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From ancient domestication to modern agriculture: The journey of maize cultivation in Tanzania, its implications for food security, challenges and resilience strategies

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Abstract

Maize (*Zea mays*), first domesticated in Southern Mexico about 9,000 years ago, has grown to be a major global staple, playing an especially crucial role in Tanzania. Introduced to East Africa by Portuguese traders in the 16th century, maize gradually became part of Tanzania’s agricultural system, replacing traditional cereals like sorghum, pearl millet, and finger millet in both cultivation and consumption. During the colonial era the production was relatively low. Since independence in 1961, acreage expanded significantly from 790,000 hectares to 4.4 million hectares by 2021, and production increased from 590,000 to over 6 million metric tons. This growth has made maize a crucial crop for food security and livelihoods in the country. Over 189 maize varieties have been officially certified in Tanzania, since 1950s. Currently, Tanzania rank 5th after South Africa, Nigeria, Ethiopia and Egypt in Africa maize producers. Despite these achievements, maize farming in Tanzania faces significant hurdles, including pests like the fall army worm, maize weevil, larger grain borer, and rodents, along with diseases such as maize lethal necrosis and gray leaf spot. The impacts of climate change also pose ongoing challenges to maize cultivation. Recently, maize attracted a lot of researches in various aspects. However, no published review report on history of maize production including varieties over time, problems and prospects. This paper provides an extensive review of maize history, production statistics, common varieties, research gaps and highlights resilient strategies needed for continuous innovation and support in maize cultivation to preserve its key role in Tanzania's economy and food security.

Keywords: Agriculture, Maize Cultivation history, Food security, Challenges, Resilient strategies, Tanzania.

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INTRODUCTION

Maize (*Zea mays*) was first domesticated from the wild grass teosinte (*Zea mays ssp. parviglumis*) in Southern Mexico approximately 9,000 years ago (Piperno & Flannery, 2001). The domestication process involved selective breeding by early Mesoamerican farmers who chose plants with desirable traits, such as larger cobs, softer kernels, and non-shattering cobs that were easier to harvest and replant, which significantly enhanced the crop's productivity (Matsuoka *et al*., 2002). Many studies showed how cultivated maize was transformed from wild maize over a few thousand years (Miracle, 1965; Doebley, 2004; Edmeades *et al*., 2017; Erenstein *et al*., 2022). At present maize is one of three important cereals providing food security and playing an essential role in the diets of billions the other being wheat and rice (Erenstein *et al*., 2022). After it was domesticated, it quickly became a main food various indigenous civilizations across the Americas, including the Olmecs, Mayans, Aztecs, and Incas. Maize was not only a primary food source but also held deep spiritual significance, often symbolizing life and fertility in these cultures (Benz, 2001).

The global spread of maize began with the arrival of Europeans in the Americas in the late 15th century. Christopher Columbus and other explorers brought maize back to Europe, where it was initially viewed as a curiosity. However, maize quickly gained popularity due to its versatility, high yield, and adaptability to various climates (Miracle, 1966). By 16th century, maize had spread throughout Southern Europe, particularly in Spain, Portugal, and Italy. Europeans introduced maize to Africa and Asia during colonial conquest, where it was rapidly adopted and became a staple crop (McCann, 2005). Maize is the third most important cereal crop consumed in the world, after rice and wheat, and is grown in all continents except in Antarctica (FAO, 2022). Maize is cultivated in roughly equal areas across tropical and temperate regions; however, the majority (70%) of its production takes place in temperate climates (Edmeades *et al*., 2017; Miracle, 1965). Maize, alongside rice and wheat, provides at least 30% of the food calories consumed by over 4.5 billion people across of the world including more than 1.4 billion people from 54 African countries; who rely maize as their primary staple (Shiferaw *et al*., 2011). Maize is grown on more than 33 million hectares in 54 countries in Africa (FAO, 2022). Maize production in Africa accounts for 7.5% of global maize production, with over 200 million people depending on it for livelihoods and food security (Abate *et al*., 2017). Projections indicates that by 2050, global demand for maize will double, driven by a growing population expected to reach approximately 9.3 billion, and increasing consumption in developing regions (Rosegrant *et al*., 2009).

In Sub-Saharan Africa (SSA), maize has overtaken traditional cereals like sorghum, pearl millet, finger millet, teff and African rice becoming a central staple food, particularly in Eastern and Southern Africa, where consumption rates are among the highest worldwide (Smale *et al*., 2011). Of the 22 countries globally where maize accounts for the highest percentage of daily calorie intake, 16 are in Africa (Shiferaw *et al*., 2011). In Eastern and Southern Africa, maize provides nearly half of the calories and protein consumed, while in West Africa, it accounts for one-fifth of the dietary calories and protein (Ranum *et al*., 2014). An estimated 208 million people in SSA depend on maize as a key source of food security and economic well-being (Smale *et al*., 2011). Maize cultivation spans over 33 million hectares of SSA's estimated 200 million hectares of cultivated land, reflecting its critical role in regional agriculture (Meyer *et al*., 2012).

CULTIVATION HISTORY OF MAIZE IN TANZANIA

Pre-Colonial Period

Before the introduction of maize, Tanzanian communities primarily relied on indigenous crops such as sorghum, millet, yams, and cassava. These crops were well-suited to the local climate and had been cultivated for centuries (Iliffe, 1979). Maize was introduced to East Africa, including present-day Tanzania, by Portuguese traders in the 16th century, primarily through the coastal regions (Miracle, 1966; McCann, 2005). However, it wasn't immediately widespread; instead, it gradually made its way into the agricultural systems of various communities, blending with existing practices. In the pre-colonial period, maize was mainly grown in small quantities, often intercropped with other staples (Iliffe, 1979).

Colonial Period

The German and later British colonial administrations played a significant role in expanding maize cultivation in Tanzania. During the German colonial period (1885–

1919), the focus was primarily on cash crops such as sisal, cotton, and coffee (Busungu, 2023; Little, 1991). However, maize began to gain prominence as a food crop, especially in the northern highlands and southern regions, where it was encouraged to meet the food needs of the growing European and African populations involved in plantation and infrastructure development (Sunseri, 2014).Under British rule (1919–1961), maize production was further promoted as part of broader agricultural policies aimed at increasing food security and reducing reliance on imported grains (Iliffe, 1979; Little, 1991). During this period, maize began to displace traditional staples like sorghum, finger millet and pearly millet, especially in regions where it was more productive (Coulson, 2013). This period saw the commercialization of maize production, particularly in the southern highlands, which became one of the key maize-producing areas after independence (Kimambo & Temu, 2009).

