THESIS

Vongmany Thidapheth

BSc. Agricultural Engineering

2024

Hungarian University of Agriculture and Life Sciences

Szent István Campus

BSc in Agricultural Engineering

The Maize Production in Lao PDR

Insider consultant: **Márton Jolánkai**
Professor Emeritus
Institute/Department: Institute of Agronomy

Author: **Vongmany Thidapheth**
FDOKSC
Institute/Department: Institute of Agricultural and Environmental Sciences

Gödöllő
2024

Table of Contents

1. Introduction

Maize (Zea mays L.), commonly called corn, is the most abundantly produced cereal in the world. It is an essential agricultural product of worldwide importance and belongs to the POACEAE family in the Zea genus. Maize, an annual cereal crop that originated in Central America, has a long history of domestication and is used for food, fodder, and oil. There are around 50 varieties, each with a unique color, texture, grain form, and size. It is cultivated on all continents except Antarctica, and tolerance to many climates and soils has made it a versatile and vital product. The global producers by volume are the United States, China, Brazil, the European Union, and Argentina; by export, they are Brazil, the United States, Argentina, and South Africa. The Lao People's Democratic Republic (Lao PDR) is emerging as a prominent contributor in Southeast Asia.

This cereal grain is essential to the human diet, supplying critical carbohydrates, proteins, vitamins, and minerals. Nevertheless, it also plays a vital role in animal feed and industrial processes. Maize cultivation is essential to Lao PDR's agricultural environment, contributing considerably to food security and economic stability. The country's various agro-ecological circumstances make it possible to cultivate several maize types, making it a key component in the country's agricultural interests.

2. Literature Review

2.1. General Overview of Laos

The Lao People's Democratic Republic (Lao PDR), located in the center of Southeast Asia, has abundant natural resources, including dense forests, flowing rivers, and a diverse ecosystem. The population is growing at a rate of roughly 2 percent annually, and the country's demographic picture has steadily improved, with a total population of 7,633,779 in 2023 (World Bank, 2024b). Despite this population rise, in 2022, Laos's labor force primarily engages in precarious employment, accounting for 66 percent of the total workforce, of which 61.5 percent is female (World Bank, 2024a).

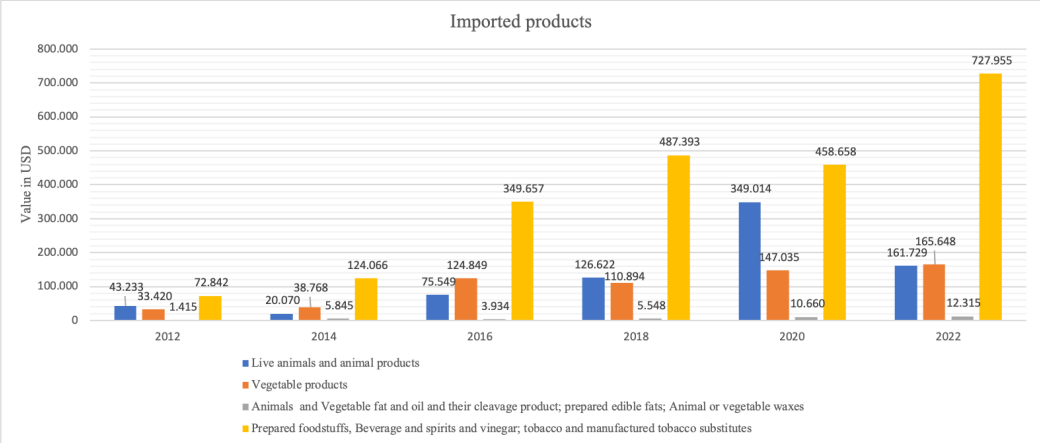
Agriculture is the backbone of Laos' economy and is strongly connected to the country's natural and climatic characteristics. The reliance on nature for subsistence highlights the susceptibility of agricultural livelihoods to the effects of climate change, which poses considerable challenges to food security and economic stability. As climate shifts and environmental disruptions continue to occur, the resilience of agricultural systems and rural populations' livelihoods are compromised, demanding proactive measures to minimize negative consequences and promote sustainable development directions.

2.1.1. Economic and policy

In 2023, Laos's GDP per capita was 2,057.4 USD, with the agriculture, forestry, and fishing sectors accounting for 16.1 percent of GDP, manufacturing for 9 percent, and industry (including construction) for 30.5 percent (World Bank, 2023).

- Import

Figure 1: Imported agriculture products value of Lao PDR;
Source: Author, based on data from the Lao Statistic Bureau, data updated August 31, 2023.



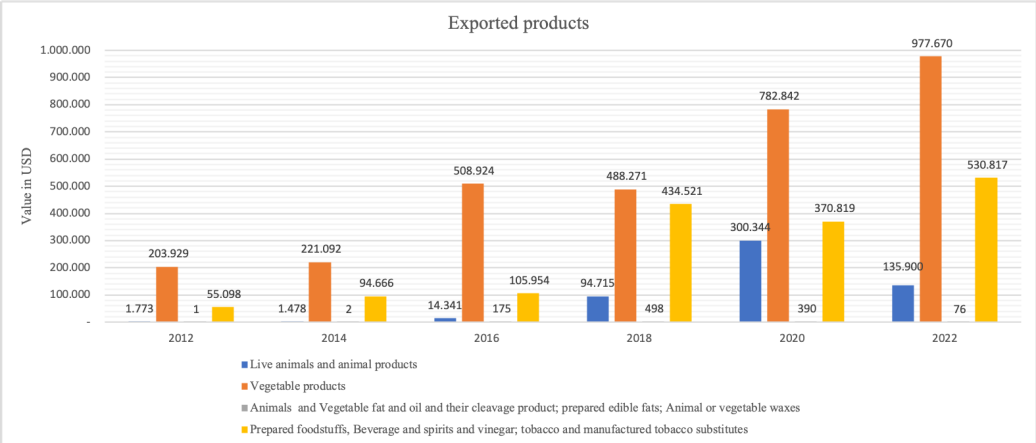
In 2022, the import value of goods was 6,858,544 (thousand USD), of which 57.80 percent came from intra-ASEAN countries, 36.51 percent from extra-ASEAN countries, and 5.68 percent from the rest of the world (LAOSIS, 2023b).

Figure (1) illustrates the values of imported products in the decade starting from 2012 to 2022. Live animals and animal products slightly increased by approximately (707%) from 43,233 to 349,014 (thousand USD) in 8 years from 2012 to 2020. However, in 2022, the imported value from this field considerably decreased by almost half from two years earlier. Vegetable products have grown nearly four hundred percent in the decade since 2012, from 33,420 (thousand USD) to 165,648 (thousand USD). Other products, such as animal and vegetable fat and oil and their cleavage products, prepared edible fats, and waxes, have remained slowly increasing. Prepared foodstuffs, beverages and spirits, vinegar, tobacco, and manufactured tobacco substitutes have risen significantly since 2012 at 72,842 (thousand USD) and have reached the highest value in 2022 at 727,955 (thousand USD).

- Export

In 2022, the export value of goods was 8,421,062 (thousand USD), of which 56.85 percent came from intra-ASEAN countries, 40.56 percent from extra-ASEAN countries, and 3.25 percent from the rest of the world (LAOSIS, 2023a).

Figure 2: Exported agriculture products value of Lao PDR;
Source: Author, based on data from the Lao Statistic Bureau, data updated August 31, 2023.



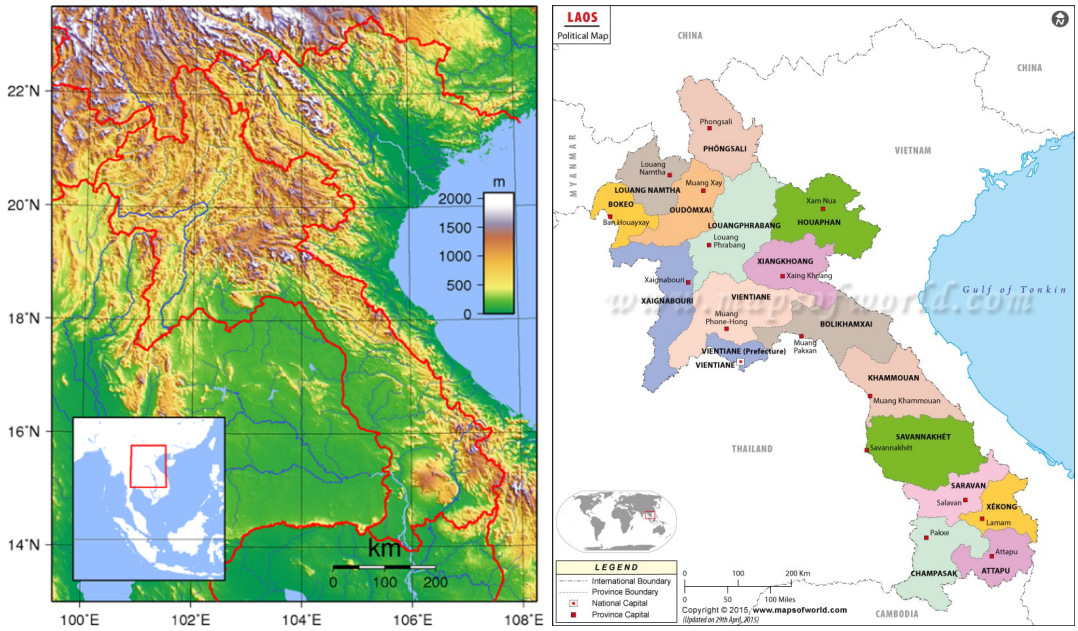
According to figure (2), Lao PDR exported products from live animals in 2012, valued at 1,773 and 1,478 (thousand USD) in 2012 and 2014, respectively. Since that year, the exported value from the live animals sector has risen dramatically every two years, at 14,341, 94,715, and 300,344 (thousand USD) from 2016 to 2020, and dropped to 136 (thousand USD) in 2022. Vegetables were the main exported product in the decade; the expected values are low but can

reach the highest point in 2022 at 977,670 (thousand USD). Animal and vegetable fat and oil and their cleavage products, prepared edible fats, and waxes rose 4,97 percent from 2012 to 2018; since then, it has fallen slightly to almost -85 percent in 2022. Prepared foodstuffs, beverages and spirits, vinegar, and tobacco also have fluctuated exported values, which can reach a peak at 530,817 (thousand USD) in 2022.

2.1.2. Geography

Laos is a landlocked country located in Southeast Asia. Laos, formally known as the Lao People's Democratic Republic (Lao PDR), is strategically situated between five neighboring nations. To the north is the People's Republic of China, Myanmar to the northwest, Thailand to the west, Vietnam to the east, and Cambodia to the south. The country's topography is distinguished by three regions: plain, plateau, and mountainous regions. The Annamite Range dominates the northern part, with high mountains and dense forests, while the center and southern lowlands comprise broad plateaus and river basins, especially the Mekong River Valley. The Mekong River, which runs along most of Laos' western border, serves as a lifeblood for agriculture, transportation, and livelihoods across the country. In addition to the Mekong, other tributaries and streams cross the country, contributing to Laos' extensive hydrological system. This diversified topography defines the natural landscapes and influences its climate, biodiversity, and socioeconomic dynamics, highlighting Laos's complex relationship between geography and human lifestyles.

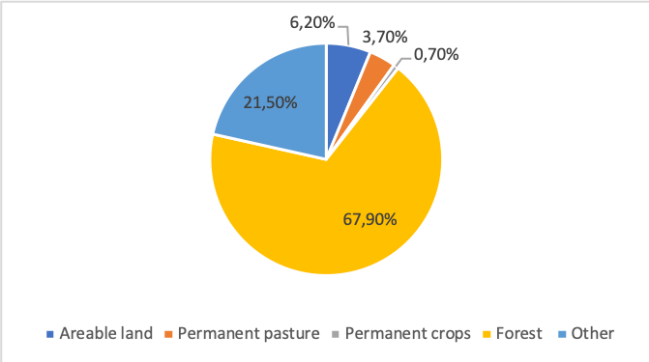
Figure 3: Topography map of Lao PDR (left) and the province's map of Lao PDR (right); Source: https://upload.wikimedia.org/wikipedia/commons/thumb/c/ce/Laos_Topography.png/800px-Laos_Topography.png, and https://images.mapsofworld.com/laos/laos-political-map.jpg



2.1.3. Soil and land

Laos' total area is 236,800 km², with the land surface covering 230,800 km² and water covering 6,000 km². According to the land law, Laos land is classified into eight categories: agricultural land, forest land, land around water resources, industrial land, communication land, cultural land, land for national defense, and construction land. Acrisols are found widely in 73 percent of the surface area, followed by Cambisols at 12 percent and Luvisols at 4 percent (CHAPLOT et al., 2010).

