.158	-0.200	0.080	0.138	0.035	0.074
PH	0.047	0.048	**0.146**	0.433	0.271	0.391	-0.119	-0.175	-0.033	-0.177
EH	0.051	0.050	0.137	**0.461**	0.252	0.391	-0.164	-0.178	-0.034	-0.151
CL	0.044	0.062	0.096	0.282	**0.412**	0.192	0.017	-0.227	-0.026	-0.147
CW	0.054	0.056	0.099	0.313	0.137	**0.578**	-0.273	-0.101	-0.034	-0.138
KRN	0.032	0.029	0.038	-0.166	0.016	0.347	**-0.456**	-0.014	-0.019	0.052
NK	0.068	0.085	0.096	0.309	0.352	0.219	-0.023	**-0.266**	-0.038	-0.075
HSW	0.034	0.044	0.095	0.254	0.222	0.291	0.086	-0.073	**-0.021**	-0.274
SP	0.097	0.100	0.083	0.271	0.187	0.337	-0.151	-0.175	-0.057	**-0.101**

Residual effect= 0.1441

negative direct effect (-0.101) on grain yield and its indirect effects *via* KRN (-0.175) and NK (-0.057) was also negative.

Discussion

Analysis of variance indicated significant mean sum of squares due to lines, testers, crosses for the traits studied indicating the presence of genetic variability among the yield attributing traits of maize genotypes, lines, testers and crosses studied (Table 4 and 6).

In the present study, high PCV and GCV was observed for most of the traits (Table 5). The GCV and PCV values ranged from low (less than 10%), moderate (10-20%) and high (more than 20%) during both *kharif* and *rabi* seasons. However, the GCV values were lower than PCV values which indicate the influence of environment for the expression of the trait. This is in line with the work of Magar *et al*. (2021); Wedwessen and Zeleke (2020). The low GCV was observed for shelling percentage and days to 50% flowering indicated that improvement through selection is less effective as they were highly affected by environment. This result is in parallel with the findings of Dutta *et al*. (2017) and Kumar *et al.* (2021).

During *kharif*, the difference between GCV and PCV was lower for traits, DFT, DFS, HSW, shelling percentage and yield. In contrast, higher difference was observed for PH, EH, CL, CW, KRN and NK which indicated that these characters are highly influenced by environment. During *rabi*, CL, NK and HSW showed higher difference between GCV and PCV and rest of the traits showed lower difference. The response to selection would be effective in those traits which are less influenced by environment.

Heritability is a measure of the phenotypic variance attributable to genetic causes and has predictive function in plant breeding. It provides information on the extent to which a particular morphogenetic trait can be transmitted to successive generation. Broad sense heritability (H^2), an estimate of the total contribution of the genetic variance to the total phenotypic variance of trait ranged from 44.81 to 97.07 (*kharif*) and 34.27 to 88.88 (*rabi*). Thus, in the present study, the estimates of heritability for various traits were found be either moderate (30-60%) or high (more than 60%), as defined by Johanson *et al*. (1955). According to Waqar *et al.* (2008) traits with high heritability can easily be fixed with simple selection resulting in quick progress. In consistent with these results Ghosh *et al*. (2014) and Bello *et al*. (2012) reported that traits with high heritability and moderately high genetic advance such as hundred seed weight, kernels per row, ear height and plant height indicate the importance of additive gene action where cautious selection may lead towards improvement for these traits.

According to Johnson *et al*. (1955), the observed GAM values were classified as low (less than 10%), moderate (10–20%), and high (greater than 20%). The genetic advance as percent of the mean (GAM) at 5% selection intensity ranged from 8.70% and 4.39% for shelling percentage to 80.81% and 48.09% for grain yield during *kharif* and *rabi,* respectively. The traits like grain yield (80.81, 48.09), hundred seed weight (43.67, 23.41), plant height (24.99, 33.48), ear height (33.39,41.17) showed high GAM in both seasons indicating possibility of genetic improvement in these traits. The results are in agreement with that of Dar *et al*. (2018) and Maruthi and Rani (2015).

Correlation among the characters may be the result of genetic association between the traits. Type of association of grain yield and its attributing traits is very important for a breeder. In the present study it is seen that genotypic correlation was higher than phenotypic correlation which indicates the presence of higher genetic association among the traits with yield. The results of correlation studies (Table 7 and 8) revealed that grain yield had significant genotypic and phenotypic association with cob position, cob length, cob width, KRN, NK, hundred seed weight and shelling percentage. The results are in parallel with the findings of Singh *et al*. (2017); Izzam *et al*. (2017) and Aman *et al*. (2020). This suggested that improvement in maize grain yield can be brought about through improvement of these traits which are linked with grain yield. Negative genotypic and phenotypic association of days to 50% flowering at both genotypic and phenotypic level were reported previously by Natraj *et al*. (2014).

Path coefficient analysis (Table 9 and 10) revealed that cob length, cob width, KRN, hundred seed weight, plant height and ear height had positive direct effect on grain yield. Positive direct of the traits on grain yield indicate the effectiveness of direct selection of these trait on grain yield (Varalakshmi *et al*., 2018). Cob width showed direct negative effect on grain yield (-0.113) during *kharif* and its genotypic correlation with grain yield was also significant (0.300) which explains the association between these traits. However, cob width showed negative indirect effect through other important traits like cob length, KRN, NK, HSW and shelling percentage with very low magnitude.

Plant height and ear height are important traits that effect the grain yield. Positive direct effect of both of these traits is undesirable. Taller plants need more nutrients to complete vegetative growth rather than reproductive stage which results in delayed maturation of cob. Plant having ear placement at higher position reduces the grain yield because of late pollination and lesser or no grain filling (Munawar *et al*., 2013). Cob length had positive direct effect on grain yield in both the seasons so, this may be used as reliable criteria for high yielding maize genotypes.

The residual effects recorded in the experiment were 0.3185 (*kharif*) and 0.1441 (*rabi*), which indicated that the traits studied in our experiment explained around 68.15 and 85.59 percent of variations during *kharif* and *rabi*, respectively. This indicated to include some more independent variable to explain more per cent variations in the grain yield in maize. Similar result with respect to residual effects was observed by Aman *et al*. (2020).

Conclusion

The genotypes included had significant genetic variability as reflected by ANOVA, GCV and PCV for the majority of traits studied and there is possibility of genetic enhancement through selection among the genotypes for grain yield and other traits of interest. Traits showing high heritability coupled with high genetic advance indicates that these traits can be improved through direct selection as the additive gene effects are predominant. Traits with a high genetic advance as percent of mean allow the improvement of these traits through selection. The combined interpretation of trait association analyses suggested placing more emphasis on traits like cob length, cob width, kernel row number, number of kernels per row, hundred seed weight to improve grain yield in maize, which showed high genotypic and phenotypic correlation with considerable direct and indirect effect on yield. Genotypic correlation explains the true association as they exclude environmental influence. Thus, the selection based on genotypic correlation is more reliable. These results might be confirmed by multi-environment testing of genotypes to come up with more accurate estimates for these genetic parameters, which would further aid in devising an appropriate breeding strategy.