Post-Colonial Period

Subsequent years after independence in 1961, Tanzania Government under the father on nation (Julius Nyerere) prioritized agricultural development as part of the broader policy of Ujamaa (African socialism). Maize was made an important crop for ensuring food security and reducing poverty (Coulson, 2013). The National Maize Program was initiated in the 1970s aimed at enhancing maize production through research and the development of high-yielding and pest-resistant varieties (Bryceson, 1988). In the 1980s and 1990s, structural adjustment programs (SAPs) which was enforced by the International Monetary Fund (IMF) and the World Bank led to the liberalization of the agricultural sector (Coulson, 2013). This shift had mixed effects on maize production. While it encouraged private sector participation and improved access to inputs like seeds and fertilizers. On the other hand, it led to reduced government support for smallholder farmers, who faced challenges in accessing credit and markets (Lofchie, 1978; Luzi-Kihupi *et al*., 2015). From 2000s and onwards, the Tanzania Government, along with international organizations, has continued to promote maize production as part of broader strategies to improve food security and reduce poverty. The focus has been on developing drought-resistant and high-yielding maize varieties to cope with the challenges posed by climate change (Luzi-Kihupi *et al*., 2015; Shiferaw *et al*., 2011)

Maize production in Tanzania has seen significant fluctuations from 1961 to 2022(Table 1). Initially, the area under maize cultivation in 1961 was 790,000 hectares but it gradually increased to reach a peak of 4,400,000 hectares in 2021(Table 1). Similarly, production showed a rising trend, starting from 590,000 tons in 1961 and peaking at 7,039,000 tons in 2021(Table 1). However, the yield per hectare, which is a crucial indicator of agricultural productivity, showed variability over the years. In 1961, the yield was 0.75 tons per hectare, reflecting the limited adoption of modern agricultural practices and inputs. By 1979, the yield had improved to 1.32 tons per hectare, demonstrating some progress in farming techniques and input use (FAO, 2022). The most significant increases in yield per hectare occurred during the late 1990s and early 2000s, particularly from 1995 onwards. In 1999, maize yield peaked at 2.53 tons per hectare, driven by better seed varieties, improved farming methods, and government interventions in agricultural support (Bryceson, 1988). Despite these improvements, yield variability persisted, often influenced by factors such as drought, poor infrastructure, and inconsistent access to quality inputs (World Bank, 2021).

Despite maize becoming dominant cereal in Tanzania, other cereals like rice have also played an essential role in ensuring food security and supporting livelihood in Tanzania. Rice, which is mainly grown in rainfed ecosystem in lowlands, has seen a considerable increase in production. However, maize production far surpasses that of rice in both area planted and total production. For instance, the introduction of high-yielding rice varieties and improved agricultural practices such as irrigation methods and system of rice intensification (SRI) led to increases in rice productivity, but these increases were often limited by the higher input requirements for rice compared to maize (Busungu, 2023; Kikuchi *et al*., 2009). Moreover, maize's high adaptability allowed it to be grown across diverse agro ecological zones, from the highlands to the lowlands; unlike rice which is more concentrated in lowlands alone (Minot *et al*., 2006). Several factors contributed to maize's ascendance as Tanzania's main staple food. Maize can be grown in a variety of agro ecological zones, unlike sorghum and millet, which are more suited to specific regions. This adaptability made maize an attractive option for farmers across the country. Over the years, Tanzanian government policies have favored maize production through subsidies, research into high-yielding varieties, and extension services. These interventions significantly improved maize productivity (Bryceson, 1988; Gollin & Goyal, 2017). Despite being a "stranger crop," maize has been rapidly integrated into Tanzanian diets. It is now a central component of ugali, a staple dish in many households (FAO, 2017). The demand for maize, both domestically and regionally, has provided strong economic incentives for farmers. Maize's dual purpose as a food and cash crop has made it more economically viable than other cereals (Meertens, 2000).

Table 1: Tanzania Maize Production Statistics from 1961-2022.

SN	Year	Area(ha)	Production(t)	Yield per hectare(t/ha)
1	1961	790000	590000	0.75
2	1962	800000	600000	0.75
3	1963	960000	850000	0.89
4	1964	930000	720000	0.77
5	1965	950000	751000	0.79
6	1966	1100000	880000	0.80
7	1967	1000000	750000	0.75
8	1968	1014000	551000	0.54
9	1969	1014000	638000	0.63
10	1970	1015000	488000	0.48
11	1971	984900	719000	0.73
12	1972	1000000	621000	0.62
13	1973	1000000	887000	0.89
14	1974	1100000	761000	0.69
15	1975	1100000	1367000	1.24
16	1976	1300000	1449000	1.11
17	1977	1300000	1664000	1.28
18	1978	1300000	1465000	1.13
19	1979	1300000	1720000	1.32
20	1980	1400000	1726000	1.23
21	1981	1350000	1839000	1.36
22	1982	1231550	1654000	1.34
23	1983	1229620	1651000	1.34
24	1984	1411830	1939000	1.37
25	1985	1576280	2093000	1.33
26	1986	1905000	2211000	1.16
27	1987	1724000	2359000	1.37
28	1988	1850000	2339000	1.26
29	1989	1980000	3128000	1.58
30	1990	1631260	2445000	1.50
31	1991	1848300	2331800	1.26
32	1992	1908163	2226424	1.17
33	1993	1824000	2282200	1.25
34	1994	1203000	1485800	1.24
35	1995	1368000	2874400	2.10
36	1996	1580000	2822000	1.79
37	1997	1564000	1831200	1.17
38	1998	2088000	2684600	1.29
39	1999	957550	2420940	2.53
40	2000	1017600	1965400	1.93
41	2001	845950	2652810	3.14
42	2002	1718200	4408420	2.57
43	2003	3462540	2613970	0.75

44	2004	3173070	4651370	1.47
45	2005	3109590	3131610	1.01
46	2006	2570147	3423020	1.33
47	2007	2600341	3659000	1.41
48	2008	3980970	5440710	1.37
49	2009	2961334	3326200	1.12
50	2010	3050710	4733070	1.55
51	2011	3287850	4340823	1.32
52	2012	4118117	5104248	1.24
53	2013	4120269	5356350	1.30
54	2014	4146000	6737197	1.62
55	2015	3787751	5902776	1.56
56	2016	3878099	6149000	1.59
57	2017	3817879	6680758	1.75
58	2018	3546448	6273151	1.77
59	2019	3428630	5652005	1.65
60	2020	4200000	6711000	1.60
61	2021	4400000	7039000	1.60
62	2022	4000000	5900000	

Source (FAOSTAT, 2022)

COMMON MAIZE VARIETIES AND THEIR IMPACT ON PRODUCTIVITY

Maize is a critical staple crop in Tanzania, contributing significantly to food security and the economy. The diverse agro-ecological zones of Tanzania allow for the cultivation of various maize varieties, each adapted to specific altitudes and climatic conditions. Over the years, the introduction of different maize varieties has played a crucial role in enhancing maize production across the country. One of the earliest maize varieties introduced in Tanzania is the Katumani variety, developed by the Kenya Agricultural Research Institute (KARI) in 1950(Table 2.a, b). Katumani is suitable for low altitudes below 1500 meters. It has been widely adopted in semi-arid regions due to its drought tolerance, contributing to increased maize production in these areas (Smale & Jayne, 2003).