Figure 4: Lao land use in 2018; Source: Author, based on data from the CIA World Factbook 2023.

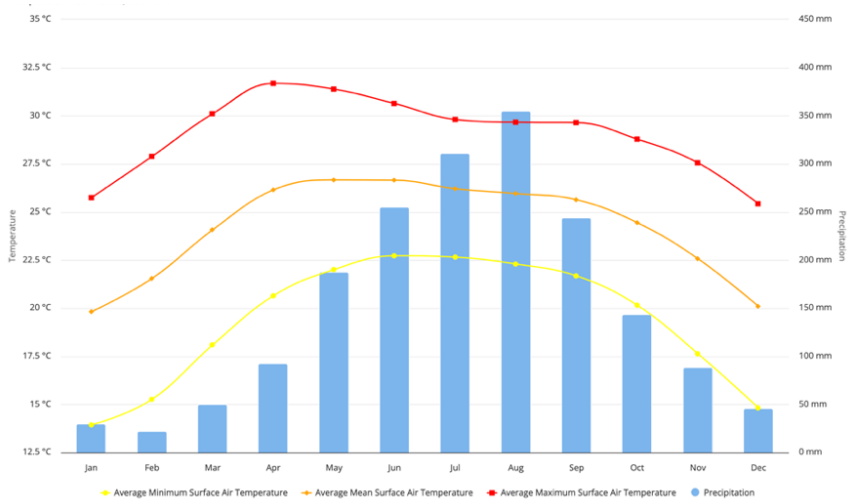


Laos' land is classified into three distinct categories: Agricultural land, which includes Arable land, Permanent crops, Permanent pasture, Forest areas, and Other lands. The Forest region occupies the most considerable portion, covering approximately 67.90% of the country's total land area. Conversely, the remaining 21.50% of land is designated for various purposes such as transportation infrastructure, urban development, and other miscellaneous uses. Additionally, Agricultural land accounts for just 10.6% of the total land area, with Arable land, Permanent crops, and Permanent pasture constituting 6.20%, 0.70%, and 3.70% of this agricultural space, respectively.

2.1.4. Climate and precipitation

Laos has a tropical climate influenced by the southeast monsoon, which increases the high annual rainfall (70 percent) and humidity. The country is divided into two main seasons: the rainy and dry seasons. The rainy season starts from May to mid-October; the highest precipitation is in August, with around 350 millimeters. On the other hand, the dry season starts from mid-October to April, during which the precipitation is less than 100 millimeters, and February is the driest month in the year. The minimum temperature, on average, is approximately 14-22 degrees Celsius, and January is the coldest month. The maximum temperature is 26-31 degrees Celsius, and the hottest month is April.

Figure 5: Annual temperature and precipitation on average;
Source: Climate Change Knowledge Portal, World Bank, 2021.



2.2.Introduction to Maize Cultivation

2.2.1. Taxonomy and origin.

Maize, scientifically known as Zea mays L., is a member of the family Poaceae and the genus Zea (Table 1). It is one of the world's most frequently produced cereal crops, renowned for its variety and nutritional benefits. Maize is classified under the grass family Poaceae and other economically significant cereals such as wheat, rice, and barley (Doebley, 2004; Eichten et al., 2011; Schnable, 2015).

Table 1: Taxonomy classification of maize; Source: Author, based on (Soreng et al., 2017).

Taxonomy	Classification
Kingdom	Plantae
Subkingdom	Tracheobionta (Vascular plant)
Supper-division	Spermatophyta (Seed plant)
Division	Magnoliophyta (Flowering plant)
Class	Lilyopsida (Monocotyledon)
Subclass	Commelinidae
Order	Cyperales
Tribe	Andropogoneae
Family	Poaceae (Grass family)
Subfamily	Panicoideae
Genus	Zea
Species	Zea mays
Subspecies	Mays

The genesis of maize and domestication dates back to ancient Meso America, when Indigenous peoples mindfully bred Balsas teosinte, Zea mays subspecies Parviglumis, a wild

grass species, to produce maize's progenitor. Archaeological evidence shows that maize production originated 10,000 years ago in modern-day Mexico and extended throughout Central and South America over millennia (Piperno & Flannery, 2001). Through generations of cultivation and hybridization, indigenous peoples changed maize from wild grass to today's prominent grain. The domestication process includes selecting favorable features, including wider kernels, higher harvest rates, and increased adaptation to various environments. Maize evolved into several landraces and cultivars that adapted to various biological niches, soil types, and climatic circumstances (Matsuoka et al., 2002).

Maize is an essential crop for production and consumption worldwide. In 2022, it had the most harvested areas in the world, at more than 2 hundred million hectares, and can produce a yield of approximately 1.1 billion tons. America is the largest producer in the world, followed by Asia, Europe, Africa, and Oceania at 577 million tons, 389 million tons, 102 million tons, 92 million tons, and 637 thousand tons, respectively.

Table 2: The maize production in different regions of the world;
Source: Author, based on data from FAOSTAT 2022.

Area	Area harvested (ha)	Yield (100g/ha)	Production (ton)
World	*203,470,007*	*57,183*	*1,163,497,383.13*
Africa	41,770,891	22,217	92,800,971.58
Americas	75,883,789	76,100	577,471,857.01
Asia	68,207,823	57,162	389,892,547.13
Europe	17,533,920	58,569	102,694,188.84
Oceania	73,583	86,680	637,818.57

2.2.2. Morphology characteristics and developments.

Maize (Zea mays L.), known for its various morphological traits and developmental phases, undergoes a complicated growth cycle. Their morphology is characterized by specific vegetative and reproductive structures, each of which plays an essential role in their growth and development (Nagy J, 2008).

A. Stems

A maize stem is a tall central stalk supporting the entire plant. The only branches on the stem serve reproductive functions. Maize's tough stem allows it to grow highly tall; depending on the type, maize plants can reach as high as 4 meters. The stem of the maize plant, characterized by nodes and internodes, provides structural support and transports water, nutrients, and photosynthetic products throughout the plant. There is only one leaf grows from each node, and stalks can contain up to 20 nodes (Kellogg, 2015).

B. Leaves

Maize leaves, arranged alternately on the stem, are the main site for photosynthesis, converting light into chemical energy (LI et al., 2010). They are structured like other grasses, consisting of a sheath that wraps around the stem and a blade that extends to intercept sunlight. The collar is where the sheath and blade meet, and the primary leaf veins are parallel. New leaves grow from a node in the sheath of older leaves. The flag leaf, the tallest leaf, is located just underneath the tassel.

C. Roots

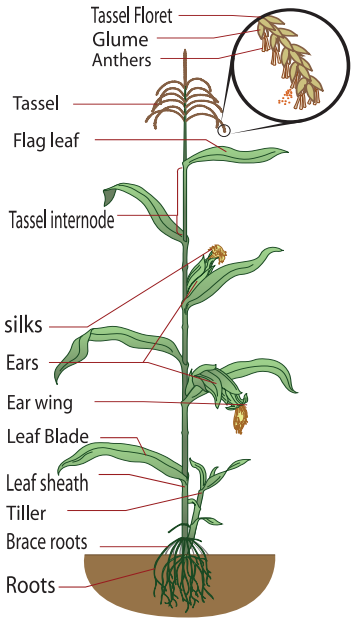
Maize plants have three root types: radicle, seminal, and nodal roots. The radicle is the primary root and is the first to develop from the kernel. Above the radicle, three to four seminal roots sprout. These roots collect water and nutrients to establish the plant. Eventually, the radicle and seminal roots die, replaced by nodal roots, which are adventitious and emerge from the stem at nodes where leaves and buds form. Healthy nodal roots can grow up to six feet (two meters) deep.

D. Inflorescence

Maize is a typical monoecious plant. It produces two imperfect blooms (male and female). Male flowers include only stamen, whereas female flowers have pistils. Although the two reproductive organs are on the same plant, they are in distinct areas.

- Male flowers, known as tassels, grow on the top of maize plants and are supported by peduncles. Tassels originate from the apical meristem of maize stalks (AGOGTR, 2008). Maize plants typically have a single tassel consisting of a central spike (rachis) and 20-50 tassel arms (branches). Male stamens are carried by each arm, with three anthers hanging on a short filament. Anthers are the male organs that produce and disperse millions of pollen into the atmosphere (Hofmann et al., 2016; VIB, 2017).
- Female flowers, or the ear, are the female reproductive component of maize, and they develop from shanks (stalk-like structures) that form from the axillary bud to the middle of the stem length. The ear consists of a cob (rachis) with rows of sessile-bearing spikelets that ultimately turn into kernels and silks (Iltis, 2000). Silks emerge first at the base of the cob, then towards the tip. Silks can be viable for up to 10 to 14 days, providing adequate time for pollination. Silks are linked to ovaries set up in rows (8-30) on a cob covered in leaves. Each ovary contains a single ovule, which transforms into a kernel.

Figure 6: Maize morphology diagram;
Source: Chiswick Chap, via Wikimedia Commons, Maize_plant_diagram.svg

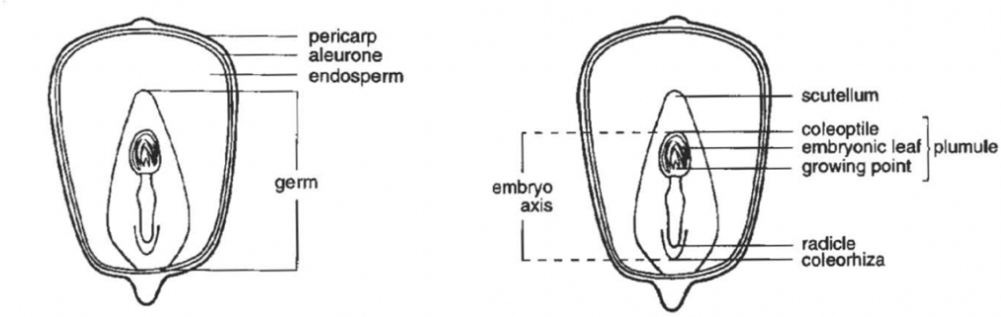


E. Fruit and seed

After fertilization, maize seeds, a combination of fruit and seed (kernel or grain), are generated. Maize kernels have a grass-like structure; they are complex, one-seeded fruits called caryopsis. The caryopsis contains the fruit wall, endosperm, and embryo.

- Fruit wall or pericarp is a protective coating developed from the ovary wall.
- Endosperm is comprised of 82-84% of the kernel's dry weight, provides energy for the growing seedling. The endosperm contains around 88% carbohydrates and 8% protein. Endosperm stores food reserves for seedlings before they build their photosynthetic structures (Edoh Ognakossan et al., 2018). Endosperm is classified into flinty (hard) or floury (soft)—the distribution of flinty and floury endosperm changes with variety and environmental circumstances. The outermost layer of the endosperm is known as the aleurone. The aleurone layer generates enzymes that turn starch into sugar. Sugar serves as an energy source for the growing seedling.
- Embryo (germ) is essential for seed germination because it carries most of the nutrients in the grain and is high in unsaturated fatty acids. This germ consists of one embryonic axis (complex), scutellum, and a single cotyledon (monocotyledon) located in a groove near the endosperm. Scutellum is a significant shield-shaped body generated when the cotyledon structure shrinks, and the basal sheath of the cotyledon elongates to form a coleoptile that covers the very first leaves. Coleorhiza is a protective sheath that surrounds the embryonic root structure and protects it from damage.

Figure 7: Maize kernel structure (left) and maize germ (right); Source: IITA/CIMMYT Research Guide 9



2.2.3. Classification of maize

Maize, known as corn, is classified into several kinds based on the characteristics of their kernels. These classifications are critical for understanding maize's numerous applications and farming techniques. The main kernel types are flint maize, dent maize, sweet maize, flour maize, waxy maize, popcorn, and pod corn. Each variety has unique characteristics that make it suitable for specific uses.