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RESEARCH PAPER

Innovative approaches to enhance maize growth and yield *via* residue and nitrogen management in conservation agriculture practices

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Abstract: A field experiment was conducted during the *kharif* season of 2018 and 2019 for exploring the influence of differential residue and nitrogen management practices on growth parameters and physiological indices of maize under conservation agriculture on a sandy loam soil at New Delhi. The treatments consisted of two cropping systems: maize-mustard-mungbean (MMuMb) and maize-wheat-mungbean (MWMb); two residue management practices of with (WR) and without residue (WoR) and four precise N management practices of recommended dose of nitrogen (RDN), 33% N at basal with green seeker (GS), 50% N at basal with GS, and 70% N at basal with GS arranged in split-split plot design and replicated thrice. The results of the study indicated that growth parameters, physiological indices and yield attributes in maize were increased significantly with residue retention and 50% N at basal with green seeker in MWMb. Higher dry matter accumulation (177.2 and 172.2 g/plant), and LAI (3.07 in second year) was recorded under 50+GS compared to RDN application. Based on pooled data of yield attributes, the highest number of cobs (65.4 10^3/ha) and cob length (19.3 cm) values were observed with the 50+GS at 90 DAS, whereas barrenness (9.2%) followed by WR (9.1%) compared with irrespective treatments. The highest grain rows per cob (17.8), grains per row (36.1) and grains per cob (453.6) in maize plants were recorded under 50+GS followed by WR (16.2, 34.6 and 414.2) as compared to other treatments.

Keywords: Conservation agriculture · Growth and yield attributes · Green seeker · Residue · Maize · Nitrogen

Introduction

Maize is grown throughout year in India and third most important cereal after wheat and rice. India needs to produce 40-45 million tons of maize to support the needs of ethanol production, growing demand from poultry. Presently maize is grown in 155 nations around the world across the agro ecologies. Maize is grown in an area of around 10 m ha, with average productivity of 3.5 tons ha^{-1} and total production of 34.15 MT (DACNET, 2022). Majority of maize produced in India 47 per cent, is used by poultry. Due to the government policies and depletion of non-renewable fuels there is boom in ethanol production increasing the demand for maize (IIMR, 2023). To meet out the tremendous need of the various industries there is need to improve the productivity and acreage without affecting the environment. Although, maize is growth throughout year, ~85 per cent of the maize is grown in *kharif* season and national average productivity of maize is low (3.4 ton /ha) compared to global average. This low productivity of maize is mainly governed by the availability of growth promoting factors such as soil moisture, declining soil fertility, poor faulty agronomic practices; lower demand based nutrient supply (Meena *et al.*, 2021; Parihar *et al.*, 2018). An Indo-Gangetic plain (IGP) is food basket of India contributing

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nearly 32 per cent of cereal production. Introduction of high yielding varieties of wheat and rice along with improved production technologies secured the food needs. Monocropping, indiscriminate use of inputs (fertilizers and pesticides) use in dominant rice and wheat lead to malnutrition, diminishing total factor productivity, and natural resource degradation affect sustainability of the agro-ecosystem and economic condition of the small farmers who are already vulnerable to climate change. To break these vicious cropping systems there is need to formulate the crop and cropping system, which are more sustainable in production, economically profitable and ecological friendly. Due to its wide adoptability in various ecologies of the country, maize can be a viable alternative to rice and a potential driver for crop diversification of the rice-wheat system in IGP of India (Parihar *et al.*, 2019; Das *et al.*, 2013). Maize is an exhaustive crop and removes large amounts of plant nutrients from the soil to support high biomass production. Thus, nutrient restoring cropping systems need to be adopted, apart from Maize-wheat cropping system authors have tested various cropping systems across IGP and South East Asia namely maize- mustard (Parihar *et al.*, 2019). Along with these declined crop production and resources, India faces the challenge of factors of production like shortage of labour, shooting up of oil prices and residue burning. Cumulative effect of these constraints, forced the global and Indian farmers to find alternate to these severities. Harvesting residues should be considered as a resource that can be utilized as organic raw material, which could be used to improve soil quality and productivity though soil C sequestration. Conservation agriculture along with precise use of natural resources (water and crop residue) along with judicious use of external inputs improves the soil physical, chemical and biological properties improving the maize production in the region (Jat *et al.*, 2019; Kumar *et al*., 2020). Tillage practices enhances the soil drying and heating/cooling processes (Ussiri and Lal, 2009) as it disturbs the soil surface and thus increases the loss of N from the soil by volatilization and results in lower N use efficiency (NUE).

Nitrogen is vital nutrient requited for growth and development of crop and its deficiency is one of the constraints to growth. Nitrogen application through crop residue along with supplying the nitrogen significantly improves the soil physical, chemical and biological fertility (Gosh, 2015). Indiscriminate use of nitrogenous fertilizers in the RW cropping systems in IGP over last decades caused the land barren and multi-nutrient deficiency. Nitrogen demand in maize is peak during silking to grain filling stage (Adhikari *et al.,* 2016) Use of precision nitrogen management tools such as green seeker, SPAD meter, leaf color chars increase the synchrony between N supply and crop demand throughout the growing season reducing the losses. Precision nitrogen management tools save 10-25 per cent of in season fertilizer N (Jat *et al.*, 2019; Manjunath *et al*., 2021). Conservation agriculture practices coupled with PNM options in Maize-wheat-mungbean and fertilizer N (Meena *et al.*, 2021). Conservation agriculture practices coupled with PNM options in maize-mustard-mungbean cropping systems found to be best in IGP (Jat *et al.*, 2019; Parihar *et al.*, 2019). In IGP noted 32.3 per cent more grains, 57.4 per cent higher economic profitability along with 43.8, 27.5 and 259.8 per cent higher protein, carbohydrate and fat yields, respectively, with maize based cropping systems. Maize growth, leaf N content, chlorophyll and yield are positively correlated and indicate the higher source and sink relations. Using the canopy chlorophyll, nitrogen demand of the crop in season can be determined. Development of critical values for N dosage and relationship between spectral canopy reflectance and yield in maize under CA are limited. Management of N in CA system is new approach involving the interaction of crop residue and nitrogen and its mechanisms in crop production. To achieve the huge demand of maize in India there is a need for proper N management practices for accelerating higher production sustainably. In this view, an attempt has been made to study the response of maize growth to crop residue and PNM options under conservation agriculture.