In 1960s, first hybrid varieties such as H622, H632, and H511 were developed through the East African Community (EAC), KARI, and Kenya Seed Company (Table 2.a, b). These hybrids were explicitly bred for mid-altitude regions from 1200 to 1700 meters. The introduction of these hybrids led to considerable increase in maize production, as they had higher yields compared to traditional varieties. The H622 and H632 varieties became more popular among farmers in the mid-altitude zones, leading to increased maize production in these areas (Duvick, 2005). In 1970s, Agricultural Research Institutes (ARI) in Tanzania developed new maize varieties, such as UCA, H6302, ICW, and H614 (Table 2.a, b). These varieties were bred to produce at a wider altitude range, from lowland areas below 900 meters to highland regions above 1500 meters (Table 2.a, b). The UCA variety, introduced in 1976, became popular in lowland regions, while H6302 and H614 were suited for highland areas (Table 2. a, b). The adaptability of these varieties to specific agro-ecological zones helped stabilize maize production across different regions of the country (TARI, 2020).

In 1980s, ARI developed composite maize varieties such as Staha, Kilima and Kito which further boosted maize production in Tanzania (Table 2.a, b). These varieties were bred for low to mid-altitude regions and were known for their resistance to pests and diseases. The Staha variety, introduced in 1983, became a most preferred among farmers in lowland areas due to its early maturity and high yield potential (Table 2.a, b). Similarly, the Kilima variety gained traction in mid-altitude zones, contributing to increased maize production in these regions (Almekinder *et al*., 2019). The introduction of hybrid varieties continued into the 1990s, with the release of CG4142, C6222, and several Pannar Seed Company varieties such as PAN6549, PAN 695, and PAN 6481(Table 2.a, b). These hybrids were specifically bred for mid-altitude regions and offered significant yield advantages over older varieties. The adoption of these hybrids by farmers in the 1990s led to a substantial increase in maize production, particularly in regions with favorable climatic conditions for maize cultivation (Tsedeke *et al*., 2015).

In the 2000s and 2010s new varieties such as Situka-M1, Situka 2, SC 627, and various Pioneer Seed Company varieties like PHB30A15 and PAN 6243 were developed (Table 2.a, b). These varieties were developed to cater to a wide range of altitudes, from lowland to highland regions (Table 2.a, b). Some of the varieties were hybrids, composites, synthetic, pure line and some produced through mass selection procedure (Luzi-Kihupi *et al*., 2015; TARI, 2020). The new varieties gave farmers more options for selecting maize varieties that were best suited to their specific agro-ecological conditions, agricultural practices and farming systems (Smale & Jayne, 2003; TARI, 2020). In recent years, TARI has continued to develop and release new maize varieties, such as UH6305 and UH615ST, which are tailored for mid to high-altitude regions (Table 2.a, b). These varieties are designed to be more resilient to climate change, with improved resistance to pests, diseases, and drought. The development and adoption of these resilient varieties are expected to play a significant role in sustaining and increasing maize production in Tanzania, particularly in the face of changing climatic conditions (TARI, 2020).

Most maize varieties produced from the 1950s to the early 2000s were open-pollinated varieties (OPVs) (Table 2.a, b), which resulted in lower productivity (Table 1). However, since 2000, hybrid varieties have become more prevalent and now constitute the majority of maize varieties in Tanzania (Table 2.a, b), leading to a steady increase in productivity. Hybrids developed by CIMMYT outperform OPVs, yielding over 20% more under optimal conditions and 30–60% more under both abiotic and biotic stress (Masuka *et al*., 2017a). To sustain this upward trend in maize productivity, Tanzania's breeding programs should prioritize the development and adoption of hybrid varieties. The impact of these maize varieties on maize production in Tanzania has been profound. The introduction of hybrid varieties has led to a steady increase in maize yields, contributing to food security and economic growth. The adaptability of these varieties to different agro-ecological zones has ensured that maize production is spread across the country, reducing the risk of crop failure due to environmental factors. Moreover, the development of pest and disease-resistant varieties has minimized losses, further enhancing maize production (Duvick, 2005; Luzi-Kihupi *et al*., 2015; TARI, 2020).

Table 2. a: Common Maize varieties grown in Tanzania from 1950s -2024.

SN	Variety Name	Company Produced	Altitude(m)	Registered (Y)
1	Katumani	KARI - Katumani	<1500	1950
2	H622	EAC/KARI/Kenya Seed Co.	1200 - 1650	1968
3	H632	Kenya Seed Co.	1200-1650	1968
4	H511	EAC/KARI/	1300 - 1700	1968
5	UCA	ARI-Ukiriguru	900-1500	1976
6	H6302	EAC	>1500	1976
7	ICW	ARI - Ilonga	0-900	1977
8	H614	EAC	>1500	1977
9	Staha	ARI - Ilonga	0 -900	1983
10	Kilima St	ARI - Ilonga	900 -1500	1983
11	Kito	ARI -Ilonga	0 -1300	1983
12	TMV - 2	ARI - Ilonga	<1500	1987
13	TMV - 1	ARI - Ilonga	<1500	1987
14	CG4142	Cargill Zimbabwe (PTY) Ltd	900- 1500	1993
15	C6222	Cargill Zimbabwe (PTY) Ltd	900 - 1500	1994
16	PAN6549	Pannar Seeds Co. Ltd	500 - 1500	1995
17	PAN 695	Pannar Seeds Co. Ltd	1000 - 1500	1995
18	PAN 6481	Pannar Seeds Co. Ltd	1000- 1500	1995
19	PAN 6195	Pannar Seeds Co.Ltd	1000 - 1500	1995
20	C5121	Cargill - Zimbabwe	1000 - 1600	1997
21	PHB30A15	Pioneer Seed Co. Ltd	1000 - 1500	1999
22	PAN 6243	Pannar Seeds Co.Ltd	1000 - 1500	1999
23	CRN3631	Monsanto Hybrid Seeds Co.	900 - 1500	1999
24	C5051	Cargill - Zimbabwe	1000 - 1600	1999