- Flint maize, also known as Zea mays indurata, is known for its rough outer layer or kernels that protect the sensitive endosperm, which can range from white to yellow to red in color. It is well-known for its ability to survive in extreme conditions, particularly in drought-prone locations. It is a staple food in many parts of the world. Flint maize is commonly processed into cornmeal for animal feed and is more resistant to insect infestations (Dowswell et al., 1996).
- Dent corn, also known as Zea mays indentata, is a grown variety of maize. Corn kernels are easily identifiable by the dent or indentation on the top of each kernel. This dent forms due to the drying rates of the soft starches within the kernel. The slower drying process of the starch on the sides compared to the starch in the center causes a collapse at the crown. Primarily cultivated for this purpose, dent corn is used to make animal feed, ethanol, and various processed food items.
- Sweet maize, known scientifically as either Zea mays saccharata or Zea mays rugosa, is primarily cultivated for consumption. Sweet corn is an excellent source of energy. The high sugar content of the kernels is caused by recessive mutations that prevent sugar conversion to starch. Sweet corn contains 20% dry matter from sugar, compared to 3% in dent maize at the green-ear stage. Sweet corn must be cooked or eaten soon after harvest to preserve its flavor; canning or freezing helps retain its quality.
- Flour maize, also known as Zea mays amylacea, is one of the oldest varieties of maize. Their soft and starchy kernels make them easy to transform into flour. The kernels of flour

corn have a high amount of soft starch, making them suited for milling. This maize produces fine flour, often used in baking and frying. Corn is a traditional food in many cultures, especially those where maize is the primary food source. In some places, flour maize is used to transport beverages and cereal. Its ease of processing makes it a good choice for home and small-scale milling.

- Waxy maize, also known as Zea mays ceratina, is named due to its kernels' waxy (dull) appearance. The unusual texture of waxy maize kernels is caused by a unique form of starch known as amylopectin. This starch is highly valued in the wet milling sector mainly for its thickening and stabilizing qualities. Waxy grain is also grown as a feed for dairy cattle and livestock.
- Popcorn, also known as Zea mays everta, is an extreme variety of flint maize. Its kernels are smaller and contain just a small amount of soft starch. It's a popular snack around the world. When heated to a high temperature, grains swell and explode, turning inside out. At a high temperature, the water in the kernel tissue's starch turns to steam, making the endosperm break up due to pressure.
- Pod corn, also known as Zea mays tunicata, has a distinct trait of reduced glume size, resulting in almost-naked grains. The primary gene involved (Tu) creates long glumes enclosing each kernel, as found in many other grasses. Tu maize differs from other kinds by having elongated glumes that cover the ear’s kernels. As a result, pod corn is more of an ornamental variety than a commercially viable crop. Pod corn is not usually grown for food but is occasionally used as a decorative feature, especially in autumn displays.

2.2.4. Growing stage

Maize growth stages are categorized as vegetative (V) and reproductive (R). The vegetative stages are defined primarily by the appearance of leaves, while the reproductive stages are based on the female inflorescence and developmental changes in the kernels (Lori J Abendroth et al., 2011). The table (3) illustrates the growing stages of maize (vegetative and reproductive).

Table 3: Growing stages of Maize; Source: (Badu-Apraku & Fakorede, 2017).

Stage	Description
VE	Emergence of the coleoptiles from the soil
V1	Appearance of the collar of the first leaf
V2	Appearance of the collar of the second leaf
Vn	Appearance of the collar of the nth leaf. Leaf number in maize is variable (may be as few as 15 and as many as 23, some of which will have dropped by flowering)

VT	Appearance of the last branch of the tassel signifying the end of vegetative growth
R0	Anthesis or male flowering begins. Pollen is shed
R1	Appearance of the silks
R2	Blister stage; kernels are filled with clear fluid; embryo visible on kernel dissection
R3	Milk stage; kernels are filled with white milky fluid
R4	Dough stage; milky fluid observed in R3 above has thickened to become a white paste; embryo has enlarged to about half the size of the kernel
R5	Dent stage; cap of kernel has become dented in dent types; milk line is close to the base when kernel is viewed from the side of both flint and dent types
R6	Black layer visible at the base of the kernel, signifying physiological maturity. At this stage, moisture content may be as high as 35%

2.2.5. Nutrition value and its importance

Corn stalks, leaves, and cobs are essential for animal feed, especially in regions where integrated farming methods are practiced. When used as fodder, maize leaves are ideal for ruminant digestion since they are high in fiber and low in protein. Stalks have less protein but contain more cellulose, and they are often chopped and fermented into silage, which preserves nutrients for livestock feed all year. Due to the stalks' high moisture content aiding fermentation, silage is a highly digestible and energy-rich feed for livestock. These maize by-products work together to encourage farms to remain sustainable by utilizing the whole plant to feed animals.

Table 4: Nutritional value per 100 grams (3.5 oz); Source: USDA Nutrient Database (August 4, 2015).

Compound	Energy
Energy	**360 KJ (86 kcal)**
Carbohydrates	**18.7 g**
Starch	5.7 g
Sugars	6.26 g
Dietary fiber	2 g
Fat	**1.35 g**
Protein	**3.27 g**
Vitamins:	
Vitamin A equiv.	9 µg
Vitamin B6	0.093 mg
Vitamin C	6.8 mg
Minerals:	
Iron	0.52 mg
Magesium	37 mg
Phosphorus	89 mg
Potassium	270 mg
Zinc	0.46 mg
Sodium	15 mg
Water	**76 g**

Maize, or corn, is a commonly consumed staple crop with high nutritional value and cultural significance. According to USDA data, a 100-gram serving of raw yellow corn kernels contains around 86 kilocalories, 3.27 grams of protein, 1.35 grams of fat, 18.7 grams of carbs, and 2 grams of dietary fiber. It also contains essential minerals such as thiamine (vitamin B1), pyridoxine (vitamin B6), folate (vitamin B9), vitamin C, magnesium, phosphorus, potassium, zinc, and sodium. These nutrients nourish corn, which is high in carbohydrates and serves as an energy source. Its fiber aids digestion and promotes gut health. Antioxidants like lutein and zeaxanthin support eye health and reduce the risk of macular degeneration. Corn is vital in diets, especially in the U.S., Mexico, Africa, and parts of Asia. It also features in industrial products, such as corn syrup and ethanol. Maize's adaptability and nutritional value are essential in global food systems and cultures.

2.3. Maize Production in Laos

Maize ranks as the second most prevalent temporary cash crop at the national level after rice in terms of total cultivation area. It is extensively grown in the northern provinces. Notably, certain northern regions of Laos are designated as rice deficit areas. Yet, they yield a surplus of maize, especially in Phongsaly, Oudomxay, Luang Prabang, and Huaphan provinces (Eliste, 2012).

Lao PDR was separated into three regions based on the country's politics: The Northern, Central, and Southern. The country’s topography has played an essential role in the agricultural production. Therefore, the amount of farming output produced in different areas will not have the same success. Table (5) illustrates the data of planted areas and harvested areas in ha, the yields in tons per ha, and the production of maize in Laos in 2021. Laos has a total planted and harvested area of maize of 137,287 ha, which can produce 5.12 tons per ha of yield and reach 703,048 tons in total production. The farmers in the Northern region can produce the highest amount of maize because they have the more extensive production areas compared to the other, followed by the Central and the Southern regions, which are 87,379 ha, 38,385 ha, and 11,523 ha, and they can produce 432,315 tons, 202,570 tons, and 68,163 tons, respectively. On the other hand, the Southern region can produce the most maize, with an average output of 5.92 tons per ha, while the Central and Northern regions can produce 5.28 and 5.12 tons per ha, respectively.

Table 5: Maize areas, yield, and production quantity in different provinces in Lao PDR.
Source: Author, based on the data from Lao Statistic Bureau 2022, data updated May 5, 2022.

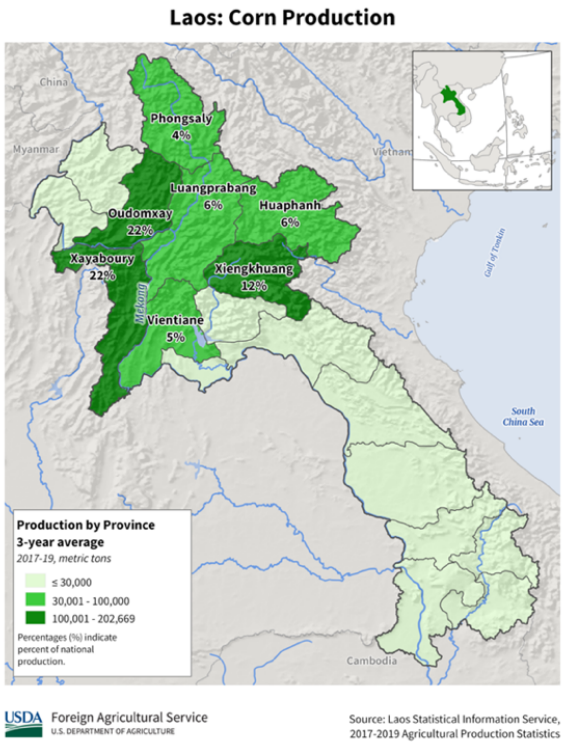
Name of Province	Name of Province	Planted Area (ha)	Harvested Area (ha)	Yield (ton/ha)	Production (ton)
		2021	2021	2021	2021
Total	Sub Summary	137.287	137.287	5,12	703.048
Northern Region	Sub Summary	87.379	87.379	4,95	432.315
	Phongsaly	3.430	3.430	4,51	15.457
	Luangnamtha	1.707	1.707	5,17	8.826
	Oudomxay	33.041	33.041	4,70	155.328
	Bokeo	725	725	4,96	3.598
	Luangprabang	9.933	9.933	5,59	55.547
	Huaphanh	7.128	7.128	5,12	36.467
	Xayaboury	31.414	31.414	5,00	157.092
Central Region	Sub Summary	38.385	38.385	5,28	202.570
	Vientiane Capital	1.818	1.818	5,85	10.638
	Xiengkhouang	23.233	23.233	4,88	113.380
	Vientiane	6.396	6.396	5,70	36.437
	Borikhamxay	1.705	1.705	5,61	9.568
	Khammuane	1.625	1.625	6,39	10.383
	Savannakhet	3.163	3.163	6,32	19.976
	Xaysomboun	445	445	4,91	2.187
Southern Region	Sub Summary	11.523	11.523	5,92	68.163
	Saravane	5.845	5.845	5,59	32.651
	Sekong	292	292	5,51	1.609
	Champasak	4.853	4.853	6,32	30.677
	Attapeu	533	533	6,06	3.226

In the Lao PDR, maize primarily grows on rain-fed fields, accounting for 93% during the wet season and 7% in the dry season (Atlas of Agriculture in the Lao PDR, 2011). The agricultural development strategy to 2025 and vision to 2030 aim to promote commercial agricultural production and increase the export of cash crops, including rice, coffee, tea, and maize. One of the critical achievements of the commercialization policy is the high volume of maize produced and exported from the Northern part of Laos to neighboring countries such as China, Vietnam, and Thailand.

From 2017 to 2019, Northern Laos had the highest maize production in many provinces compared to Central and Southern Laos. The total output was 77 percent, and the average production produced by Oudomxay was 22 percent, Xayaboury 22 percent, Xiengkhuang 12 percent, Luangprabang 6 percent, Huaphanh 6 percent, Vientiane 5 percent, and Phongsaly 4 percent (figure 8).

The maize variety LVN 10, originating in Vietnam, is the most productive in northern Laos. This variety has gained popularity among farmers due to its adaptability and favorable regional growing conditions. It is characterized by high yield potential and resilience against local pests and diseases, making it a preferred choice for both smallholder and commercial farmers.

Figure 8: Corn production areas in Lao PDR.
Source: Laos Statistic Information Service, 2017-2019 Agricultural Production Statistics. https://ipad.fas.usda.gov/countrysummary/images/LA/cropprod/Laos_Corn.png



Laos's economic development benefits from its proximity to China, Vietnam, and Thailand. Regional trade reaching the uplands offers smallholders chances to enhance and diversify their livelihoods, including income generation from maize cultivation. Conversely, the new commercial cross-border farming in regional trade introduces challenges for smallholders and producers. These include unsustainable production methods driven by high demand. Additionally, farmers often face limited knowledge and experience, along with a lack of bargaining power, unfair agreement or contact farming, and so on.