Materials and methods

The fixed plot experiment was conducted during *kharif* 2018 and 2019 at ICAR-Indian Agricultural Research Institute, New Delhi. The trial was initiated during 2012 and the study was a part of the long-term experiment on maize-wheat-mungbean and maize-mustard-mungbean cropping system under conservation agriculture. The soil was sandy loam, slightly alkaline (pH 7.8) having 0.42 per cent organic carbon, low in available N (240 kg/ha), medium in available P (15.2 kg/ha) and high in available potassium (240.8 kg/ha). The weather condition was congenial for crop growth, rainfall was well distributed during both seasons. The experiment was laid out in split-split plot design, with treatment combinations of two maize based cropping systems: maize-mustard-mungbean (MMuMb) and maize-wheat-mungbean (MWMb) as main plot; two crop residue management options with residue (WR) and without residue (WoR) as sub plots and four nitrogen management [PNM_1- Recommended dose of nitrogen (RDN), PNM_2- 33% basal RDN+ Green seeker guided N application (33+GS), PNM_3- 50% basal RDN + GS guided N application (50+GS), PNM_4- 70% basal RDN + GS guided N application (70+GS)]. Fertilizer application to the treatments done in the form of urea, single super phosphate and muriate of potash. Previous crop (Green gram) residue was placed in the with residue (WR) treatments, while removed from the without residue (WoR). Green seeker was used for in season N requirement calculation at 32 and 42 DAS. Maize (cv. DMH-1) was planted at 67 cm × 45 cm spacing. Recommended package of practices for plant protection, irrigation and weed management done uniformly irrespective of the treatments. The observations are recorded treatment wise and the growth attributes viz., plant height (cm), leaf area index and dry matter accumulation (g/plant) were recorded with standard procedure. The physiological indices *viz.*, crop growth rate (g/plant/day), relative growth rate (mg/g/day) and net assimilation rate (g/cm^2 leaf area/day) were also computed using standard formulae. The yield attributes viz., Cobs (10^3/ha), barrenness (%), cob length (cm), grain rows per cob, grains per row and grains per cob were recorded in maize at harvest.

The data recorded were analyzed with analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for a split-split-plot design using Microsoft excel-2010. The least significant difference tested at 5% level of significance. The Bartlett's homogeneity test was performed before pooled analysis.

Results and discussion

Plant stand at harvest stage

The data pertaining to plant stand at harvest for the individual year and pooled analysis are presented in Table 1. The cropping system (CS), crop residue management (CRM) and precision nitrogen management (PNM) was significantly influenced the final plant stand of maize. However, CS had a non-significant effect in the final plant stand with higher in MWMb (65.7 and 63.7 x10^3 plants/ha) during both the years. The WR (67.1 x10^3

Table 1. Effect of cropping systems, residue and precision nitrogen management options on plant stand of *kharif* maize crop under conservation agriculture in the study

Treatments	Plant stand at harvest (×10^3/ha)		
	2018	2019	Pooled
Cropping system (CS)			
MMuMb	65.5	61.4	63.5
MWMb	65.7	63.7	64.7
SEm±	0.53	0.59	0.40
LSD ($P \leq 0.05$)	NS	NS	NS
Crop residue management (CRM)			
WoR	64.2	57.8	61.0
WR	67.1	67.3	67.2
SEm±	0.67	0.85	0.54
LSD (P≤0.05)	2.61	3.32	1.75
Precision nitrogen management (PNM)			
RDN	63.5	62.7	63.1
33+GS	65.8	62.6	64.2
50+GS	67.9	62.6	65.3
70+GS	65.2	62.3	63.8
SEm±	2.06	1.08	1.16
LSD (P≤0.05)	6.00	NS	NS
CS ×CRM	NS	NS	NS
CS×PNM	8.48	NS	NS
CRM×PNM	8.48	4.47	NS
CS×CRM×PNM	12.00	NS	NS
Year			
Year-1	-	-	65.6
Year-2	-	-	62.5
SEm±	-	-	0.40
LSD (P≤0.05)	-	-	1.55
Y×CS	-	-	NS
Y×CRM	-	-	2.48
Y×CS×CRM	-	-	NS
Y×PNM	-	-	NS
Y×CS×PNM	-	-	NS
Y×CRM×PNM	-	-	NS
Y×CS×CRM×PNM	-	-	NS

Where; CS: Cropping system; CRM: Crop residue management; PNM: Precision nitrogen management; MMuMb: Maize-Mustard-Mungbean; MWMb: Maize-Wheat-Mungbean; WoR: Without residue; WR: With residue; RDN: Recommended dose of nitrogen; GS: Green seeker; NS: Non-significant plants/ha) and 50+GS (67.9 x10^3 plants/ha) had significantly higher final plant stands over MMuMb, WoR and the rest of PNM treatments, respectively. The second year had a significantly lower final plant stand initially compared to the first year. On the pooled basis, the residue application gave 10.2 per cent higher final plant stand over the WoR treatment. The plant population of maize was lower in case of conservation agriculture plots due to the effect of termites and resistance from the crop residue. While after, crop residue had beneficial effect providing the moisture for early growth and development. The use of 50+GS gave significant effect at final plants stand of maize over RDN, 33+GS and 70+GS during first year, while the differences were non–significant during second year (Table 2). The interactions among the treatments found inconsistent throughout the experiment. However, the Y×CRM had an interaction effect with years on the final plant stand of the maize crop indicating beneficial effect of CA on plant growth upon years (Table 1).

Growth attributes

The plant height, leaf area index and dry matter accumulation of maize was responsive to various treatments in the application and are significantly influenced at 90 DAS (Table 2). The plant height of maize shown significant difference due to crop residue and PNM options while CS has not reported a significant difference. Application of 50+GS recorded the highest plant height, RDN and 70+GS being at par with each other. Although the difference in plant height was non-significant in the years while the 2018 cropping season was higher compared to 2019, and similarly, there is no significant interaction between treatment and years.

The photosynthetic efficiency and dry matter accumulation was depends on the leaf characters, which upon depends on the nitrogen supply to the plant through soil. The leaf area index (LAI) reached highest at 60-90 days and declined at 90 DAS (Table 2). Residue added plots (WR) consistently observed the highest LAI during 2018 and 2019 as well as with pooled data at 90 DAS (3.01, 2.87 & 2.94). The congenial conditions, higher soil moisture and lower soil temperature might have favoured the maize to produce higher leaf area and index. Meena *et al.* (2021); Parihar *et al.* (2018); (2019); Jat *et al.* (2019) also observed beneficial effect of crop residue in CA. Further, the effect of PNM the LAI at 90 DAS, 70+GS reported the highest LAI after 50+GS. Higher crop residue addition from the previous crop (Wheat and Mung bean), beneficial effect of Crop residue and higher N at basal might have improved the mineralization of crop residue releasing N for longer time. This resulted in the highest LAI with MWMb × WR and WR×50+GS treatment combinations. The interaction of Y × CS × CRM was significant for 90 DAS of the crop (Table 2).