25	H625	Kenya Seed Co. Ltd	1500 - 2400	2000
26	Situka-M1	AR-Selian	1000-1500	2001
27	Situka 2	AR-Selian	500-1600	2001
28	SC 627	SEED CO. Ltd	500-1400	2001
29	Pwani H04	Kenya Seed Co	0-800	2001
30	PHB30H83	Pioneer Seed Co.	800-1800	2001
31	PHB30G97	Pioneer Seed Co.	800-1500	2001
32	PAN 77	Pannar Seeds Co. Ltd	>1500	2001
33	PAN 691	Pannar Seeds Co. Ltd	>1500	2001
34	PAN 15	Pannar Seeds Co. Ltd	500-1500	2001
35	Lishe –H2	ARI - Selian	500-1600	2001
36	Lishe - HI	ARI - Selian	1000 - 1500	2001
37	H513	Kenya Seed Co. Ltd	900 - 1500	2001
38	DK 8071	Monsonto Hybrid Seeds Co.	1000-1600	2001
39	CRN 3891	Mansanto Hybrid Seeds Co.	900-1500	2001
40	Uh615	ARI - Uyole	1200 - 1800	2001
41	Lishe –K1	ARI-Selian	500-1600	2001
42	H628	Kenya Seed Co. Ltd	150-180	2002
43	DK8051	Monsanto Hybrid Seed Co.	120-140	2002
44	DK8031	Monsanto Hybrid Seed Co	100-110	2002
45	DH01	Kenya Seed Co. Ltd	90-120	2002
46	**H515**	Kenya Seed Co. Ltd	1200-1600	2003
47	UH615	ARI-Uyole	1200-1800	2003
48	SC 713	SEED CO. Ltd	500-1400	2003
49	SC 513	SEED CO. Ltd	500-1400	2003
50	SC 407	SEED CO. Ltd	500-1400	2003
51	SC 403	SEED CO. Ltd	500-1400	2003
52	PAN 63	Pannar (Pty) Ltd	850 - 1500	2003
53	PAN 33	Pannar (Pty) Ltd	850 - 1500	2003
54	Longe 4	FICA SEED Ltd	900 -1500	2003
55	KS H 519	Kenya Seed Co. Ltd	1400-1700	2003
56	DH 04	Kenya Seed Co. Ltd	500-1200	2003
57	DH 03	Kenya Seed Co. Ltd	200-1000	2003
58	PAN 23	Pannar (Pty) Ltd	850-1500	2003
59	Longe 2H	FICA SEED Ltd	900 - 1500	2003
60	UH 6303	ARI-Uyole	1200-1800	2004
61	PAN 4M-19	Pannar (Pty) Ltd	0- 1500	2004
62	PAN 4 M-17	Pannar (Pty) Ltd	0- 1500	2004
63	Longe 6H	FICA SEED Ltd	900 - 1500	2004
64	TAN H611	Tanseed International	0-1500	2006
65	TAN 254	Tanseed International	0-1500	2006
66	TAN 250	Tanseed International	0-1500	2006
67	VUMILIA H1	ARI Selian	500- 1500	2007
68	VUMILIA K1	ARI Selian	500- 1500	2007
69	WH 403	Western Seed Co. Ltd	1000-1800	2007
70	WH 502	Western Seed Co. Ltd	1000-1800	2007
71	WH 505	Western Seed Co. Ltd	1000-1800	2007
72	Bora	ARI Ilonga	0-1000	2008
73	TAN H600	Tanseed International	0-1500	2009
74	TAN 222	Tanseed International	0-1500	2009
75	UHS 5210	ARI-Uyole	1200-1600	2009
76	UHS 5350	ARI-Uyole	1200-1600	2009
77	P2859W	Pioneer Hybrid Seeds Ltd	600 -1600	2010
78	TZM 523	Suba Agro TE.Co Ltd	900 -1500	2011
79	TZH 538	Suba Agro TE.Co Ltd	900 -1500	2011
80	TZH 526	Suba Agro TE.Co Ltd	900 -1500	2011
81	TZH 417	Suba Agro TE.Co Ltd	800 -1500	2011
82	MERU H600	Meru Agro-Tours & C Co. Ltd	1000 -1600	2011

83	MERU H501	Meru Agro-Tours & C Co. Ltd	500 -1200	2011
84	MERU H500	Meru Agro-Tours & C Co. Ltd	800 -1400	2011
85	DKC90-89	Monsanto Tanzania Ltd	900 -1500	2011
86	30G19	Pioneer Oversees Corporation	1200 -1800	2011
87	PAN 4M-21	Pannar seed Company (T) Ltd	400 - 1200	2012
88	NATA H 105	Aminata Quality Seed Ltd	500 - 1700	2012
89	NATA H 104	Aminata Quality Seed Ltd	500 -1700	2012
90	KH 600-15A	East Africa Seed (T) Ltd	2000 - 3000	2012
91	ZMS 402	Bajuta International (T) Ltd	500 - 1700	2012
92	ZMS 606	Bajuta International (T) Ltd	500 - 1700	2012
93	P3812W	Pioneer Overseas Corporation	600 - 1700	2013
94	P3812W	Pioneer Hybrid Seeds Ltd	600 - 1700	2013
95	MERU HB515	Meru Agro-Tours & C Co. Ltd	800 - 1200	2013

Source: (TOSCI 2024)

Table 2. b: Common Maize varieties grown in Tanzania from 1950s -2024.

SN	Variety Name	Company Produced	Altitude(m)	Registered (Y)
96	MAMSH913	Multi-Agro Trading Supplier	900 - 1500	2013
97	K6Q	Aminata Quality Seed Ltd	0 - 1600	2013
98	WE2109	Tcst	0 - 1500	2013
99	WE2112	Tcst	0 - 1500	2013
100	UHS 401	Ari-Uyole	500 - 1500	2014
101	SC 719	Seedco Tanzania Ltd	800 - 1500	2014
102	SC 533	Seedco Tanzania Ltd	400 -1600	2014
103	SC 529	Seedco Tanzania Ltd	400 -1600	2014
104	MERU HB 621	Meru Agro-Tours & C Co. Ltd	800 - 1200	2014
105	MERU HB 509	Meru Agro-Tours & C Co. Ltd	800 - 1200	2014
106	MERU HB 507	Meru Agro-Tours & C Co. Ltd	800 - 1200	2014
107	MAMSH 591	Multi-Agro Trading Supplier	900 - 1500	2014
108	Lubango	Iffa Seed Company Ltd	900 - 1500	2014
109	KH 500- 43A	East Africa Seed (T) Ltd	600 - 1500	2014
110	CP 808	Chareon Pokphand P(T) Ltd	400 - 800	2014
111	CP 201	Chareon Pokphand P(T) Ltd	400 - 800	2014
112	BSI 1	Chareon Pokphand P (T) Ltd	900 - 1900	2014
113	WE 3102	Ari-Ilonga	0 - 1500	2014
114	WE 3117	Ari-Ilonga	0 - 1500	2014
115	WE3113	Ari-Ilonga	0 - 1500	2014
116	T105	Ari Tumbi	600- 1500	2016
117	T104	Ari Tumbi	600- 1500	2016
118	NATA K 8	Aminata Quality Seed Ltd	0- 1600	2016
119	NATA H401	Aminata Quality Seed Ltd	400- 1500	2016
120	MERU LISHE 511	Meru Agro-Tours & C Co. Ltd	800 - 1200	2016
121	MERU LISHE 503	Meru Agro-Tours & C Co. Ltd	800 - 1200	2016
122	Krishna Hybrid-1	Krishna Seed Company Ltd	600-1200	2016
123	Krishna Hybrid-2	Krishna Seed Company Ltd	600-1200	2016
124	Kisongo	Iffa Seed Company Ltd	600-1200	2016
125	Kaspidi	Iffa Seed Company Ltd	600-1200	2016
126	WE4102	Ari-Ilonga	0 - 1500	2016
127	WE4106	Ari-Ilonga	0 - 1500	2016
128	WE4110	Ari-Ilonga	0 - 1500	2016
129	WE4112	Ari-Ilonga	0 - 1500	2016
130	WE4114	Ari-Ilonga	0 - 1500	2016