2.4. Maize production in the neighboring countries

2.4.1. Thailand

In 2018, Thailand imported 153,662.73 tons of maize valued at approximately $27.3 million, primarily from Cambodia and Laos. At the same time, the country exported 82,428.27 tons, worth around $21.6 million, to significant trading partners such as the Philippines, Hong Kong, Indonesia, and Myanmar. These numbers show that Thailand imports more maize than it exports, mainly due to the increasing demand for industrial products like animal feed. The growing need for maize aligns with the expansion of the livestock industry. However, domestic production cannot meet this demand, leading to the necessity of importing alternative raw materials like wheat and corn residues from ethanol production to supplement animal feed production (Thai Customs Office, 2019).

2.4.2. Vietnam

Maize plays a crucial role in Vietnam's agriculture and economy, particularly as a critical component of the animal feed industry. Maize production in Vietnam has remained relatively stable recently, with approximately 4.43 million metric tons produced in 2023. This output mainly serves the animal feed sector, as maize is a key ingredient in livestock and poultry feed.

In 2022, Vietnam imported approximately 10 million metric tons of maize, a significant increase driven by the demand for cheaper feed alternatives, as corn prices remained lower than wheat and rice. Argentina is Vietnam's largest supplier, accounting for nearly 60% of its maize imports, followed by Brazil and India (Tridge, 2022). In terms of exports, Vietnam exported around $49 million worth of maize in 2022, with the Philippines being the largest buyer, followed by Cambodia and Laos (Trend Economy, 2024).

2.4.3. China

China is the second-largest maize producer globally, after the United States, with a production of approximately 272.6 million metric tons in 2021- 2022. Maize is primarily used in animal feed to support the rapidly growing livestock industry, including poultry, swine, and aquaculture sectors. The crop is also essential for producing starch and ethanol, highlighting its economic importance.

Despite being a top producer, China's maize demand exceeds domestic supply, mainly due to its expanding animal feed industry. This has made China one of the largest maize importers globally, with imports reaching about 20 million metric tons annually. In 2022, China imported 6.81 billion USD, and the critical maize import partners include the United States, Ukraine, Brazil, Burma, and Bulgaria. On the export side, China exported a relatively small amount of maize, around 6.64 million USD, with volumes far outweighed by its imports. The main exported destinations were Vietnam, Tajikistan, Chile, Angola, and Uzbekistan (OEC World, 2022).

2.5.Production Techniques

2.5.1. Cultivar selection

Cultivar selection is crucial in maize production, affecting yield, disease resistance, and environmental conditions. An appropriate cultivar can enhance productivity and promote sustainable farming, especially in diverse areas like Laos (Banziger et al., 1996). Additionally,

maize variety is vital for fulfilling market needs, serving roles from human food to animal feed and industrial uses (Shiferaw et al., 2011). Optimal cultivar selection can enhance resource efficiency, lower production costs, and improve resilience to climate change, thus enhancing food security (FAO, 2015).

A. Potential and adaptability

Maize yield potential depends on adaptability to environmental conditions. Cultivars suited to local climate, soil type, and altitude achieve higher productivity and resilience against drought and nutrient deficiencies (Banziger, 2000). Varieties adapted to high temperatures and low moisture maintain yield stability despite suboptimal agricultural practices (Fischer & Edmeades, 2010). Understanding the local agroecological context is vital for selecting cultivars that enhance yield and reduce resource inputs. Adaptive traits, like root structure and leaf shape, significantly improve maize performance in diverse environments, contributing to food security and agricultural sustainability (Prasanna et al., 2021).

B. Growth cycle duration

The growth cycle duration of maize cultivars affects their productivity and adaptability. Early-maturing varieties are particularly beneficial in limited growing seasons, allowing farmers to harvest before adverse weather like drought or frost (Menkir et al., 2016). Conversely, late-maturing cultivars yield more in favorable environments with longer seasons (Echarte, 2011). Selecting cultivars that align with local growth cycles enhances yield and fits regional agricultural practices, contributing to sustainable maize production.

C. Pests and diseases resistant

Pest and disease resistance is crucial in maize cultivar selection, impacting yield stability and food security. Cultivars resistant to pests like the fall armyworm and diseases such as maize lethal necrosis reduce chemical inputs and lower production costs (Golhasan et al., 2016). Resistant varieties perform better under stress, ensuring yields even in adverse conditions.

D. Hybrids vs. Pollinated

This decision is crucial for yield and response to ecological factors related to maize cultivar preferences. Hybrids result from crossbreeding different parent lines, offering benefits like higher yield, pest tolerance, and uniformity (Duvick et al., 2003). However, hybrid seeds

require annual purchase, as some traits may not pass to future generations. In contrast, open-pollinated varieties can be harvested and replanted, providing long-term advantages and cost savings for farmers (Saha et al., 2000). While hybrids generally yield more than open-pollinated varieties, they may lack seed autonomy and adaptability in varying environments.

2.5.2. Climatic requirement

A. Temperature

Temperature is a critical factor in the site selection for maize planting, as it directly influences germination, growth, and overall yield. Maize thrives in warm conditions, with optimal growth temperatures ranging from 20°C to 30°C (Lobell et al., 2011). Temperatures below 10°C can severely inhibit germination and early seedling development, while extreme heat above 35°C can cause stress, leading to reduced kernel formation and yield loss (Zhao et al., 2017). Therefore, selecting a planting site that consistently maintains suitable temperatures throughout the growing season is essential for maximizing maize productivity.

B. Water requirement

The other important feature that raises concerns regarding the availability is the site's location for maize cultivation. Like other cereal crops, maize requires water throughout its growth, especially during critical reproductive stages like flowering and grain development, which require about 500-800 mm for optimal yields (B. GOUTHAMI & B. ASHOK KUMAR, 2022). Insufficient water leads to drought stress, harming crop yield and quality. Therefore, each site must have reliable water sources, preferably rainwater or irrigation, to ensure even watering during growth and enhance yields, minimizing the need for frequent irrigation.

2.5.3. Soil requirement and preparation

Soil quality is essential for successful maize cultivation, directly influencing nutrient availability, root growth, and overall plant vitality. Maize grows best in well-drained, loamy soils with a pH of 5.8 to 7.0, which offers a balanced nutrient profile (WU et al., 2011). A high organic matter content in the soil improves water retention and supplies key nutrients, enhancing maize growth and yield.

Proper soil preparation is essential for creating a favorable environment for maize planting. This process includes tilling the soil to break up compaction, improve aeration, and enhance moisture infiltration (Rátonyi et al., 2005).

2.5.4. Planting

Planting is the process of dropping seeds into the seedbed for intended crop growth and development. Maize planting commences when soil preparation is complete, suitable for soil moisture content, and if the minimum air temperature remains between 10 and 15 °C.

Maize planting depth ranges from 5 cm (heavy soil) to 10 cm (sandy soil), depending on soil type and planting date. Plant population varies based on rain-fed or irrigated systems, prevailing environmental conditions, and the variety used (AGOGTR, 2008).

2.5.5. Cultural practices

Soil tillage is a farming practice involving soil cultivation that modifies its structure and stability to support plant growth. To improve crop establishment, tillage is traditionally done 1-3 times, depending on field conditions. Tilling should reach a depth of 10-20 cm to enhance water absorption and root development (Belfield & Brown, 2009; Espinoza L. & Ross J., 2010).

Soil tillage improves water infiltration and aeration, both essential for plant growth. After tillage, harrowing is performed to level the field, preparing an ideal seed bed. Farmers might choose minimum or no tillage for maize cultivation in regions with minimal weed issues and soil erosion. No-tillage means seeds are directly sown into the ground without disturbing the soil until harvest (Espinoza L. & Ross J., 2010; George Acquaah, 2012; Nafziger et al., 2008).

Table 6: Common soil tillage system with its advantages and disadvantages. Source: (Jéan du Plessis, 2003).

Tillage System	Advantages	Disadvantages
No-till	• Low fuel consumption • Quicker adaptation to optimum planting date • Lower machinery costs • Best control of wind and water erosion	• Higher application of herbicide and intensive herbicide management necessary • Requires: - Management inputs - Special or adapted planters - More expensive equipment • Possible compaction of soil and accumulation of nutrient in top soil • Earlier occurrence of leaf diseases • Possible insect populations
Stubble mulching	• Fuel saving (compared to ploughing) • Good control/better management of: - Wind and water erosion	• Soil preparation dependent on spring rains • Greater possibility of leaf diseases

	- Soil compaction - Weed control	
Reduced tillage	• Greater fuel economy (than e.g. ploughing) • Control of: - Wind erosion - Insect population • Accumulation of nutrients not a problem	• Poor management of water erosion • Better weed management
Conventional tillage	• Good weed and insect control • Lowest management input	• Highest: - Fuel consumption - Machinery costs • Waiting period for suitable soil water • No control of water and wind erosion

2.5.6. Water management

Maize is an efficient water user for overall dry matter production and could be one of the highest-yielding grain crops. To achieve optimal production, medium-maturity grain crops require about 500 to 800 mm of water (B. GOUTHAMI & B. ASHOK KUMAR, 2022). Various irrigation techniques, such as furrow, drip, and sprinkler irrigation, can be used.

2.5.7. Fertilizers

Maize aggressively consumes soil nutrients during its growth and development. Normally, maize fields are supplemented with nutrients from inorganic fertilizers, but organic fertilizers can also be used (Espinoza L. & Ross J., 2010). Organic fertilizers are found in the form of manures and have not been commonly used for fertility supplementation in maize due to their bulkiness, which poses management difficulties since maize is typically planted over a large area. The most common inorganic fertilizers used in maize cultivation are nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn).

A. Nitrogen (N)

Nitrogen fertilizer is vital for maize growth and should be applied 2-3 times during the growing stages. Nitrogen efficiency is indicated by light green leaves. Apply fertilizer 50 mm next to the seed and 50 mm below the soil. Direct contact between N and the plant leads to the burn and sometimes death. Apply N when the soil is moist, as it may dry after application. The required amount of N per hectare depends on soil requirements and plant density.

B. Phosphorus (P)

Phosphorus is important in providing nutrients to young seedlings from the early stage. The fertilizer is applied 50 mm below the seed, to the side, and then buried. Deficiency of P occurs in dark green leaves, reddish-purple tips, and margins.

C. Potassium (K)

Potassium should be placed 50 mm below and beside the seed during planting and done just once. The quantity of K applied per hectare should be 30-50 kg, depending on the soil requirements. Lack of K is reflected as yellow or necrotic leaf margins, beginning at the lower leaves and moving upward to younger leaves; it is also implicated in stalk rot and lodging.

D. Zinc (Zn)

Zinc is a crucial microelement that is mostly applied similarly to P and K. A lack of Zn is characterized by light streaks or bands between leaf veins while the midrib and leaf tip remain green, leading to stunted growth (Manzeke et al., 2014).

2.5.8. Weed management

Weed is one of the significant constraints facing maize production worldwide. Weed control after planting, during the first six to eight weeks, is very important due to they will suck the nutrients and moisture content in the soil, leading to the competition of the weeds and maize roots and yield loss. Weeding can be done by hand or machine, depending on the field conditions. It can be conducted 2-3 times during the vegetative stages and before maturity (Agriculture and Agri-Food Canada, 2018).

2.5.9. Harvest

Maize harvesting is commonly conducted by hand and using machines such as combined harvesters.

A. Manual harvesting

Hand harvesting maize involves picking ears from plants when kernels are mature, indicated by dry husks and color change. This method is common in small-scale farming, where labor is available and machinery is impractical. Despite being labor-intensive and time-consuming, it enables selective harvesting, reduces plant damage, and improves quality control. It's beneficial in areas with limited access to modern equipment. The proper moisture content to begin harvest is 18-20% (AGOGTR, 2008). Later, ears are removed and threshed or used as maize hay.

B. Mechanical harvesting

Mechanical harvesting has revolutionized maize production by increasing efficiency and lowering labor costs. Machines like combine harvesters can cut, thresh, and clean maize, greatly accelerating the processing of large fields (Wang et al., 2021). This technique is particularly advantageous for commercial farming, as it allows timely crop harvesting to reduce spoilage and improve grain quality. Contemporary equipment also reduces crop damage, resulting in more whole kernels, enhanced yields, and increased profitability.