Similar observations were recorded in dry matter accumulation (DMA), MWMb cropping system, reported higher values of DMA at 90 DAS during both the years and data pooled basis (158.6, 162.8 and 160.7 g/plant) (Table 2 and Figure 1). Among CRM & PNM, the highest dry-matter production on the pooled basis was reported with the treatment combination of WR & 50+GS treatment (163.5 and 174.5 g /plant, respectively) at 90 DAS of the crop. The increase in pooled DMA at 90 DAS due to MWMb, WR, and 50+GS was 4.6, 8.3 and 17.0 per cent over MMuMb, WoR and RDN, respectively. Significant interaction of the treatments were observed among the treatments (Table 3), the MWMb cropping system combined with WR-50+GS gave significantly higher DMA at 90 DAS (197.8 g/plant). The higher value of these growth parameters due to residue application was observed, which enhanced the nutrient supply through its subsequent decomposition coupled with favourable moisture condition created conducive environment for vigorous root growth which ultimately resulted better crop growth and development (Das *et al.,* 2013; Singh *et al.,* 2007). Ram (2005) has also reported that residue retention on soil surface enhanced crop growth parameters at different crop stages as compared to its removal. In contrast to this, in temperate regions negative effect of residue retention on crop growth was noticed probably due to high initial soil organic carbon and slow residue degradation and immobilization of applied nutrients (Rice and Smith, 1984; Thuy *et al.,* 2008). Accordingly, more number of leaves with expanded leaf blade was produced consequently increased leaf area index.

Plant growth rates

The data pertaining to CGR, RGR and NAR in maize plants at 90 DAS are presented in Table 4. The cropping system tested no significant effect on CGR at 60-90 DAS during the both years. However, on the pooled data at 90 DAS,

Table 2. Effect of cropping systems, residue and nitrogen management options on plant height, LAI and DMA of *kharif* maize at 90 DAS (days after sowing) under conservation agriculture

Treatments	Plant height (cm)			LAI			DMA (g/plant)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
Cropping system (CS)									
MMuMb	183.9	182.4	183.2	2.75	2.65	2.70	154.7	152.7	153.7
MWMb	187.3	182.4	184.8	2.97	2.81	2.89	158.6	162.8	160.7
SEm±	3.02	2.71	2.03	0.06	0.12	0.07	3.84	2.62	2.32
LSD (P≤0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop residue management (CRM)									
WoR	182.8	179.9	181.3	2.71	2.58	2.64	150.2	151.7	150.9
WR	188.5	184.9	186.7	3.01	2.87	2.94	163.1	163.9	163.5
SEm±	2.03	1.00	1.13	0.05	0.07	0.04	1.17	1.99	1.15
LSD (P≤0.05)	NS	3.94	3.69	0.202	0.284	0.145	4.59	7.80	3.76
Precision nitrogen management (PNM)									
RDN	184.1	180.5	182.3	2.83	2.63	2.73	148.9	149.0	148.9
33+GS	183.4	182.4	182.9	2.68	2.62	2.65	143.9	154.7	149.3
50+GS	191.9	187.9	189.9	2.99	3.07	3.03	177.2	172.2	174.7
70+GS	183.1	178.7	180.9	2.94	2.59	2.77	156.5	155.2	155.8
SEm±	2.36	2.77	1.82	0.07	0.12	0.07	3.52	2.44	2.14
LSD (P≤0.05)	6.88	NS	5.17	0.21	0.35	0.20	10.27	7.11	6.09
CS ×CRM	NS	5.6	NS	NS	0.40	NS	6.49	NS	NS
CS×PNM	NS	NS	NS	0.299	NS	NS	NS	10.05	NS
CRM×PNM	NS	NS	NS	0.299	NS	NS	14.53	10.05	8.61
CS×CRM×PNM	NS	NS	NS	0.424	NS	NS	20.55	14.22	12.17
Year									
Year-1	-	-	185.6	-	-	2.86	-	-	20.7
Year-2	-	-	182.4	-	-	2.73	-	-	19.3
SEm±	-	-	2.03	-	-	0.066	-	-	2.32
LSD (P≤0.05)	-	-	NS	-	-	NS	-	-	NS
Y×CS	-	-	NS	-	-	NS	-	-	NS
Y×CRM	-	-	NS	-	-	NS	-	-	NS
Y×CS×CRM	-	-	NS	-	-	0.289	-	-	7.52
Y×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CS×PNM	-	-	NS	-	-	NS	-	-	12.17
Y×CRM×PNM	-	-	NS	-	-	NS	-	-	12.17
Y×CS×CRM×PNM	-	-	NS	-	-	NS	-	-	17.21

Where; CS: Cropping system; CRM: Crop residue management; PNM: Precision nitrogen management; MMuMb: Maize-Mustard-Mungbean; MWMb: Maize-Wheat-Mungbean; WoR: Without residue; WR: With residue; RDN: Recommended dose of nitrogen; GS: Green seeker; NS: Non-significant

CGR was significantly higher in MWMb cropping system. Crop growth was maximum with WR treatment and consistently increased with the age of the crop during both years (19.8 g/plant/day). Surprisingly, the CGR was significantly influenced by PNM options at 90 DAS on pooled basis. Among PNM options, the highest CGR was recorded with 50+GS treatment at 90 (Table 4).

Relative growth rate of maize under CA was significantly influenced unlike CGR. The difference in RGR due to the cropping system and CRM was significant