131	WE4115	Ari-Ilonga	0 - 1500	2016
132	**TH 619**	Tropical Seed (Ea) Ltd.	800 - 1500	2017
133	TH 617	Tropical Seed (Ea) Ltd.	800 - 1500	2017
134	SY 514	Syngenta Tanzania Ltd	800 - 1900	2017
135	MAMSH 458	Mamsh	900 - 1500	2017
136	MAMSH 457	Mamsh	900 - 1500	2017
137	HPH 1322	Matc	800 - 1200	2017
138	HPH 1317	Matc	800 - 1200	2017
139	H352	Agriseed Technologies	200 - 1700	2017
140	H351	Agriseed Technologies	200 - 1700	2017
141	TH 501	Ari Tumbi	800 -1500	2018
142	SC 419	Seedco Tanzania Ltd	100 - 1000	2018
143	DK777	Monsanto Tz Ltd	500 - 1900	2018
144	SY 734	Syngenta SA	NI	2019
145	SY 5344	Syngenta Tanzania Ltd	700 - 1900	2019
146	SY 455	Syngenta SA	NI	2019
147	SC 727	Seed Co Zambia	NI	2019
148	SC 637	Seed Co Zambia	NI	2019
149	SC 633	Seed Co Zambia	NI	2019
150	SC 608	Seed Co Zambia	800 - 1600	2019
151	SC 303	Seed Co Zambia	100 – 800	2019
152	PAN 7M-81	Pannar Seed (Pvt) Ltd	NI	2019
153	Lake 601	Lake Agriculture	NI	2019
154	KKS 603	Andrew Henderson	NI	2019
155	KKS 507	Andrew Henderson	NI	2019
156	KKS 501	Andrew Henderson	NI	2019
157	EAS 5019	East Africa Seed (T) Ltd	800 - 2000	2019
158	DKC90-53	Monsanto Tanzania Ltd	NI	2019
159	DKC80-73	Monsanto Tanzania Ltd	NI	2019
160	DKC80-53	Monsanto Tanzania Ltd	NI	2019
161	DKC80-33	Monsanto Hybrid Seed Co.	800 - 1600	2019
162	CAP9001	Capstone Seeds S. A	NA	2019
163	AMH501	Alsem Seed Company	0 - 1500	2019
164	AMH500	Alsem Seed Company	0 - 1500	2019
165	WE 5135	Ari-Ilonga	0 - 1500	2019
166	WE 5141	Ari-Ilonga	0 - 1500	2019
167	WE 7118	Ari-Ilonga	0 - 1500	2019
168	WE 7133	Ari-Ilonga	0 - 1500	2019
169	UH6305	Tari	1200-2000	2020
170	UH615ST	Tari	1200-2000	2020
171	SY 5054	Syngenta Tanzania Ltd	800-1600	2020
172	EASH 902	East Africa Seed (T) Ltd	100-800	2020
173	EASH 1231	East Africa Seed (T) Ltd	800-1200	2020
174	EASH 1129	East Africa Seed (T) Ltd	800-1200	2020
175	ZMS 405	Zambia Seed Company Ltd	800-1400	2020
176	ZMS 528	Zambia Seed Company Ltd	800-1400	2020
177	ZMS 638	Zambia Seed Company Ltd	800-1400	2020
178	ZMS 720	Zambia Seed Company Ltd	800-1400	2020
179	S3	Chareon Pokphand P Co.Ltd.	NI	2021
180	S1	Chareon Pokphand P Co.Ltd.	NI	2021
181	P2809W	Pannar Overseas Co (T) Ltd	600-1700	2021
182	Dhahabu Tamu	Africasia Seed Co. Ltd	NI	2021
183	PAN 7M-87	Corteva Agri.Sciencs Ltd	700-1600	2022
184	PAN 3M-05	Corteva Agri.Sciencs Ltd	0- 1200	2022
185	Meru HB 505	Meru Agro-Tours & C Co. Ltd	500-1200	2022
186	WH509	Western Seed Co. Ltd	700-1500	2022
187	WH605	Western Seed Co. Ltd	1500-2200	2022
188	PAN 4M-11	Corteva Agri.Sciencs Ltd	0-1100	2023

189	P2848W	Corteva Agri.Sciencs Ltd	0-110	2023

Source (TOSCI 2024). NI denotes production Altitude not indicated.

Table 3. Common Pests and diseases challenging Maize production in Tanzania.

SN	Name	Causative agent	Yield losses	Source
1	Maize Streak Disease	Maize Streak Virus	20% - 50%	Bosque-Pérez 2000
2	Lethal Necrosis Disease	Maize Chlorotic Mottle Virus	Up to 100%	Mahuku *et al*., 2015
3	Northern Leaf Blight	*Exserohilum turcicum*	30-50%	Pratt and Gordon 2006
4	Gray Leaf Spot	*Cercospora zeina*	30-60%,	Ward *et al*.,1999
5	Maize Ear Smut	*Ustilago maydis*	5% to 20%,	Pratt & Gordon 2006
6	Maize Rust Disease	*Puccinia sorghi/Puccinia polysora*	10% to 50%	Rhind *et al*.1952
7	Fall Armyworm	*Spodoptera frugiperda*	20-50%,	Day *et al*., 2017
8	Stem Borers	*Busseola fusca/Chilo partellus*	10-50%,	Kfir *et al*., 2002
9	Larger Grain Borer	*Prostephanus truncatus*	40-100%	Hodges & Farrell 2004
10	Maize Weevil	*Sitophilus zeamais*	10-50%	Meikle *et al*.,1998
11	Angoumois Grain Moth	*Sitotroga cerealella*	20-30%	Hill, 1990
12	Red Flour Beetle	*Tribolium castaneum*.	5-30%,	Beckett *et al*.,2007
13	Cutworms	*Agrotis spp.*	10% to 30%.	Casmuz *et al*., 2010.
14	Microtoxins	*Aspergilus flavus*	_	Kamala *et al*., 2017
15	Rats	*Rattus rattus/Mastomys natalensis*	10% to 20%	Leirs *et al*., 1996.

PEST AND DISEASES OF MAIZE IN TANZANIA

One of the most significant challenges in Maize production is the threat from pests and diseases both in field and storage. In field, maize is frequently threatened by stem borers, particularly *Busseola fusca*, Chilo *partellus* and invasive Spodoptera *frugiperda(*Table 3). These pests bore into maize stems, causing severe yield losses by disrupting nutrient flow and reducing plant vigor (Table 3). Most farmers use insecticides like pyrethroids, lambda-cyhalothrin and cultural practices such as crop rotation, monitoring, traps and intercropping with legumes in management of the pests (Kfir *et al*., 2002; Day *et al*., 2017; Harrison *et al.*, 2019).

Storage pests which devastating in Tanzania include the large grain borer (*Prostephanus truncatus*), the lesser grain borer (*Rhyzopertha dominica*), maize weevils (*Sitophilus zeamais*), Angoumois grain moth (*Sitotroga cerealella*), red flour beetle (*Tribolium castaneum*), and rodents particularly *Rattus rattus* and *Mastomys natalensis*(Table 3). These pests damage stored maize by boring into the grains, leading to weight loss and reduced quality. The management of storage pest in Tanzania employs different strategies including biological such as neem extracts, natural enemies such as cat for rats, chemical methods like phosphine fumigation, and cultural practices such as proper maize drying and the use of hermetic storage bags (Leirs *et al*., 1996; Abass *et al*., 2013). Furthermore, fungal contamination is very prevalent in Tanzania maize storage (Mollay *et al*., 2020). The fungus *Aspergillus* and *Fusarium* species, which produce harmful mycotoxins, poses a serious risk. Mitigation strategies include the use of biocontrol agents, fungicides, and proper drying and storage practices to prevent fungal growth (Hell *et al*., 2008; Kang'ethe & Langat, 2009).