2.5.10. Storage and transport

Proper storage and transport of maize are vital for reducing losses and keeping the grain in good condition. After maize reaches physiological maturity (PM), delaying the harvest to allow for natural drying can save on drying costs. However, this practice may lead to yield losses due to kernel respiration and issues like lodging and ear drop, mainly when grain moisture exceeds 200 g/kg (Finck C., 1995). Studies show that maize can be harvested with minimal dry matter or quality loss if done at the proper moisture level, typically between 200 g/kg and 260 g/kg (Nolte et al., 1976).

Storage areas must be well-ventilated and kept at appropriate moisture levels to avoid spoilage, as high humidity can cause mold growth and lower grain quality (Hurburgh et al., 2020). Generally, grains with moisture content below 12.5% last longer in storage. During transport, it is essential to reduce grain damage and keep moisture levels low so that the maize arrives at markets in the best condition. Using effective drying methods and good transport practices helps minimize post-harvest losses and improves the profitability of maize production.

2.6. Insects, diseases, weeds, and their management

Pests, diseases, and weeds result in substantial annual yield losses for maize farmers, particularly in Laos. Many farmers struggle to manage these threats effectively due to limited knowledge and access to mechanical tools. While pesticides are available, their high cost and associated health risks hinder widespread use. This lack of effective control measures significantly affects crop productivity.

Sustainable management practices are essential to improve agricultural outcomes. This can be achieved by identifying and addressing the most common pests, diseases, and weeds in various regions of Laos.

A. Insects

Figure 9: Maize pests such as Corn borer (1), Corn armyworm (2), Cotton bollworm (3), Corn aphids (4), and Maize weevil (5); Source: AZ animals https://a-z-animals.com/

- The corn borer, scientifically known as Ostrinia nubilalis, affects many hosts and results in significant crop losses and decreased farmer income. It also impacts the environment, including water availability; for example, drought conditions can cause it to decline, while irrigation helps to enhance it (G. L. Windham, 2007). Integrated pest management strategies, including using natural enemies like Trichogramma wasps, are being explored as sustainable methods for controlling CB populations in corn.
- The corn armyworm (Mythimna separata) is a significant pest in maize, particularly in Asia. The larvae of this moth feed on maize leaves, stems, and ears. They cause considerable defoliation, reducing the plant's photosynthetic capacity, and feed on maize ears, which reduces yield and quality (Hay-Roe et al., 2016). The best methods to control this pest include early planting, natural predators, and insecticides (Herrero et al., 2016).
- Cotton Bollworm (Helicoverpa armigera), though more commonly a cotton pest, also attacks maize. The larvae feed on the maize cobs and leaves. They damage the silks and develop kernels, reducing grain quality (CABI Compendium, 2021). Biological control is achieved through parasitoids, specific pesticides, and timely planting.
- Corn aphids (Rhopalosiphum maidis) are small, soft-bodied insects that feed on maize by sucking sap from the leaves and stems. Aphids cause wilting, reduce plant vigor and may transmit viruses like maize dwarf mosaic virus (MDMV)—use natural predators like ladybugs and lacewings, insecticidal soaps, and timely insecticide application.
- Maize Weevil (Sitophilus zeamais) is a common pest in stored maize grains. It bores into maize kernels, causing post-harvest losses. Its larvae feed inside the kernel, significantly

reducing grain weight and quality. Biological controls, frequent facility cleaning, and proper storage methods are all used to manage this pest.

B. Diseases

Figure 10: Ustilago maydis (1), Bipolaris maydis (2), Common rust (3); Source: https://www.inaturalist.org/ and Pernosclerospera sorghi (4), Blumeria graminis tritici (5); Source: https://www.naturepl.com/blog/

- Common Smut (Ustilago maydis) is a fungal pathogen that infects all parts of the maize plant, producing large, swollen galls filled with spores. Galls develop on leaves, stems, and ears, leading to yield loss (Djamei, 2023; H. K. CHEUNG, n.d.). Methods of control include crop rotation, planting resistant cultivars, and pulling contaminated plants.
- Downy Mildew (Pernosclerospora sorghi) is a fungal disease that affects maize leaves. Their symptoms are pale yellow streaks on the leaves, stunted growth, and reduced ear development.
- Powdery Mildew (Blumeria graminis tritici) is a fungal disease that attacks maize leaves—the powdery growth on the upper surface of leaves and reduced plant vigor (Côté-Beaulieu et al., 2009).
- Southern Corn Leaf Blight (Bipolaris maydis) is a fungal pathogen that thrives in warm, humid conditions. The tiny, tan lesions on leaves can merge and cause large areas of leaf blight (Tripathi et al., 2023).

- Corn rusts affecting maize include Puccinia sorghi (common rust), Puccinia polysora (southern rust), and Physopella zeae. Common rust appears as reddish-brown pustules and thrives in cooler climates, while southern rust, caused by P. polysora, develops orange pustules in warmer, more humid environments. Both types reduce photosynthesis and weaken the plant, leading to lower yields. Physopella zeae, less commonly observed, causes similar damage, impacting leaf function and reducing plant health. All three types require careful management to prevent significant yield loss (Hooker, 1985; Rochi et al., 2018; Yang et al., 2024).

C. Weeds

In Asia, maize weeds include Barnyard Grass (Echinochloa crus-galli), a fast-growing weed competing for water, nutrients, and light. Amaranthus species are invasive broadleaf weeds that reduce yields. Nightshade (Solanum nigrum) is toxic to livestock, while Bathurst Bur (Xanthium spinosum) hinders crop growth with its spiny structure. The parasitic weed Striga (Striga hermonthica) is especially harmful, draining nutrients from maize roots and severely impacting yield.

Figure 11: Echinochloa crus-galli (1), Solanum nigrum (2), Xanthium spinosum (3), and Striga hermothica (4); Source: https://commons.wikimedia.org/

Successful weed management in maize requires a combination of various strategies. Crop rotation interrupts weed life cycles by altering the crop environment, while mulching prevents weed growth by blocking sunlight. Performing early tilling helps manage weeds before they compete with young maize plants. Growing cover crops such as legumes can naturally suppress weeds by outcompeting them. Selective herbicides, when applied carefully, can effectively eliminate weeds while keeping the maize unharmed. When used together, these methods offer a comprehensive strategy for weed management and safeguarding maize yields.

3. Material and Method

3.1.Material

- Camera and voice recording.
- Two printed forms.

Figure 12: The examples of an interview form used in the survey (English version). The upper form was used to interview local farmers in different areas, and the lower form was used to interview the fruit sellers in various markets in Laos.

Surveying maize (corn) cultivation with local farmers. Date….....				
Location				
Village		District		
Province				
Name of the species				
Areas of planting				
Average corn's size				
Average corn's weigh				
Price per 1Kg (cob)				
Price per 1Kg (grain)				
Price per 1Kg (milled)				
Market				
Other comment				

Surveying maize (corn) sold in general markets. Date….....									
Name of the market									
Village				District					
Province									
Varieties	Average size	Price per 1Kg (cob)		Price per 1Kg (grain)		Price per 1Kg (milled)		Place of origin	Other comment
		Buy	Sale	Buy	Sale	Buy	Sale		

3.2.Methods

3.2.1. Secondary document

This thesis presents a comprehensive analysis incorporating various sources, including secondary documents, literary works, local interviews, and reports from both governmental and non-governmental organizations. The studies were made to focus on the basic maize production and cultivation methods to learn about the villagers' local farming and target customers in both domestic and international markets.

3.2.2. Raw material

The maize cultivation interviews with local farmers were conducted in two different provinces in Laos: Xiengkhuang and Vientiane. This took place from late June to early October 2024. Xiengkhuang province had two large-scale farms and two locally circulating system farms. In Vientiane province, one small farm primarily planted a particular variety for the domestic market. These interviews aimed to study their cultivation practices, varieties, planting areas, average weight and size per ear, prices, problems such as diseases and pests, markets, and consumer preferences.

The survey of maize sales in general markets delves into five major markets in Vientiane Capital since July 2024. The markets are the KHUADIN market, the TALAD LAO market, the View Mall Shopping Center, the Lao-Aussie Market, and the THONG KHAN KHAM market. This survey will focus on consumer preferences based on each variety, the origin of maize, price range, corn products, and the market's average corn size.

4. Results and Evaluation

4.1.Local farmers production

4.1.1. Producing for domestic markets

A. Phonsavan Village, Xiengkhuang Province

On August 8, 2024, during the rainy season, a survey on maize cultivation was conducted with a local farmer in Phonsavan village, Pek district, Xiengkhuang province, Northern part of Laos. The farmers in this region primarily cultivate the LVN10 maize variety, which originates from Vietnam. One farmer, in particular, manages an 8-hectare planting area, dividing his land strategically to manage the workload. He plants 4 hectares of maize in the first generation and, after 40 days, plants the remaining 4 hectares for the second generation. This staggered planting schedule allows his family to easily care for the crops in manageable stages.

Figure 13: A farmer in Phonsavan Village produced maize packed in a 50 Kg bag and sold directly to the village collector or trader. The first two pictures were the maize sold in the whole cob (1-2), the milled machine and the milled form ready to feed animals (3-4), the LVN 10 seed variety origins from Vietnam (5), and the symptom of the crop caused by Downey mildew and Corn rust (6-7); Photos taken by the farmer (August 8, 2024)

The maize grown in this area typically takes 80 to 95 days to mature before it's ready for harvest. After the maize harvest, the farmer shifts to growing vegetables, choosing crops based on local market demands before beginning the maize production cycle again. The market sizes, on average, 3 to 4 cobs of corn weigh per 1 kilogram. The price of maize varies depending on its form: 0.16 USD per kilogram for cobs, 0.20 USD per kilogram for grains, and 0.30 USD per kilogram for milled maize (Exchange currency 1 USD = 22,156 LAK; Source: XE Currency

Oct 6, 2024). The primary buyers are local villagers who use the maize to feed their poultry, swine, and fish, contributing to the community's agricultural and economic livelihood.

The farmer also faced significant challenges, particularly during the rainy season when crop diseases tend to thrive. Two of the most persistent problems are Downy mildew and Common rust, both of which can severely impact maize yields.

B. Phonkham Village, Xiengkhuang Province

A survey was conducted in Phonkham village, Pek district of Xiengkhuang province, on August 10, 2024. Located in the district's center, this village is a hub for offices and a shopping center. A farmer relies on maize production as his primary source of income and manages a total of 9 hectares of land. His planting area is divided into two large fields dedicated to different maize varieties.

Figure 14: Maize from Phonkham village selling in the markets (1-3), a package of sweet corn seeds from Vietnam (4), a package of CP 535 variety from Thailand (5), Common smut disease (6), the effect of corn armyworm (7-8). Photos taken by the farmers (August 10, 2024)

The larger field, covering 6 hectares, is planted with Golden Sweet Corn, a variety sourced from Vietnam due to its affordability. This variety is particularly advantageous because it can be grown three times annually, maximizing the use of his land. The other field, covering 3 hectares, is planted with the well-known CP535 variety from Thailand. Although the farmer mentioned that LVN10 from Vietnam is cheaper, he prefers CP535 for its better yield and larger maize cobs, which fetch a higher price on the market. However, due to an oversupply of maize produced by other producers, he limits its cultivation to 3 hectares and focuses on delivering

the sweet corn. CP535 produces a yield of 3 to 5 tons per hectare, which is sufficient to meet his family's financial needs while balancing market demand.

The price of maize grain in this region fluctuates between 0.18 USD to 0.20 USD per kilogram, depending on the season. Despite the profitable returns, the farmer faces significant challenges, particularly with pests like the Corn Armyworm and diseases such as Common Smut. These are difficult to control and often unavoidable, affecting crop production and yield loss.

C. Hin Herb District, Vientiane Province

A survey was conducted in the Hin Herb district on July 22, 2024, in Vientiane province. The farmers benefit from fertile soil and reliable access to water from the Nam Xong River, one of the most important rivers in Laos. The farmers in this area cultivate waxy and sweet corn for human consumption across a 5-hectare plot. The land is divided into four fields, allowing the farmers to produce corn throughout the year by staggering the planting cycle. New maize generations are planted in different fields every 30 to 45 days, ensuring a continuous supply and avoiding product overload.