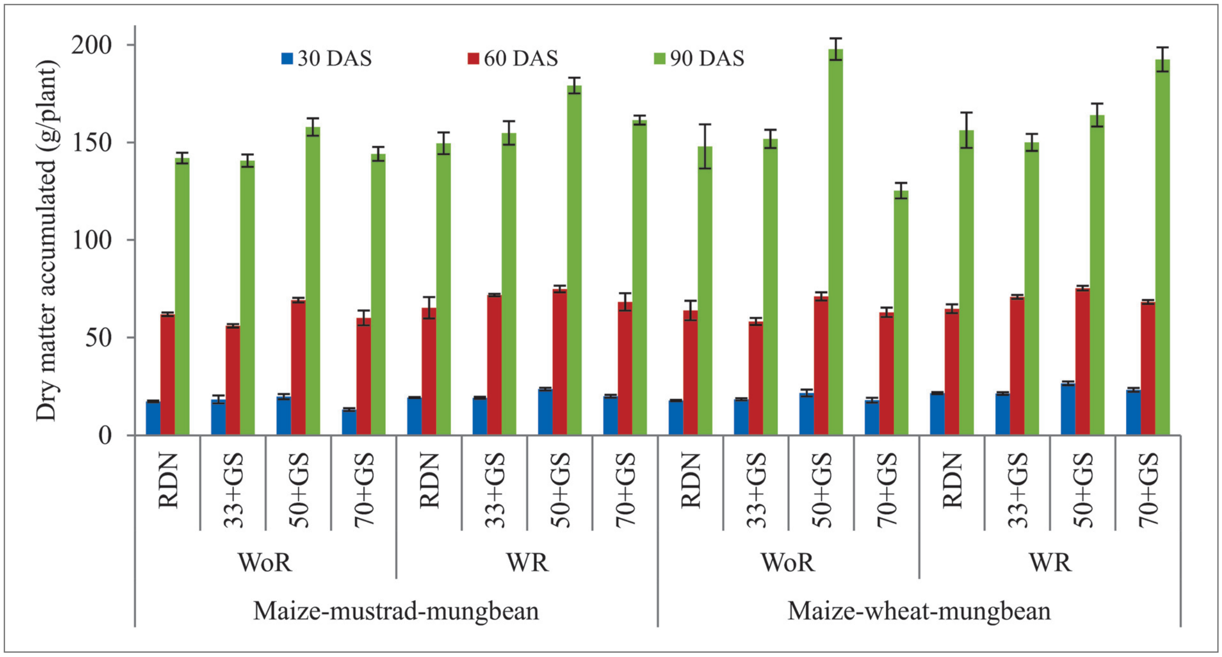

Figure 1. Dry matter accumulation in maize at different intervals as influenced by cropping systems, crop residue and PNM options under conservation agriculture (pooled mean of 2 years). The vertical bars represent the standard deviation

Table 3. Interaction effect of cropping system, residue and nitrogen management options on dry matter accumulation (DMA) of maize under conservation agriculture

CS×CRM×PNM	Pooled DMA (g/plant) at 90 DAS			
	RDN	33+GS	50+GS	70+GS
MMuMb-WoR	142.0	140.6	157.9	144.1
MMuMb-WR	149.6	154.8	179.1	161.5
MWMb-WoR	147.9	151.8	197.8	125.3
MWMb-WR	156.3	150.0	164.0	192.5
LSD *($P \leq 0.05$)*	12.17			

at 60-90 DAS during both the years and on pooled basis (Table 4). Among PNM options, 50+GS treatment (72.9 mg/g/day) followed by RDN (71.1 mg/g/day) recorded higher RGR. The difference in mean NAR was significant only on pooled basis. No significant difference in NAR was noted due to crop residue addition during both the years as well as combined analysis. Meena *et al.* (2021) noted similar observations under maize based cropping systems under CA. Effects of residue retention's enhancement in crop growth were also reported by many workers in varied ecologies (Campbell *et al.*, 2000).

Yield Attributes

The conservation agriculture supported the robust growth of maize, which inturn positively influenced the yield attributes (Table 5 and 6). The MWMb non-significantly reported higher cobs/ha compared to MMuMb (64.9; 53.4 and 59.1×10^3). However, 11.32 per cent higher cobs/ha were produced in residue retained treatment (WR) over residue removal (WoR). Among PNM options, 50+GS treatments produced significantly higher cobs per ha, followed by 70+GS on a pooled basis. Due to PNM options, 14.38% more cobs are recorded compared to RDN and among PNM 10.9 per cent higher cobs are noted compared to 70+GS. There was a significant difference in cobs per ha due to growing seasons of 2018 and 2019, on average 20 per cent higher cobs are obtained during the 2018 cropping season compared to 2019. The failure of a plant to produce a normal ear is termed as bareness in maize. The MMuMb cropping system resulted higher barrenness (8.6%) compared to MWMb (8.0%) in the study (Table 6). Similarly, WoR recorded significantly higher barrenness (7.4%) compared to WR. Among PNM options, the lowest barrenness was recorded with 50+GS treatment (7.0%). No significant effect was observed in cob length by cropping systems while WR resulted in significantly lengthy cobs (18.4 cm) compared to WoR (17.9 cm). Application of 50+GS produced higher cob length (19.2 cm) however, 70% basal + GS treatment (18.4 cm) and 33% basal + GS (PNM2) and RDN were found statistically at par (Table 4). Yield attributes are mostly governed by the genetic

Table 4. Effect of cropping systems, residue and nitrogen management options on CGR, RGR and NAR of *kharif* maize at 60-90 DAS under conservation agriculture

Treatments	CGR (g/plant/day)			RGR (mg/g/day)			NAR (mg/cm^2 LA/day)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
Cropping system (CS)									
MMuMb	17.5	17.7	17.6	71.2	70.3	70.8	4.47	4.34	4.41
MWMb	20.3	19.8	20.0	72.7	71.9	72.3	4.64	4.62	4.63
SEm±	0.78	0.55	0.48	0.17	0.25	0.15	0.051	0.078	0.047
LSD (P≤0.05)	NS	NS	1.87	1.05	1.52	0.60	NS	NS	0.184
Crop residue management (CRM)									
WoR	17.3	18.2	17.8	71.2	70.5	70.9	4.5	4.4	4.5
WR	20.5	19.3	19.9	72.7	71.7	72.2	4.6	4.6	4.6
SEm±	0.63	0.45	0.39	0.17	0.17	0.12	0.045	0.052	0.034
LSD (P≤0.05)	2.47	NS	1.26	0.67	0.66	0.39	NS	NS	NS
Precision nitrogen management (PNM)									
RDN	20.5	18.2	19.3	73.1	70.2	71.7	4.96	4.03	4.50
33+GS	15.1	17.7	16.4	69.7	70.9	70.3	4.09	4.69	4.39
50+GS	20.9	21.3	21.1	73.5	72.4	72.9	4.84	4.63	4.74
70+GS	19.2	17.8	18.5	71.5	70.9	71.2	4.33	4.57	4.45
SEm±	0.80	0.52	0.48	0.15	0.22	0.14	0.1	0.1	0.1
LSD (P≤0.05)	2.34	1.51	1.36	0.44	NS	0.38	NS	NS	0.152
CS ×CRM	NS	NS	NS	NS	NS	NS	NS	0.291	0.159
CS×PNM	NS	NS	NS	NS	NS	0.54	NS	NS	0.215
CRM×PNM	3.31	2.14	1.92	NS	NS	0.54	NS	NS	0.215
CS×CRM×PNM	4.68	NS	2.72	NS	NS	0.77	NS	NS	0.304
Year									
Year-1	-	-	18.9	-	-	72.0	-	-	4.56
Year-2	-	-	18.8	-	-	2.0	-	-	4.48
SEm±	-	-	0.48	-	-	0.15	-	-	0.047
LSD (P≤0.05)	-	-	NS	-	-	0.60	-	-	NS
Y×CS	-	-	1.87	-	-	NS	-	-	NS
Y×CRM	-	-	NS	-	-	NS	-	-	NS
Y×CS×CRM	-	-	NS	-	-	NS	-	-	0.224
Y×PNM	-	-	1.22	-	-	0.54	-	-	0.215
Y×CS×PNM	-	-	1.73	-	-	0.77	-	-	0.304
Y×CRM×PNM	-	-	NS	-	-	0.77	-	-	0.304
Y×CS×CRM×PNM	-	-	NS	-	-	1.09	-	-	0.430

Where; CS: Cropping system; CRM: Crop residue management; PNM: Precision nitrogen management; MMuMb: Maize-Mustard-Mungbean; MWMb: Maize-Wheat-Mungbean; WoR: Without residue; WR: With residue; RDN: Recommended dose of nitrogen; GS: Green seeker; NS: Non-significant

factors and seldom influenced by the management factors might be the reason for non-significance response of maize to cropping system followed.