Diseases represent a considerable big to maize production in Tanzania, with diseases such as maize lethal necrosis disease (MLND), maize ear smut, maize streak disease, maize rust disease, chlorotic mottle virus (MCMV), and sugarcane mosaic virus (SCMV) (Table 3). Among these, maize streak disease and lethal necrosis disease are particularly devastating, leading to substantial yield reductions and severely endangering food security in affected areas (Table 3). Managemt strategies farmer's employs include chemical control focuses on managing insect vectors, such as thrips and aphids, which play a key role in disease transmission (Leirs *et al*., 1996). Additionally, cultural practices are widely adopted to mitigate the impact of these diseases, including the use of certified virus-free seeds to prevent initial infections, cultivating maize varieties bred for resistance to these pathogens, and rotating crops to disrupt the disease cycle and reduce pathogen buildup in the soil (Bosque-Pérez 2000; Pratt & Gordon 2006; Mahuku *et al*., 2015).

Effective management of pests and diseases in Tanzania necessitates an integrated approach that combines biological, chemical, and cultural control measures to ensure sustainable production and storage. Biological control involves the use of natural predators, parasitoids, and biopesticides to manage pests such as the fall armyworm and maize weevil, which significantly impact crop yields. For example, beneficial insects like Trichogramma wasps and biopesticides derived from *Bacillus thuringiensis* have shown promise in controlling pest populations while minimizing harm to non-target organisms and the environment (Prasanna *et al*., 2018). Chemical control measures, such as the judicious application of insecticides and fungicides, play a crucial role in managing pest outbreaks and diseases like maize lethal necrosis and gray leaf spot. However, the emphasis is on using these chemicals as part of an integrated pest management (IPM) strategy that reduces reliance on pesticides to minimize environmental impacts and prevent the development of pest resistance. Proper timing and targeted application of pesticides can help control pest populations effectively without compromising the safety of maize consumers and the environment.
Cultural control practices, including crop rotation, intercropping, and timely planting, are essential in breaking the life cycles of pests and diseases. Crop rotation with legumes, for example, can improve soil fertility while disrupting pest habitats. Proper field sanitation, such as removing crop residues and practicing conservation tillage, helps reduce pest breeding sites and disease prevalence (CIMMYT, 2019). Additionally, post-harvest handling practices like the use of hermetic storage bags and metal silos can protect harvested maize from pests such as the larger grain borer, significantly reducing post-harvest losses (Hellin & Meijer, 2006).

FARMERS PROFIT MARGIN CHALLENGES

Profit margins represent important motivation to farmers considers a specific crop to include in cropping system (Gollin & Goyal 2017; Moshi *et al*., 2023). The profit margin for maize farmers in Tanzania is very due to high production costs, which include seeds, fertilizers, pesticides, and labor. Input costs have been rising due to inflation and supply chain disruptions, squeezing farmers' profit margins (Olagunju *et al*., 2021; Moshi *et al*., 2023). The cost of hybrid seeds and chemical fertilizers, which are essential for high yields, can be excessively expensive for smallholder farmers; leading to lower net incomes (Merteen, 2000; Amare *et al*., 2013). Yield variability is another factor which affects farmers' profit margins. Moreover, factors such as inadequate access to quality seeds, unreliable rainfall, and poor soil fertility contribute to unpredictable maize yields which in turn results in income variations from year to year making it difficult for farmers to achieve stable profits (Shee *et al*., 2019).

Factors related to pests and diseases causes' substantial yield losses and increase production costs due to the need for pest and disease management measures. The economic impact of these pests and diseases can significantly reduce farmers' profit margins (Harrison *et al*., 2019). Furthermore, maize prices in Tanzania are highly volatile due by seasonal variations, market demand, and regional supply imbalances. Price fluctuations make it difficult for farmers to predict their income and plan for future investments. Market prices can drop considerably during the harvest season due to oversupply, while prices can rise during the lean season, affecting farmers' profitability (Moshi *et al*., 2023). Above all, inability to access to markets, poor infrastructure and storage facilities hinders farmers to sell at favorable prices in more lucrative markets. Farmers in Tanzania usually lack access to timely and accurate market information such as current prices and demand trends. This information asymmetry prevents them from making informed decisions about when and where to sell their maize, impacting their ability to maximize profits (Lofchie, 1978; Cooksey, 2011; Shee *et al*., 2019; Wineman and Jayne 2020).

The maize value chain in Tanzania faces significant inefficiencies that impede the development of consistent value-added products. One important issue is inappropriate processing facilities, which restricts opportunities for activities such as milling, fortification, and other value-adding processes. This limitation reduces farmers' ability to maximize profits from various revenue streams associated with maize products (Merteen, 2000; Amare *et al*., 2013; Shee *et al*., 2019).

Limited access to financial services is another important barrier preventing maize farmers from achieving optimal profit margins. Restricted access to credit hinders farmers from scaling up operations from small-scale to large-scale production. It also limits their ability to purchase and utilize high-quality inputs, adopt modern farming technologies, and invest in infrastructure improvements. Without sufficient financial resources, farmers face difficulties in addressing production and market challenges effectively (Gollin & Goyal, 2017; Mafie et al., 2021). Extension services, which provide farmers with technical advice and support, are often weak or inadequate in Tanzania. This limits farmers' access to best practices for crop management, pest control, and soil fertility. Improving extension services could help farmers adopt more effective techniques, enhance productivity, and improve their position in the maize value chain (Moshi *et al*., 2023). According to (Masuka *et al*., 2017a, b) the rapid adoption of enhanced drought-tolerant maize varieties could result in financial gains ranging from US$362 million to US$590 million over seven years. Similarly, the use of maize varieties tolerant to low nitrogen conditions offers substantial economic benefits, with potential gross returns of US$100 million to US$136 million for producers.