Figure 15: The production of two waxy corn varieties produced by the farmer, including sweet purple (a) and sweet berry (b), both seed varieties are from Thailand; Photos taken by the farmer (July 22, 2024)

The varieties grown, both waxy and sweet corn, are sourced from seeds from Thailand and produced to meet consumer preferences. Each field produces around 3 to 4 tons of corn, averaging 4 to 5 cobs per kilogram. These varieties take 60 to 70 days to mature and be ready

for harvest. Prices range from 0.45 USD to 1.58 USD per kilogram (Exchange currency 1 USD = 22,156 LAK; Source: XE Currency Oct 6, 2024), depending on the season and variety.

Despite the favorable growing conditions, the farmer faces several challenges, particularly flooding during the rainy season, which can damage crops. Additionally, pests such as locusts, snails, and worms frequently threaten the maize fields. However, by carefully managing planting cycles, the farmer is able to maintain a steady and consistent harvest to meet market demands year-round.

4.1.2. Producing for international markets in Xiengkhuang province

A. Kham District

In a survey conducted in July 11, 2024 in Kham District, Xiengkhuang Province. A farmer shared his experience of producing maize primarily for Vietnamese collectors. He has been planting the LVN 10 variety since 2000, when it gained popularity due to its affordability and a government initiative that encouraged villagers to grow it. According to the farmer, the production standards required by the Vietnamese collectors were reasonable, as they only needed to meet an average quality, which reduced stress on the producers. His total planting area spans 13 hectares, with maize cultivation serving as his family's primary source of income. The price of maize (shelled cob) ranges from 0.15 to 0.22 USD per kilogram. However, he faces ongoing challenges, such as fluctuating temperatures, common maize diseases, and pests, which affect his production output.

Figure 16: A sample of maize cob suitable for the collector's standard. Photo taken on July 11, 2024.

From this May, 2024, in addition to producing the LVN 10 variety, the producers in this village also cultivate new and specialty varieties introduced by the government. Laos relies heavily on imported hybrid maize seeds, primarily from Thailand and Vietnam, which creates dependency on external suppliers and exposes farmers to price fluctuations. To improve access to quality maize seed, CIMMYT and Laos' National Agriculture and Forestry Research

Institute (NAFRI) have begun evaluating high-yielding maize hybrids for better grains and quality.

B. Nhonghet District

In July 2024, a survey was conducted in Nhonghet district, where a farmer has primarily cultivated the LVN 10 maize variety since his father's generation. This variety has proven to be well-suited to the local soil conditions, making it a staple crop for the area. The farmer produces maize for both Vietnamese and Chinese collectors, and in situations where he cannot meet the collectors' demands, he buys additional maize from nearby local producers at a fair price. He emphasized that maize cultivation is his main source of income, driven by strong and steady market demand from neighboring countries. Annually, he exports between 150 to 200 tons of maize. However, like many farmers, he faces challenges such as pests, diseases, high humidity, weeds, and occasional storage issues, which can impact the quality and yield of his crop.

4.2.Markets of Laos' maize production

The market is a system where buyers and sellers come together to change goods, services, or assets, often involving and agreeing upon currency or value. It can be physical, like wholesale and retail markets, or virtual, such as online marketplaces and digital platforms. Markets vary widely, ranging from small local markets to vast international or global markets.

4.2.1. Domestic market in Vientiane Capital

The domestic market in Laos refers to the marketplace for goods and services within the country, primarily driven by local consumers, businesses, and government entities. In Vientiane Capital, vibrant local markets showcase fresh products, handicrafts, and street food, highlighting the rich cultural heritage of the country. The domestic market is influenced by local customs, economic conditions, and government policies, and it plays a vital role in supporting small-scale enterprises and contributing to the nation's overall economic development. This domestic market survey will study the varieties, origins, market size, market trends, prices, and consumer preferences for corn in the capital of Laos.

A. Wholesale markets

- KHUADIN market

Figure 17: Maize seeds for animal feeders sell in 50 Kg per bag (1), waxy corn sells in a large bag (2), and cooked waxy corn sells retail in three cobs per pack (3) in KHUADIN market, Vientiane Capital. Source: Own work (July 8, 2024).

KHUADIN is the most important wholesale market in central Vientiane, where all agricultural and animal products are sold. This bustling market serves as a vital hub, collecting agricultural products from local farmers within Laos and neighboring countries to supply nearby retail markets. Most goods are sold in large bags or crates, facilitating bulk transactions. Currently, maize grains from neighboring provinces are sold in 30-50 kg per bag, while waxy corn is available in 10-30 kg per bag. Prices in the KHUADIN market are flexible and depend on quantity, with maize grain priced between 0.20 USD and 0.45 USD per kilogram and waxy corn ranging from 0.90 USD to 1.20 USD, fluctuating according to the season.

- Lao – Aussie market

Figure 18: Figure: Sweet corn sells in 5 Kg per bag (1-2), and maize cobs sell in 50 Kg per bag (3) in the Lao-Aussie market, Vientiane Capital. Source: Own work (July 9, 2024).

The Lao-Aussie market is one of the largest wholesale markets in the region. This market specializes in diverse products, including vegetables, fruits, animal products, and other goods. During a recent survey, the LVN 10 maize from many provinces emerged as the best-selling variety compared to the others throughout the year, with prices ranging from 0.15 to 0.35 USD per kilogram (cob). Additionally, sweet corn produced in Vientiane province has a favorable market size and low transportation costs, with 0.70 to 1.00 USD per kilogram. Both

maize and sweet corn are typically sold in large bags, catering to bulk buyers and reflecting the market's role in supporting local agriculture and commerce in Laos.

- THONG KHAN KHAM market

Figure 19: Sweet corn from Vientiane province packed in 5 Kg and 50 Kg per bag in THONG KHAN KHAM market, Vientiane Capital. Source: Own work (July 8, 2024).

THONG KHAN KHAM Market is a sub-morning market that offers a variety of fresh and dried foods. During a survey, sweet corn from Vientiane province was available for sale, with 5 kg and 50 kg bag options. The pricing reflects a tiered approach, with the smaller bag priced at 1.00 USD per kilogram while the larger bag is 0.90 USD per kilogram. The sweet corn is characterized by a yield of 2.5 to 3 cobs per kilogram, appealing to consumers looking for quality produce.

B. Retail markets

- TALAD LAO market

TALAD LAO market is the newest and one of the most significant retail markets in the capital. It is located near the southern bus terminal and Vientiane Railway Station. This bustling marketplace offers a diverse selection of vegetables, fruits, and agricultural and animal products, sourcing items from various producers, including imports from Thailand.

Figure 20: Sweet corn and waxy corn sold in the TALAD LAO market by piece or kilogram in the raw form (1-3) and cooked form (4). Source: Own work (August 12, 2024).

As a retail market, TALAD LAO provides flexibility in purchasing, with many products sold by piece to kilograms. Currently, sweet and waxy corn are among the best-selling fruits in this market, available in both raw and cooked forms, such as boiled or steamed. The pricing reflects this variety, with raw corn priced at 1.10 USD per kilogram and cooked corn at 1.25 USD per kilogram.

- View Mall Shopping Center

Figure 21: The pictures of corn products in View Mall Grocery Store: Corn milk, price 0.6 USD (1) and sweet corn 500 g sealed in a package, price 1.35 USD (2). Source: Own work (October 18, 2024).

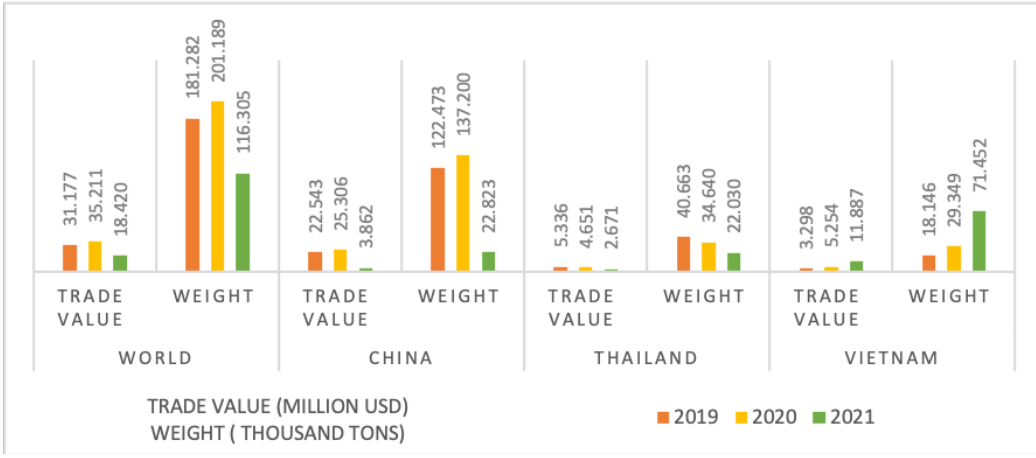
From April to October, a survey was conducted at View Mall, a renowned international shopping center located on 13th Road, just 3 kilometers from downtown. View Mall houses numerous stores, but the standout is the View Mall Grocery Store, famous for its diverse range of products. The store features well-known brands from Thailand, China, Japan, Korea, and Australia, as well as premium and local brands from Laos. Customers can find various fresh vegetables, dried goods, and processed food products. Regarding corn-based products, the grocery offers fresh, sweet, and waxy corn, all neatly packed in sealed bags. Additionally, the store sells snacks and desserts made from corn, both imported from abroad and sourced locally in Laos. This variety makes the store a popular destination for both international and local customers.

4.2.2. International market

Laos' maize export strategies emphasize vital areas to enhance trade and improve agricultural outcomes. First, the country benefits from trade agreements such as the ASEAN Free Trade Area (AFTA), which lowers tariffs and simplifies cross-border trade with neighboring countries such as Vietnam, Thailand, and China. Furthermore, government support

programs aimed at boosting maize production, improving seed quality, and supporting sustainable farming practices have contributed to increased export capacity. Adherence to phytosanitary regulations guarantees that maize exports align with international pest and disease management standards, making trade more efficient. Lastly, the government promotes local maize processing into value-added products like cornmeal before export, thereby raising overall export value and reducing dependence on raw maize exports.

Figure 22: The trade value and weight of maize exported to China, Thailand, and Vietnam.
Source: Author, based on UN Comtrade Database, accessed October 2, 2024.



The graph illustrates the global maize trade experienced significant fluctuations between 2019 and 2021, particularly in the export markets of China, Thailand, and Vietnam. Globally, the trade value of maize exports peaked in 2020 at 35.211 million USD, with a corresponding weight of 201.189 thousand tons, before dropping sharply in 2021 to 18.42 million USD and 116.305 thousand tons. This reflects a major downturn in maize export volumes, likely due to shifting market dynamics or global disruptions during the period.

In China, maize imports from Laos significantly decreased between 2020 to 2021. The trade value fell from 25.306 million USD and 137.2 thousand tons in 2020 to 3.862 million USD and 22.823 thousand tons in 2021, highlighting a drastic reduction in maize imports. However, Thailand experienced a steady decline in maize imports, with the trade value falling from 5.336 million USD and 40.663 thousand tons in 2019 to 2.67 million USD and 22.03 thousand tons in 2021, showing a consistent decrease in value and volume over the years. In contrast, Vietnam saw a substantial increase in maize imports, with the trade value rising from 5.252 million USD and 29.349 thousand tons in 2020 to 11.887 million USD and 71.452 thousand tons in 2021, reflecting strong and growing demand for maize exports from Laos.

4.3. SWOT Analysis

4.3.1. Strengths

- Diverse Varieties and Adaptability**:** Laos has access to various maize varieties, such as LVN10 from Vietnam and many varieties from Thailand, suited to different agroecological zones. This adaptability allows farmers to produce maize even in areas with less favorable conditions, such as the northern provinces.
- Strategic Location for Trade**:** Laos' proximity to key regional markets like China, Vietnam, and Thailand offers significant export potential. Trade agreements like the ASEAN Free Trade Area (AFTA) provide opportunities for tariff reduction and streamlined cross-border trade.
- Consistent Market Demand**:** Both domestic and international markets show consistent demand for maize, whether for local consumption, animal feed, or export. Markets in Vientiane Capital, such as KHUADIN and Lao-Aussie, facilitate large-scale maize distribution, while countries like Vietnam continue to increase imports from Laos.
- Year-Round Production**:** Farmers in areas like Hin Herb District, Vientiane Province, manage multiple planting cycles, ensuring a steady supply of maize throughout the year. This allows them to meet both local and international demand efficiently.
- Growing Technical Expertise**:** Studies in northern Laos have shown that farmers with more experience in maize production tend to achieve higher efficiency. This expertise in managing inputs, such as labor and machinery, improves overall productivity.