The difference in the mean value of grain rows/cob due to the cropping system and CRM options were non-significant during both the years and in the pooled analysis (Table 6). Application of N as 50+GS significantly improved grains row/cob (36.1) on pooled analysis. Similarly, another important yield trait grains/row was significantly differed with cropping system and residue application, highest reporting from MWMb and WR (34.3 and 34.6) compared to MMuMb and WoR on pooled

Table 5. Effect of cropping systems, residue and nitrogen management options on cob parameters of *kharif* maize under conservation agriculture in the study

Treatments	Cobs (10^3/ha)			Barrenness (%)			Cob Length (cm)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
Cropping system (CS)									
MMuMb	64.9	53.4	59.1	9.6	7.6	8.6	17.9	18.0	17.9
MWMb	65.1	54.4	59.8	8.0	8.0	8.0	18.0	18.6	18.3
SEm±	0.59	0.66	0.44	3.20	0.93	1.67	0.30	0.22	0.19
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop residue management (CRM)									
WoR	61.2	51.4	56.3	7.4	7.5	7.4	17.8	17.9	17.9
WR	68.9	56.4	62.6	10.2	8.1	9.1	18.1	18.7	18.4
SEm±	0.48	0.59	0.38	1.26	1.28	0.90	0.32	0.12	0.17
LSD ($P \leq 0.05$)	1.87	2.31	1.23	NS	NS	NS	NS	0.49	NS
Precision nitrogen management (PNM)									
RDN	64.4	49.9	57.1	8.7	7.6	8.2	17.4	17.5	17.5
33+GS	61.6	51.2	56.4	9.6	8.0	8.8	17.4	17.4	17.4
50+GS	70.0	60.7	65.4	6.6	7.3	7.0	18.7	20.0	19.3
70+GS	64.0	53.9	58.9	10.2	8.2	9.2	18.5	18.3	18.4
SEm±	1.50	0.78	0.85	4.12	3.07	2.57	0.34	0.28	0.22
LSD ($P \leq 0.05$)	4.39	2.27	2.41	NS	NS	NS	0.99	0.81	0.62
CS ×CRM	2.65	NS	1.75	NS	NS	NS	NS	NS	NS
CS×PNM	NS	3.22	NS	17.02	NS	NS	NS	NS	NS
CRM×PNM	NS	3.22	3.41	NS	NS	NS	NS	NS	0.88
CS×CRM×PNM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year									
Year-1	-	-	65.0	-	-	8.8	-	-	18.0
Year-2	-	-	53.9	-	-	7.8	-	-	18.3
SEm±	-	-	0.44	-	-	1.67	-	-	0.19
LSD ($P \leq 0.05$)	-	-	1.73	-	-	NS	-	-	NS
Y×CS	-	-	NS	-	-	NS	-	-	NS
Y×CRM	-	-	1.75	-	-	NS	-	-	NS
Y×CS×CRM	-	-	NS	-	-	NS	-	-	1.12
Y×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CS×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CRM×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CS×CRM×PNM	-	-	NS	-	-	NS	-	-	NS

Where; CS: Cropping system; CRM: Crop residue management; PNM: Precision nitrogen management; MMuMb: Maize-Mustard-Mungbean; MWMb: Maize-Wheat-Mungbean; WoR: Without residue; WR: With residue; RDN: Recommended dose of nitrogen; GS: Green seeker; NS: Non-significant

analysis, respectively. Grains /row were also observed highest in 50+GS (PNM3) treatment, lowest numbers of grains/row were reported from RDN. No significant differences were found in interaction for grains/row (Table 6). On pooled basis grains/cob was significantly affected by treatments except cropping system. Application of residue (WR) improved the grains/cob (414.2). The PNM options also increased the grains/cob, 50+ GS (PNM3) treatments reporting higher number of grains/ cob (453.6) on pooled basis. In fact, crop residue retention improves water and nutrient availability to crop and inhibit crop-weed competition for nutrients, ultimately produced higher yield (Saad *et al.*, 2015; Radheshyam *et al*., 2021).

Table 6. Effect of cropping system, residue and nitrogen management options on yield attributes of *kharif* maize under conservation agriculture in the study

Treatments	Grain rows /Cob			Grains/row			Grains/cob		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
Cropping system (CS)									
MMuMb	15.1	15.8	15.4	32.2	33.2	32.7	425.3	380.4	402.8
MWMb	15.8	16.5	16.2	33.5	35.0	34.3	427.3	377.1	402.2
SEm±	0.40	0.31	0.25	0.29	0.14	0.16	6.22	5.70	4.22
LSD (P≤0.05)	NS	NS	NS	NS	0.85	0.62	NS	NS	NS
Crop residue management (CRM)									
WoR	14.9	15.8	15.4	31.4	33.2	32.3	419.8	362.0	390.9
WR	16.0	16.5	16.2	34.3	35.0	34.6	432.8	395.5	414.2
SEm±	0.32	0.22	0.19	0.29	0.33	0.22	5.78	2.95	3.24
LSD (P≤0.05)	NS	NS	0.63	1.13	1.29	0.71	NS	11.58	10.58
Precision nitrogen management (PNM)									
RDN	14.5	15.8	15.2	31.1	31.6	31.4	399.3	340.2	369.7
33+GS	15.0	15.4	15.2	32.2	34.5	33.4	406.8	365.7	386.2
50+GS	17.6	17.9	17.8	35.9	36.2	36.1	459.6	447.5	453.6
70+GS	14.7	15.4	15.1	32.2	34.1	33.1	439.5	361.7	400.6
SEm±	0.40	0.33	0.26	0.36	0.35	0.25	10.22	11.14	7.56
LSD (P≤0.05)	1.17	0.97	0.74	1.06	1.02	0.72	29.82	32.51	21.49
CS ×CRM	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS×PNM	NS	NS	1.05	NS	NS	NS	NS	NS	NS
CRM×PNM	1.65	NS	1.05	NS	NS	NS	NS	NS	30.39
CS×CRM×PNM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year									
Year-1	-	-	15.5	-	-	32.9	-	-	426.3
Year-2	-	-	16.2	-	-	34.1	-	-	378.8
SEm±	-	-	0.25	-	-	0.16	-	-	4.22
LSD (P≤0.05)	-	-	NS	-	-	0.62	-	-	16.57
Y×CS	-	-	NS	-	-	NS	-	-	NS
Y×CRM	-	-	NS	-	-	NS	-	-	NS
Y×CS×CRM	-	-	NS	-	-	NS	-	-	NS
Y×PNM	-	-	NS	-	-	1.01	-	-	30.39
Y×CS×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CRM×PNM	-	-	NS	-	-	NS	-	-	NS
Y×CS×CRM×PNM	-	-	NS	-	-	NS	-	-	NS