RESEARCH GAPS AND CONTENTIOUS ISSUES IN MAIZE PRODUCTION

The production and research of maize in Tanzania faces multiple challenges and gaps that require a multi-disciplinary approach to address effectively. One area with huge potentials but not yet exploited is mutation breeding (Table 4), Globally, over 3,300 mutant crop varieties have been released, including several maize varieties with improved disease resistance, nutritional content, and adaptability (Saif, 2023; IAEA, 2024). No varieties of maize registered by TOSCI or listed by IAEA is of mutagenic origin. Also, Tanzania has no mutant's germplasm that can be included in national breeding program (TARI 2024; TOSCI 2024; IAEA, 2024). Specific research on mutations that will benefit maize varieties through improvement yield, nutrition, tolerance to biotic and abiotic stresses. Socio-economic factors affecting farmers' acceptance of mutation-bred varieties also need exploration to guide effective policy development and breeding programs tailored to local needs (Table 4). Similarly, the use of GMO technology in maize production and consumption remains a contentious issue in Tanzania due to regulatory, ethical, and social concerns (Abkallo *et al*., 2024; Mmbando, 2024). While genetically modified organisms (GMOs) have demonstrated increased yields and enhanced resistance to pests and diseases in many countries, there is a lack of sufficient information and awareness in Tanzania. For example, Bt maize has been successfully cultivated across the USA, Canada, Europe, and several developing nations, covering substantial crop areas (Abbas, 2018; James, 2016). However, Tanzania's regulatory framework for GMOs is still under development, with no established policies or legislation in place. Additionally, neighboring countries that share borders with Tanzania have already adopted GMO practices, increasing the likelihood of GMO seeds being introduced, either intentionally or unintentionally, into Tanzanian agriculture. Research is essential to fill these knowledge gaps, support evidence-based policymaking, and promote public understanding and acceptance of GMOs (Table 4). The adoption of intelligent agriculture (IA) technologies, such as AI, IoT, and data analytics, represents another underexplored area in Tanzanian maize production (Table 4). These technologies can be game changer in maize production by optimizing inputs, reducing costs, management of irrigation, pest, diseases and increasing yields (Pukrongt *et al*., 2024). For example, AI-driven unmanned aerial vehicles (UAVs) can provide effective pest management without environmental harm (Usigbe *et al*., 2024). However, their application in Tanzania is limited, and little research has been conducted on their adaptability, cost-effectiveness, and socio-economic impacts on smallholder farmers. Research should focus on developing context-specific IA solutions that are affordable, user-friendly and scalable. The maize seed system in Tanzania requires considerable improvement.Although certified maize varieties are available, only few percent use it. A study conducted in 2010s showed only 18% of maize-growing areas in the country are planted with fresh, improved seeds, with the majority of farmers relying on farm-saved seeds (Langyintuo *et al*., 2010; Smale et al., 2013; Almekinders *et al.,* 2019). Many farmers unknowingly recycle hybrid seeds, which segregate in the F2 generation, leading to reduced yields. The seed system faces challenges such as weak linkages between seed producers and farmers, poor quality control, counterfeit seeds, and insufficient policy support. Additionally, there is limited understanding of farmers' knowledge, perceptions, and attitudes toward certified seeds. Research is urgently needed to assess the performance of existing seed systems, identify obstacles to seed access, and design strategies to enhance seed distribution, particularly in remote and underserved areas (Table 4). Exploring the use of wild crop relatives (CWR) for maize improvement is another promising but under-researched area (Table 4). Wild relatives possess genetic diversity that can be used to develop maize varieties with better resistance to diseases, pests, and climate stress (Satori *et al*., 2021). While there is evidence of wild relatives for other crops like rice and sorghum in Tanzania (Appa *et al*., 1996; Davis & Mvungi, 2004; Katayama *et al*., 1988), research on maize wild relatives is sparse. Further studies should focus on identifying suitable wild relatives and integrating them into breeding programs to enhance maize resilience. Value addition in maize production offers substantial potential to enhance economic benefits for farmers and contribute to the broader economy by creating additional revenue streams through processed products (Table 4). Maize can be transformed into various food and industrial products, including traditional dishes, snacks, starch, ethanol, and corn oil (Yadav & Supriya, 2014; Gollin & Goyal 2017; Olagunju *et al*., 2021. Additionally, by-products such as hay, leaves, and cobs remain underutilized and lack sufficient research on their potential applications (Gollin & Goyal 2017). Notwithstanding this opportunity, there is limited data on important factors such as market potential, consumer preferences, and the socio-economic drivers influencing value addition. In order to address these gaps, research should focus on identifying high-value maize-based products, analyzing market trends, and evaluating the role of government policies and incentives in supporting diversification and innovation within the maize value chain. Nutritional deficiencies in Tanzanian diets also highpoint the need for biofortification in maize breeding programs (Table 4). While maize is rich in carbohydrates, it lacks essential nutrients such as lysine, tryptophan, vitamin A, and minerals like iron and zinc (Jin *et al*., 2013; Wessells & Brown, 2012). Biofortification, which involves breeding crops for enhanced nutrient content, could address these deficiencies. Despite the potential, only one biofortified maize variety, Jesca, has been released in Tanzania (Ndimbo *et al*., 2022). More research is needed to incorporate biofortification as a key objective in breeding programs and to evaluate its impact on nutrition and health outcomes. Gene editing technologies, such as CRISPR-Cas9, also offer promising avenues for maize improvement. These technologies can create targeted genetic changes to enhance maize resistance to pests, diseases, and environmental stresses (Chen *et al*., 2019; Shi *et al*., 2017). However, in Tanzania, gene editing is not yet utilized due to technological limitations and ethical concerns (Abkallo *et al*., 2024; Mmbando, 2024). More research is needed to develop regulatory frameworks that balance safety, ethical considerations, and public acceptance (Table 4). Climate-smart agriculture (CSA) practices are crucial for adapting maize farming to climate change (Table 4). CSA aims to increase productivity, build resilience, and reduce greenhouse gas emissions (Shikuku *et al*., 2017). While there is some government support for CSA initiatives under the Agricultural Sector Development Plan II (Jones *et al*., 2023), research on their effectiveness and adoption in Tanzania’s diverse agro-ecological zones is limited. Studies should identify effective CSA practices, assess their economic viability, and understand the socio-economic factors influencing adoption among smallholder farmers. Finally, aflatoxins and fumonisins contamination pose serious risks to maize production, food safety, and public health in Tanzania (Kamala *et al*., 2017; Mollay *et al*., 2020). Despite known risks, there is a lack of research on farmers’ awareness, mitigation strategies, and cost-effective interventions to reduce contamination levels. More studies should assess risk factors and develop integrated management strategies combining agricultural practices, resistant varieties, storage technologies, and awareness campaigns to ensure food safety (Table 4).

Table 4. Research and contentious issues in Maize Production in Tanzania

SN	Area of Contention / Research Gap	Descriptions
1	Mutation Breeding	Utilizing induced mutations to develop new maize varieties with improved traits. Limited research is available on the potential of mutation breeding in enhancing maize resilience and yield in Tanzania
2	GMO Technology	Application or acceptance of genetically modified organisms (GMOs) in maize production and consumption. There is a lack of studies on farmer awareness, perception, policies and regulatory frameworks specific to Tanzania
3	IA Technology (Intelligent Agriculture)	Use of technologies like AI and IoT for precision farming in maize cultivation. Research on the adoption, efficiency, and barriers to intelligent agriculture technology in Tanzania is minimal.
4	Maize Seed Systems	Enhancing the development, distribution, and adoption of improved maize seeds. Gaps exist in understanding seed system efficiency and access, particularly for smallholder farmers.
5	Utilization of Wild Crop Relatives	Exploring the potential of wild relatives of maize for genetic improvement and resilience against climate change. Limited studies or inventory of wild relatives and their use in breeding programs.
6	Value Addition	Strategies for increasing the economic value of maize through processing and product development. Research is needed to explore product streams, market potential, value chain development, and policy support.
7	Biofortification	Developing maize varieties with enhanced nutritional content to combat malnutrition. More research is needed to understand consumer acceptance and scalability of biofortified maize varieties.
8	Biotechnology/ Gene Editing	Use of biotechnology such as CRISPR and other gene-editing technologies for targeted improvements in maize. There is a lack of research on regulatory, ethical, and acceptance issues surrounding gene editing in Tanzania.
9	Climate Smart Agriculture	Approaches to adapt maize farming to climate change while minimizing environmental impacts. Insufficient data on effective climate-smart practices tailored for Tanzanian agro-ecological zones.
10	Aflatoxin	Addressing contamination issues in maize production and storage to ensure food safety. Research gaps exist in understanding the extent of aflatoxin contamination and effective mitigation strategies.