4.3.2. Weaknesses

- Pests and Diseases: Farmers frequently face challenges with pests such as corn armyworm and diseases like downy mildew and common rust, which can significantly reduce yields. Farmers also struggle to manage other diseases, such as common smut, which further impacts production.
- Reliance on Traditional Cultivation Methods: Many farmers still rely on traditional farming techniques, limiting the efficiency of maize production. This results in lower yields compared to countries where mechanized farming and advanced agricultural technologies are employed.
- Inconsistent Infrastructure: Limited access to proper storage facilities, irrigation systems, and transportation infrastructure leads to post-harvest losses and limits the quality of

maize available for both local consumption and export. This is particularly evident during the rainy season, when flooding can damage crops.

- Market Price Volatility: Maize prices fluctuate seasonally, which can affect farmers' incomes. Oversupply in local markets or increased competition from neighboring countries can also drive prices down.
- Price Volatility and Farmer Dependency**:** Traders set maize prices, and farmers have little control over them. This price volatility has been identified as a significant factor that discourages farmers from continuing maize production.
- Environmental Degradation**:** The expansion of maize cultivation, particularly through slash-and-burn farming techniques, has led to soil degradation and deforestation. Overuse of chemical fertilizers has also caused soil depletion, which in turn forces farmers to increase input use, reducing profitability.
- Low Technical Efficiency in Some Areas**:** While some farmers in northern Laos are technically efficient, many still operate below optimal productivity levels.

4.3.3. Opportunities

- Expansion of Export Markets**:** Laos can increase its maize exports with trade agreements in place and growing demand from neighboring countries like Vietnam. The rise in Vietnam’s maize imports in 2021 shows strong potential for expanding into regional markets.
- Value-Added Processing**:** Encouraging the processing of maize into value-added products, such as cornmeal or animal feed, can boost the profitability of maize farming. This will reduce reliance on raw maize exports and create more opportunities for Lao farmers.
- Government Support and Programs**:** Government initiatives aimed at improving seed quality, promoting sustainable farming practices, and enhancing production standards can help increase maize yields. These programs, along with improved access to phytosanitary regulations, can ensure Lao maize meets international standards, opening doors for increased exports.
- Adoption of Modern Agricultural Technologies**:** Introducing mechanized farming and advanced pest management systems could significantly increase yields. This would help address the labor-intensive nature of maize farming and reduce the losses caused by pests and diseases.

- Sustainable Farming Practices**:** With the growing awareness of environmental issues, there is an opportunity to transition to more sustainable farming practices. Promoting crop rotation, agroforestry, and soil conservation could mitigate the negative environmental impacts of maize production and improve long-term sustainability.
- Government and NGO Support**:** Both the government of Laos and international organizations, such as the Australian Centre for International Agricultural Research (ACIAR), have been supporting improving farming practices and infrastructure.

4.3.4. Threats

- Climate and Pest Vulnerability: Maize production is highly susceptible to climate variability, including floods, droughts, and pests such as armyworms.
- Rising Input Costs: The increasing cost of chemical fertilizers and other inputs threatens the profitability of maize production. In some regions, farmers have had to increase their fertilizer use to maintain yields, but the rising cost of inputs is cutting into their profits.
- Market Competition: Competition from other countries, such as India, is growing in the Vietnamese maize market. This increased competition threatens Laos' position as a key supplier, particularly if Lao farmers cannot improve the quality and consistency of their maize exports.
- Shifting Government Priorities: The Lao government has focused more on promoting alternative crops and reducing environmental damage caused by maize cultivation. This shift away from supporting maize as a key cash crop may lead to reduced investment in the sector, making it harder for farmers to sustain their livelihoods.

5. Conclusion and Recommendation

Maize continues to be an important crop in Lao PDR agriculture since it is an important food and economic security crop. Maize has been widely grown and can be considered the staple food and the main source of income, especially in Xiengkhuang and Vientiane provinces. However, as indicated by this study, some hurdles limit agricultural production, for instance, pests, diseases, price fluctuations, and poor innovation adoption. These problems have, however, restricted farmers from fully exploiting export options, though there is great potential for maize as an export crop market, especially in Vietnam, Thailand, and China.

The interviews conducted with local farmers showed the proposal's relevance, aiming to enhance support for Lao small farmers to maximize benefits from smallholder agriculture and existing land governance. Possible ways in which these challenges could be handled include cultivar selection for farmers, crop rotation, and the effectiveness of irrigation delivery. However, there is much potential in this sense for the future, depending on this data, especially when determining the approaches to enhance the availability of better and improved seeds, better market access, and efficient farming methods. Increased trade liberalization through regionalization could enhance output, making maize production financially viable in Laos.

Several measures should be implemented to help Laos improve its maize industry; increased use of technology such as farm machinery, efficient pest management, and access to market to ensure that productivity is improved and benefits are realized. In this case, mechanized planting and harvesting should be accorded the highest priority with the intention of decreasing on the number of workload required from the farmers. Application of biological and chemicals in pest control also for instance registering integrated pest management practices to enable farmers to protect yields against pests. Specifically more reliable measures of irrigation could help secure consistent yields annually while also allowing for agricultural diversification which underpins food security.

Alongside improving farm practices, market diversification and value-added processing, such as converting maize to cornmeal or animal feed, can create new income streams for farmers. Increasing trade with neighboring countries like Vietnam, Thailand, and China will also drive demand and price stability for maize exports, supporting both the local economy and farmer livelihoods. Additionally, helping farmers adopt climate-resilient maize cultivars will enhance their crop's adaptability to changing environmental conditions, reducing the risks of weather fluctuations.

To enhance productivity, farmers must shift from older varieties like the traditional LVN 10 to modern, high-yield varieties better suited to current market demands and environmental challenges. Providing a consistent supply of improved seed varieties can lead to better yields and quality. Additionally, government support to stabilize maize prices would help farmers rely on steady income year-round, thereby fostering increased investment in production.

Ultimately, continuous government support for research and development of pest-resistant and drought-tolerant maize seeds is essential for long-term growth. Partnering with international organizations can further introduce cutting-edge agricultural technologies to Laos, nurturing a sustainable and robust maize sector capable of thriving in both local and global markets.

In conclusion, the examined opportunities indicate that to achieve the unrealized productivity in maize production in Laos, new approaches and measures need to be targeted to address the problem of structural characteristics of the agricultural development model. The continued technological development in improving infrastructure and educating farmers, in conjunction with aspirations towards sustainable farming, will be key factors that will result in higher yields of maize both domestically and internationally in the years to com.

6. List of References

AGOGTR. (2008). *The Biology of Zea mays L. ssp mays (maize or corn)*.

Agriculture and Agri-Food Canada. (2018). *Evaluation of reduced-risk weed management approaches for annual grass control in sweet corn*.

Atlas of Agriculture in the Lao PDR. (2011). *Atlas of Agriculture Lao PDR Pattern and trends between 1999 to 2011*. Swiss Agency for Development and Cooperation (SDC). https://doi.org/https://doi.org/10.7892/boris.116598

B. GOUTHAMI, & B. ASHOK KUMAR. (2022). *water management in maize*. *2*(7). www.justagriculture.in

Badu-Apraku, B., & Fakorede, M. A. B. (2017). *Advances in Genetic Enhancement of Early and Extra-Early Maize for Sub-Saharan Africa*. Springer International Publishing. https://doi.org/10.1007/978-3-319-64852-1

Belfield, Stephanie., & Brown, Christine. (2009). *A guide to upland cropping in Cambodia : maize*. Australian Government, Australian Centre for International Agricultural Research.

CABI Compendium. (2021). *Helicoverpa armigera (cotton bollworm)*. CABI Head Office, Wallingford, UK. https://doi.org/https://doi.org/10.1079/cabicompendium.26757

CHAPLOT, V., BOUAHOM, B., & VALENTIN, C. (2010). Soil organic carbon stocks in Laos: spatial variations and controlling factors. *Global Change Biology*, *16*(4), 1380–1393. https://doi.org/10.1111/j.1365-2486.2009.02013.x

Côté-Beaulieu, C., Chain, F., Menzies, J. G., Kinrade, S. D., & Bélanger, R. R. (2009). Absorption of aqueous inorganic and organic silicon compounds by wheat and their effect on growth and powdery mildew control. *Environmental and Experimental Botany*, *65*(2–3), 155–161. https://doi.org/10.1016/j.envexpbot.2008.09.003

Djamei, A. (2023). Ustilago maydis. *Current Biology*, *33*(11), R458–R460. https://doi.org/10.1016/j.cub.2023.02.069

Doebley, J. (2004). The Genetics of Maize Evolution. *Annual Review of Genetics*, *38*(1), 37–59. https://doi.org/10.1146/annurev.genet.38.072902.092425

Dowswell, C. R., Paliwal, R. L., & Cantrell, R. P. (1996). *Maize in the Third World*. CRC Press. https://doi.org/10.1201/9780429042171

Duvick, D. N., Smith, J. S. C., & Cooper, M. (2003). Long-Term Selection in a Commercial Hybrid Maize Breeding Program. In *Plant Breeding Reviews* (pp. 109–151). Wiley. https://doi.org/10.1002/9780470650288.ch4

Echarte, L. , et al. (2011). Influence of maize hybrids on grain yield and kernel composition. *Field Crops Research*, *124*(3), 245–253. https://doi.org/10.1016/j.fcr.2011.06.006

Edoh Ognakossan, K., Mutungi, C. M., Otieno, T. O., Affognon, H. D., Sila, D. N., & Owino, W. O. (2018). Quantitative and quality losses caused by rodents in on-farm stored maize: a case study in the low land tropical zone of Kenya. *Food Security*, *10*(6), 1525–1537. https://doi.org/10.1007/s12571-018-0861-9

Eichten, S. R., Foerster, J. M., de Leon, N., Kai, Y., Yeh, C.-T., Liu, S., Jeddeloh, J. A., Schnable, P. S., Kaeppler, S. M., & Springer, N. M. (2011). B73-Mo17 Near-Isogenic Lines Demonstrate Dispersed Structural Variation in Maize . *Plant Physiology*, *156*(4), 1679–1690. https://doi.org/10.1104/pp.111.174748

Eliste, P. and S. N. (2012). *Lao People's Democratic Republic Rice Policy Study, Food and Agriculture Organization (FAO), Rome, Italy.*

Espinoza L., & Ross J. (2010). *Corn Production Handbook*. University of Arkansas. https://doi.org/https://doi.org/MP437-2M-2-03N

FAO. (2015). *The State of Food and Agriculture 2015 (SOFA): Social Protection and Agriculture: Breaking the Cycle of Rural Poverty*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/3/a-i4910e.pdf

Finck C. (1995). Field dry down robs yield. *Farm Journal*, *119*(11), 14–15.

Fischer, R. A. (Tony), & Edmeades, G. O. (2010). Breeding and Cereal Yield Progress. *Crop Science*, *50*(S1). https://doi.org/10.2135/cropsci2009.10.0564

G. L. Windham, W. P. W. and F. M. D. (2007). *Effects of the Southwestern Corn Borer on Aspergillus flavus Kernel Infection and Aflatoxin Accumulation in Maize Hybrids* (6). https://doi.org/https://doi.org/10.1094/PDIS.1999.83.6.535

George Acquaah. (2012). *Principles of Plant Genetics and Breeding, 2nd Edition*.