Where; CS: Cropping system; CRM: Crop residue management; PNM: Precision nitrogen management; MMuMb: Maize-Mustard-Mungbean; MWMb: Maize-Wheat-Mungbean; WoR: Without residue; WR: With residue; RDN: Recommended dose of nitrogen; GS: Green seeker; NS: Non-significant

Conclusion

Maize could be a scalable alternative to rice-wheat cropping system in the IGP for higher yield and profitability under CA. It was concluded that the 50% basal application of N with Green seeker (GS) and residue retention in the MWMb system was found significantly superior for enhancing growth attributes, yield and yield attributes in maize under conservation agriculture.

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RESEARCH PAPER

Effect of packaging materials and storage duration on seed germination of maize inbred

S. J. Dodiya · M. B. Patel · P. K. Parmar · K. Patil · K. H. Patel

Abstract: The germination percent of inbred IGI 1103 affected significantly with storage duration. The rate of seed deterioration was higher in ambient conditions compare to cold storage because of uncontrolled environmental conditions. Seed packaging materials also significantly affected seed deterioration. Among two types of packaging materials, aluminium foil bag (P_2) was found superior for maintaining viability. Cloth bag (P_1) is not safe for maize inbred line seed storage for longer time. From the result of present study, it was concluded that maize inbred IGI 1103 kept in aluminium bag in cold storage for longer period minimize the deterioration effect on seed germination status.

Keywords: Inbred · Storage · Packing materials · Environment · Germination

Introduction

Seeds are required to be kept in safe storage since they are harvested in the proceeding season and usually used for sowing in the subsequent season often after a time gap of six months or longer. Even if properly dried after harvest, exposure to moist and humid conditions during storage causes the kernel to absorb water from the surroundings (Devereau *et al.*, 2002), leading to increased maize moisture contents, which results in enhanced deterioration. It is also stated that seed vigour decreases with increasing water content especially in high temperature environments and high air humidity. Inbreeds have less vigour when compared to maize hybrid seed and are more susceptible to drying temperatures, in the form of cobs, compared to commercial hybrids, requiring moderate drying regimes (Moldovan *et al.*, 2015). However, it varies among genotypes/maize parental lines. Poor seed storability is a major problem in maize. The longevity of seed in storage is influenced by the initial seed quality as well as conditions of storage (Oyekale, 2012). Storage of seed beyond optimum storage period might result in reduced germination potential, seedling establishment and final seed production. The hygroscopic nature of maize seed sometimes makes them unsafe for storage in an open container (Adetumbi *et al.*, 2009). In addition, the seed must be packaged using moisture vapour proof containers like polythene bags, aluminium foil bag, gunny bag lined with polythene with or without desiccating agent to properly maintain the quality of seed for a longer period (Singh and Singh, 1992).

Materials and methods

The experiment was carried out at the Department of Seed Science and Technology, Anand Agricultural University, Anand during the year 2020-21. The seeds of a male inbred line (IGI 1103) were obtained from Main Maize Research Station, AAU, Godhra. The seeds used for this experiment were already stored for 7 months under ambient condition in cloth bag before conducting this research. The seeds of inbred line IGI 1103 were packed in two packaging containers *viz.*, cloth bag (P_1) and aluminum foil bag (P_2). The packed seeds were stored in 4°C (Cold) (E_2) and ambient storage (Room temperature) conditions (E_1), for three different durations *viz.*, 6 months (D_1), 9 months (D_2) and 12 months (D_3).

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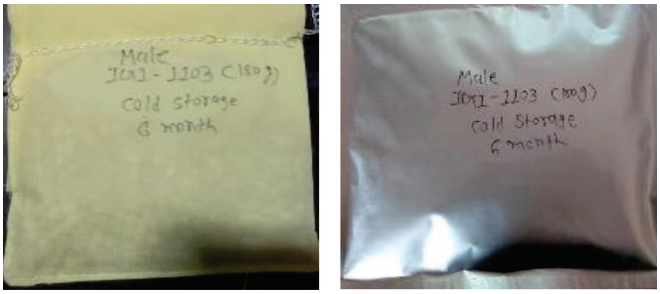
Germination percentage was determined by following the between paper towel method as prescribed under ISTA rules. Four replications of 100 seeds each were kept for germination in rolled towels in a germinator maintained at 25°C and 95 per cent relative humidity. Final count was taken on 7th day. The germination was calculated based on normal seedlings counted on the final day and expressed in per cent.

Results and discussion

The inbred line was influenced by packaging materials, storage duration and environmental condition and their interaction was found significant (Table 1 & Plate 1&2).

Effect of packaging materials

The effect of packaging materials on germination was significant over different storage durations at 6, 9 and 12 months of storage. The line IGI 1103 seed stored in aluminum foil bag (P_2) recorded significantly higher germination (70.17) due to its moisture and vapor impervious nature. The seeds stored in the cloth bag (P_1) recorded the lowest germination percent (62.78) and recorded fast reduction due to its moisture pervious nature. This higher moisture in the seed may be the main reason of quick quality deterioration in the seeds of cloth bag.