FUTURE PERSPECTIVES AND RESILIENT FACTORS IN MAIZE CULTIVATION

Climate change impacts maize production in Tanzania in several critical ways. Rising temperatures can significantly affect maize growth and development. Maize is sensitive to temperature extremes, particularly during the critical flowering and grain-filling stages. High temperatures can cause poor kernel formation, reduce grain yield, and increase water stress. In Tanzania, where the average temperature has been rising, these effects are compounded by already high temperatures, potentially leading to lower maize yields and reduced food security (Cooksey, 2011; Lobell *et al*., 2011; Schlenker & Lobell, 2010). For example, a study found that maize yields in sub-Saharan Africa could decrease by up to 20% due to increased temperatures (Schlenker & Lobell, 2010). Additionally, climate change influences the distribution and prevalence of maize pests and diseases. Rising temperatures expand the range of pests such as the fall armyworm (*Spodoptera frugiperda*), a major threat to maize crops in Tanzania. Increased humidity also fosters fungal diseases like maize lethal necrosis disease (MLND), which has caused substantial yield losses in recent years. These combined challenges place significant strain on farmers' ability to effectively manage pest and disease outbreaks (Choudhury *et al*., 2019; Hafez *et al*., 2020; Muriuki *et al*., 2022).

Climate change also impacts maize production by altering rainfall patterns. The increased frequency of droughts and irregular rainfall disturbs soil moisture levels essential for maize growth. Prolonged dry spells can hamper germination and early development, while excessive rainfall may result in flooding, soil erosion, and nutrient leaching. In Tanzania, these changes aggravate existing challenges, reducing crop yields and intensifying the vulnerability of smallholder farmers (Kumwenda *et al*., 2006; Cairns *et al*., 2013). Research indicates that rainfall variability in East Africa is expected to intensify, potentially leading to more frequent and severe droughts (Cairns *et al.,* 2013).

Biotechnology offers several strategies to address the challenges posed by climate change. Genetic engineering can introduce traits such as drought tolerance, heat resistance, and pest resistance into maize varieties. For instance, Bt maize, which incorporates a gene from *Bacillus thuringiensis*, offers resistance to pests like the stem borer and fall armyworm, reducing reliance on chemical pesticides and improving yield stability (Warburton *et al*., 2002). Similarly, drought-tolerant maize varieties are being developed to withstand water stress and maintain productivity under adverse conditions (Reddy *et al*., 2017; Kaur *et al*., 2021).

Genetic modifications can enhance maize efficiency in nutrient and water use, making crops more adaptable to changing environmental conditions. Researchers are developing maize varieties with improved photosynthetic efficiency, enhanced root systems, and better water-use efficiency. These improvements aim to ensure that maize can thrive even under stressful conditions, maintaining productivity and resilience (Tester & Langridge, 2010; Ghosh *et al*., 2022). For example, research has identified genetic pathways that improve maize's ability to cope with heat stress, potentially increasing yield in warmer climates (Yuan *et al*., 2016).

Marker-assisted selection (MAS) accelerates the breeding of maize varieties with desirable traits by using molecular markers linked to specific traits. This approach allows breeders to select for traits such as drought tolerance and disease resistance more efficiently. MAS helps identify and incorporate beneficial traits into new maize varieties, making them better suited to changing climate conditions (Collard & Mackill, 2008; Wu *et al*., 2023). For instance, MAS has been used to develop maize varieties with improved resistance to MLND and other diseases (Huang *et al*., 2018). Collaborative efforts among researchers, policymakers, and farmers are essential for the successful deployment of biotechnology in maize production. For example, integrating biotechnology with conservation agriculture practices can improve the overall resilience of maize production systems (Friedrichs *et al*., 2017; Zhao *et al*., 2019). Additionally, incorporating biotechnology with agro-ecological approaches can provide a holistic solution to climate change impacts on maize (Pretty, 2020).

Advances in genomics and next-generation sequencing technologies provide insights into the genetic basis of maize adaptation to climate stress. Understanding the maize genome enables precise breeding and genetic modification strategies to enhance resilience. Genomic studies help identify genetic markers associated with stress tolerance, enabling the development of more robust maize varieties. These insights are crucial for developing maize that can adapt to varying environmental conditions and maintain high yields (Varshney *et al*., 2017; Hao *et al*., 2020). Recent advancements in genomics have facilitated the identification of genes associated with drought and heat tolerance, paving the way for more resilient maize varieties (Hao *et al*., 2020; Zhi *et al*., 2021).

Investing in capacity building and research is vital for addressing future challenges in maize production. Strengthening local research institutions and training programs accelerates the development and adoption of climate-resilient maize varieties. Building local expertise and infrastructure supports the effective implementation of biotechnological solutions and enhances agricultural sustainability. Research initiatives should focus on developing technologies tailored to local conditions and needs, ensuring that innovations are accessible and beneficial to Tanzanian farmers (Morris *et al*., 2013; Kassie *et al*., 2013). Additionally, fostering international collaborations and partnerships can enhance research capabilities and resource sharing, contributing to more effective solutions for maize production challenges (Pardey *et al*., 2016; van Eenennaam *et al*., 2018).

CONCLUSION

Maize is indispensable staple crop in Tanzania, both in terms of production and consumption. Before the colonial era, maize production was limited and primarily focused on subsistence farming. During the colonial period, agricultural policies emphasized cash crops to supply raw materials for European industries, leaving maize cultivation underdeveloped. However, since independence, maize production has grown steadily, fueled by the adoption of improved varieties, expansion of cultivated land, and the implementation of good agricultural practices.

Today, Tanzania ranks 5th in Africa for maize production. In 2021, the country achieved a record-breaking harvest of 7.039 million tons, cultivated on 4.4 million hectares. The main factor behind maize's widespread adoption is its dual role as both a food and cash crop, ensuring household food security while providing farmers with a dependable source of income. Maize's adaptability further underscores its importance, with varieties suited to diverse altitudes and environmental conditions, from lowland plains to highland regions. Moreover, maize integrates seamlessly into various farming systems, enabling intercropping with legumes, beans, and other staple crops, which enhances productivity and promotes sustainable agriculture.

Despite its importance, maize production in Tanzania faces significant challenges. These include pests and diseases, the adverse effects of climate change, low adoption rates of improved varieties, an underdeveloped value chain, and limited profit margins for farmers. Overcoming these challenges requires a comprehensive and multifaceted approach. Key strategies include strengthening extension services, improving access to financing and markets, enhancing value chain development, promoting climate-smart agricultural practices, adopting integrated pest management, improving seed systems, and conducting targeted research to address gaps in maize production. Furthermore, advanced technologies such as irrigation systems, biotechnologies, and artificial intelligence hold great potential to boost productivity and resilience in maize farming.

Tanzania must prioritize research, innovation, and the implementation of targeted interventions to transform its maize sector. By doing so, the country can improve farmer livelihoods, strengthen food security, and ensure sustainable agricultural development for future generations.

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