Golhasan, B., Heydari, R., Álvarez-Ortega, S., Esmaeili, M., Castillo, P., & Palomares-Rius, J. E. (2016). Aphelenchoides iranicus n. sp. (Nematoda: Aphelenchoididae) from West Azerbaijan province, Iran. *Nematology*, *18*(8), 973–985. https://doi.org/10.1163/15685411-00003009

H. K. CHEUNG. (n.d.). *Characterization of a putative Ustilago maydis pathogenesis gene, UPE*. https://doi.org/https://www.apsnet.org/meetings/Documents/2010_Meeting_Abstracts/a10ma139.htm

Hay-Roe, M. M., Meagher, R. L., Nagoshi, R. N., & Newman, Y. (2016). Distributional patterns of fall armyworm parasitoids in a corn field and a pasture field in Florida. *Biological Control*, *96*, 48–56. https://doi.org/10.1016/j.biocontrol.2016.02.003

Herrero, S., Bel, Y., Hernández-Martínez, P., & Ferré, J. (2016). Susceptibility, mechanisms of response and resistance to Bacillus thuringiensis toxins in Spodoptera spp. *Current Opinion in Insect Science*, *15*, 89–96. https://doi.org/10.1016/j.cois.2016.04.006

Hofmann, F., Kruse-Plass, M., Kuhn, U., Otto, M., Schlechtriemen, U., Schröder, B., Vögel, R., & Wosniok, W. (2016). Accumulation and variability of maize pollen deposition on leaves of European Lepidoptera host plants and relation to release rates and deposition determined by standardised technical sampling. *Environmental Sciences Europe*, *28*(1), 14. https://doi.org/10.1186/s12302-016-0082-9

Hooker, A. L. (1985). Corn and Sorghum Rusts. In *Diseases, Distribution, Epidemiology, and Control* (pp. 207–236). Elsevier. https://doi.org/10.1016/B978-0-12-148402-6.50015-8

Hurburgh, C. R., Parvej, M. R., Hanna, H. M., & Licht, M. A. (2020). Dynamics of corn dry matter content and grain quality after physiological maturity. *Agronomy Journal*, *112*(2), 998–1011. https://doi.org/10.1002/agj2.20042

Iltis, H. H. (2000). Homeotic Sexual Translocations and the Origin of Maize (Zea mays, Poaceae): A New Look at an Old Problem. *Economic Botany*, *54*(1), 7–42. http://www.jstor.org/stable/4256247

Jéan du Plessis. (2003). *Maize production*. www.nda.agric.za/publications

Kellogg, E. A. (2015). Description of the Family, Vegetative Morphology and Anatomy. In *Flowering Plants. Monocots* (pp. 3–23). Springer International Publishing. https://doi.org/10.1007/978-3-319-15332-2_1

LAOSIS. (2023a). *Export value in goods in Lao PDR*. Laos Statistical Information Service. https://laosis.lsb.gov.la/tblInfo/TblInfoList.do?rootId=2101000&menuId=2101101&lang=en&keyword=&searchType=undefined

LAOSIS. (2023b). *Import value in goods in Lao PDR*. Department of Economic Statistics, Lao Buraue of Statistics' Ministry of Planning and Investment the Data Based on Department of Customs, Ministry of Finance. https://laosis.lsb.gov.la/tblInfo/TblInfoList.do?rootId=2101000&menuId=2101101&lang=en&keyword=&searchType=undefined

LI, W.-J., LIU, Z.-Z., SHI, Y.-S., SONG, Y.-C., WANG, T.-Y., XU, C.-W., & LI, Y. (2010). Detection of Consensus Genomic Region of QTLs Relevant to Drought-Tolerance in

Maize by QTL Meta-Analysis and Bioinformatics Approach. *Acta Agronomica Sinica*, *36*(9), 1457–1467. https://doi.org/10.1016/S1875-2780(09)60072-9

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate Trends and Global Crop Production Since 1980. *Science*, *333*(6042), 616–620. https://doi.org/10.1126/science.1204531

Lori J Abendroth, Roger W. Elmore, Matthew J. Boyer, & Stephanie K. Marlay. (2011). *Corn growth and development. PMR 1009*.

M. Banziger, G.O. Edmaedes, M. Cortes C., & A. Ortega C. (1996). Developing drought and Low N-Tolerant Maize. *From Stress-Tolerant Populations To Hybrids: The Role of Source Germplasm*, 263–273.

Manzeke, G. M., Mtambanengwe, F., Nezomba, H., & Mapfumo, P. (2014). Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. *Field Crops Research*, *166*, 128–136. https://doi.org/10.1016/j.fcr.2014.05.019

MARIANNE BÄNZIGER, P. S. S. D. H. A. B. V. (2000). *Breeding for improved drought tolerance in maize adapted to southern Africa*. *65*(3), 291–300. https://www.researchgate.net/publication/237335976_Breeding_for_improved_drought_tolerance_in_maize_adapted_to_southern_Africa

Matsuoka, Y., Mitchell, S. E., Kresovich, S., Goodman, M., & Doebley, J. (2002). Microsatellites in Zea – variability, patterns of mutations, and use for evolutionary studies. *Theoretical and Applied Genetics*, *104*(2), 436–450. https://doi.org/10.1007/s001220100694

Menkir, A., Crossa, J., Meseka, S., Bossey, B., Ado, S. G., Obengantiwi, K., Yallou, C. G., Coulibaly, Nt., Olaoye, G., & Alidu, H. (2016). Comparative performance of top-cross maize hybrids under managed drought stress and variable rainfed environments. *Euphytica*, *212*(3), 455–472. https://doi.org/10.1007/s10681-016-1777-0

Nafziger, E., Reviewed, |, & Sawyer, J. (2008). *Nitrogen Management for Corn*.

Nagy, J. (2008). Maize production. *Akadémiai Kiadó. Budapest*. ISBN 9789630586368

Nolte, B. H., Byg, D. M., & Gill, W. E. (1976). *Timely Field Operations for Corn and Soybeans in Ohio*. http://hdl.handle.net/1811/90539

OEC World. (2022). Maize (corn) starch in china. In *BACI*. https://oec.world/en/profile/bilateral-product/maize-corn-starch/reporter/chn?redirect=true

Piperno, D. R., & Flannery, K. V. (2001). The earliest archaeological maize (*Zea mays* L.) from highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences*, *98*(4), 2101–2103. https://doi.org/10.1073/pnas.98.4.2101

Prasanna, B. M., Cairns, J. E., Zaidi, P. H., Beyene, Y., Makumbi, D., Gowda, M., Magorokosho, C., Zaman-Allah, M., Olsen, M., Das, A., Worku, M., Gethi, J., Vivek, B. S., Nair, S. K., Rashid, Z., Vinayan, M. T., Issa, A. B., San Vicente, F., Dhliwayo, T., & Zhang, X. (2021). Beat the stress: breeding for climate resilience in maize for the tropical rainfed environments. *Theoretical and Applied Genetics*, *134*(6), 1729–1752. https://doi.org/10.1007/s00122-021-03773-7

Rátonyi, T., Huzsvai, L., Nagy, J., & Megyes, A. (2005). Evaluation of soil tillage systems in maize production. *Acta Agronomica Hungarica*, *53*(1), 53–57. https://doi.org/10.1556/AAgr.53.2005.1.7

Rochi, L., Diéguez, M. J., Burguener, G., Darino, M. A., Pergolesi, M. F., Ingala, L. R., Cuyeu, A. R., Turjanski, A., Kreff, E. D., & Sacco, F. (2018). Characterization and comparative analysis of the genome of Puccinia sorghi Schwein, the causal agent of maize common rust. *Fungal Genetics and Biology*, *112*, 31–39. https://doi.org/10.1016/j.fgb.2016.10.001

Saha, S., Jenkins, J. N., & McCarty, J. C. (2000). A Novel Strategy for General Sustainability and Resistance Management in Pest and Pathogen Resistant Crops. *Journal of New Seeds*, *2*(3), 53–61. https://doi.org/10.1300/J153v02n03_04

Schnable, J. C. (2015). Genome Evolution in Maize: From Genomes Back to Genes. *Annual Review of Plant Biology*, *66*(1), 329–343. https://doi.org/10.1146/annurev-arplant-043014-115604

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, *3*(2), 307–327. https://doi.org/10.1007/s12571-011-0132-8

Soreng, R. J., Peterson, P. M., Romaschenko, K., Davidse, G., Teisher, J. K., Clark, L. G., Barberá, P., Gillespie, L. J., & Zuloaga, F. O. (2017). A worldwide phylogenetic classification of the Poaceae (Gramineae) II: An update and a comparison of two 2015 classifications. *Journal of Systematics and Evolution*, *55*(4), 259–290. https://doi.org/10.1111/jse.12262

Trend Economy. (2024). *Vietnam | Imports and Exports | World | Maize (corn) | Value (US$) and Value Growth, YoY (%) | 2011 - 2022*. TrendEconomy. https://trendeconomy.com/data/h2/Vietnam/1005

Tridge. (2022). *Maize (Corn) in Vietnam*. https://www.tridge.com/intelligences/corn/VN

Tripathi, A., Akhtar, J., Kumar, P., Kalaiponmani, K., & Chalam, V. C. (2023). Diagnostic assay for molecular detection of Bipolaris maydis and Stenocarpella maydis for safe exchange and long-term conservation of maize germplasm. *Physiological and Molecular Plant Pathology*, *128*, 102165. https://doi.org/10.1016/J.PMPP.2023.102165

VIB. (2017). *Maize in Africa*. (ipbo.sites.vib.be)

Wang, K., Xie, R., Ming, B., Hou, P., Xue, J., & Li, S. (2021). Review of combine harvester losses for maize and influencing factors. *International Journal of Agricultural and Biological Engineering*, *14*(1), 1–10. https://doi.org/10.25165/j.ijabe.20211401.6034

World Bank. (2023). *GPD per capita in USD - Lao PDR*. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=LA

World Bank. (2024a). *Labor force participation rate, total (% of population ages 15+) (national estimate) - Lao PDR*. International Labour Organization. https://data.worldbank.org/indicator/SL.TLF.CACT.FE.NE.ZS?end=2023&locations=LA&start=1960&view=chart

World Bank. (2024b). *Population, total - Lao PDR*. United Nations Population Division. World Population Prospects: 2022 Revision; Statistical Databases and Publications from National Statistical Offices. https://data.worldbank.org/indicator/SP.POP.TOTL?end=2023&locations=LA&start=1960&view=char

WU, Y.-Z., HUANG, M.-B., & WARRINGTON, D. N. (2011). Responses of Different Physiological Indices for Maize (Zea mays) to Soil Water Availability. *Pedosphere*, *21*(5), 639–649. https://doi.org/10.1016/S1002-0160(11)60166-5

Yang, L., Li, L., Dong, Z., Zhu, J., Guo, W., Song, Y., Cui, H., Lv, S., Sindhu, L., & Men, X. (2024). EIRP model driven by machine learning for predicting the occurrence risk of southern corn rust (Puccinia polysora Underw.) in northern China. *Agricultural and Forest Meteorology*, *356*, 110149. https://doi.org/10.1016/j.agrformet.2024.110149

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Ciais, P., Durand, J.-L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C., … Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, *114*(35), 9326–9331. https://doi.org/10.1073/pnas.1701762114

List of Figures

List of Tables

DECLARATION

the public access and authenticity of the thesis/dissertation/portfolio[1]

Student's name:	Vongmany Thidapheth
Student's Neptun code:	FDOKSC
Title of thesis:	The Maize Production in Lao PDR
Year of publication:	2024
Name of the consultant's institute:	Institute of Agronomy
Name of consultant's department:	The Former Faculty of Agricultural and Environmental Sciences

I declare that the final thesis/thesis/dissertation/portfolio submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography.

If the above statement is untrue, I understand that I will be disqualified from the final examination by the final examination board and that I will have to take the final examination after writing a new thesis.

I do not allow editing of the submitted thesis, but I allow the viewing and printing, which is a PDF document.

I acknowledge that the use and exploitation of my thesis as an intellectual work is governed by the intellectual property management regulations of the Hungarian University of Agricultural and Life Sciences.

I acknowledge that the electronic version of my thesis will be uploaded to the library repository of the Hungarian University of Agricultural and Life Sciences. I acknowledge that the defended and

- not confidential thesis after the defence
- confidential thesis 5 years after the submission

will be available publicly and can be searched in the repository system of the University.

Date: ____2024____ year ____11____ month __04__ day

Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of _____ **VONGMANY THIDAPHETH**___ (FDOKSC) ___, I here declare that the final essay/thesis/master's thesis/portfolio[1] has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I **recommend**/don't recommend[2] the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes **no***[3]

Place and date: Gödöllő, 04.11.2024.

Dr Márton Jolánkai
Internal supervisor

[1] Please select applicable and delete non-applicable.
[2] Please underline applicable.
[3] Please underline applicable.