P_1 (cloth bag) P_2 (aluminum foil bag)

Plate 1. Packing material used in experiment

Table 1. Effect of packaging materials, storage duration and environmental condition on germination percentage of maize (*Zea mays* L.) IGI 1103 inbred

Particulars		Storage Duration (Months)			
		D1	D2	D3	Mean
Interaction P×D					P
Packagingmaterials	P1	92.67	70.00	25.67	62.78
	P2	93.33	77.00	40.17	70.17
Interaction EXD					E
Environmentalconditions	E1	91.67	67.67	19.50	59.61
	E2	94.33	79.33	46.33	73.33
Interaction PXEXD					PXE
E1	P1	91.33	61.33	14.67	55.78
	P2	94.00	78.67	36.67	69.78
E2	P1	92.00	74.00	24.33	63.44
	P2	94.67	80.00	56.00	76.89
Duration mean		93.00	73.50	32.92	
Overallmean			66.47		

Comparing mean	S.Em.(±)	CD@ 5%
Packaging material (P)	0.96	2.18
Duration (D)	1.18	3.45
Interaction PXD	1.67	4.88
Environmental condition (E)	0.96	2.82
Interaction PXE	1.37	NS
Interaction EXD	1.67	2.82
Interaction PXEXD	2.36	6.91
CV (%)	6.16	

Storage period	Environmental condition	Packaging materials
D1: 6 months	E1: Ambient condition	P1: Cloth bag
D2: 9 monthsD3: 12 months	E2: Cold Storage	P2: Aluminium foil bag

NS: Non-significant

Effect of storage duration

In maize parental line IGI1103, seed germination potential decreased as per progressive storage duration. Significantly the highest germination percent (93.00) was recorded at 6 months (D_1) storage duration and reduced to (73.50) at 9 months (D_2) of storage. The seed germination of stored inbred line IGI1103 seed of maize maintained has germination percent as per Indian minimum seed certification standard (IMSCS) at very initial 6 months

D_1 D_2 D_3

Cold Storage (E_2) X Cloth bag (P_1) Interaction with different duration

D_1 D_2 D_3

Cold Storage (E_2) X Aluminium bag (P_2) Interaction with different duration

D_1 D_2 D_3

Ambient condition (E_1) X Cloth bag (P_1) Interaction with different duration

D_1 D_2 D_3

Ambient condition (E_1) X Aluminium bag (P_2) Interaction with different duration

D_1: 6 Month D_2: 9 month D_3: 12 month

Plate 2. Effect of packaging materials, storage duration and environmental condition on germination percentage of maize (*Zea mays* L.) IGI 1103 Inbred line

(D_1) of storage duration irrespective of packaging materials. At the end of 12 months (D_3) of storage significantly the lowest germination per cent (32.92) recorded.

Effect of environmental condition

The observation on germination indicated that the germination of maize inbred line IGI 1103 seeds was significantly influenced by different environmental conditions. Higher germination percentage (73.33) was recorded in (E_2) cold storage (4°C) condition compare to (E_1) ambient condition (59.61). The probable reason for high rate of reduction in germination in ambient condition was high temperatures during storage enhance seed deterioration for fast metabolic activities under moist condition (McDonald, 1999).

Interaction effect of packaging materials and storage duration

The significant difference was observed due to interaction effect of packaging materials and storage duration in germination percentage of maize inbred line IGI1103 seeds. A significantly higher germination percentage (93.33) was recorded by the seeds stored in Aluminum foil bags for six months (P_2D_1). At the end of twelve months, seeds stored in cloth bags (P_1D_3) showed lower germination percentage (25.86). The maize seed is hygroscopic and absorbs moisture from surrounding environment and rapidly loose viability. This may be the reason for lower viability in cloth bag.

Interaction effect of packaging materials and environmental condition

The observation on germination in maize inbred line IGI 1103 seeds indicated that the interaction effect of packaging materials and environmental condition found non-significant. Seeds stored in aluminum foil bag in cold storage (P_2E_2) recorded higher germination percentage (76.89) whereas; seeds stored in cloth bag in ambient condition (P_1E_1) recorded numerically the lowest germination percentage (55.78).

Interaction effect of storage duration and environmental condition

Germination percentage was greatly influenced by different combination on storage duration and environmental condition and also found significant differences observed in this study. Significantly the higher germination per cent (94.33) was maintained bythe maize inbred line IGI 1103 seeds stored in cold storage for six months (D_1E_2) and decrease as storage duration increases. At the end of twelve months, seeds stored in ambient condition (D_3E_1) showed maximum deterioration and recorded lower germination percentage (19.50). Compared to ambient condition at the end of storage duration, cold condition maintained higher germination percentage.

Interaction effect of packaging materials, storage duration and environmental condition

Data pertaining to germination percentage of maize inbred line IGI1103 seeds showed significantly influenced of combine effect of packaging materials, storage duration and environmental condition on germination percentage and the differences were also found significant. Numerically higher germination (94.67) was recorded bythe seeds stored under cold storage up to six months in aluminium foil bags ($P_2D_1E_2$) followed by ambient condition in aluminium foil bags for same duration (92.00).

The decrease in the germination percentage over the storage duration might be attributed to deterioration due to fluctuating temperature, moisture content and relative humidity as influenced by packaging materials. Cloth bags having porous nature and reacts with change in atmospheric condition. Aluminum foil bags sustain viability for longer storage duration because of its impervious nature so protected the seeds from surrounding environmental factors. The results are in concurrence with the earlier finding of Owolade *et al*. (2011) in sorghum, Rajasekaran (2004) in brinjal hybrid and Patil and Gouda (2007) in rice hybrid seeds.

At the initial stage of storage, germination percentage of seeds was higher because of initial vigorous nature of seeds and it decrease further increase in storage period. As reported by Walter *et al*. (2005) the length of storage time is strongly influenced by environmental and genetic factors such as storage temperature and seed moisture content. When seeds deteriorate during storage, they lose vigour, become more sensitive to stress during germination and ultimately become unable to germinate. These findings were also reported by Rajjou and Debeaujon (2008) and Borza *et al.* (2017) in maize.

Storage of seeds under low temperatures or cold storage (4ºC) can extend the lifetime use of maize seeds. Under ambient condition high temperatures accelerated respiration quickly so that faster the changes in food reserves in the seeds that have an impact on the decrease in germination percentage and vigour of the seeds. The rate of seed deterioration enhances with increased moisture levels. Seed moisture content fluctuates with long-term changes in atmospheric humidity. Low temperature and air humidity limit the increase of seed moisture content and the rate of respiration of the seeds during the storage period. These results conform with a finding of Wang *et al*. (2018), Gupta (2010) in rice and Timoteo and Marcos (2013) in corn genotype. Germination per cent, viability, vigour and other seeds quality parameters significantly reduced with natural ageing. The seed germination of stored IGI1103 inbred line seed of maize maintained its germination percent above Indian Minimum Seed Certification Standard (IMSCS) at very initial 13 months of storage duration irrespective of packaging materials. Maize inbred lines seeds are packaged in aluminium foil bags and kept in a cold environment (4°C) for long periods without affecting the germination of the seeds.

Conclusion

The rate of seed deterioration was higher in ambient conditions compared to low temperatures or cold storage (4^{o}C) which can extend the life span of maize inbred seeds. The seed germination percentage of the stored maize inbred line (IGI1103) was maintained above the Indian Minimum Seed Certification Standard for an initial 13 months of storage duration in cold storage irrespective of packaging materials. Seed packaging materials also significantly affected seed deterioration. Among the two types of packaging materials, aluminium foil bag was found superior for maintaining the seed viability of maize inbred.

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