Chapter 5

Future grain crops

Callistus Bvenura and Learnmore Kambizi

Department of Horticultural Sciences, Faculty of Applied Sciences, Cape Peninsula University of Technology, Bellville, South Africa

1 Introduction

Although the second industrial revolution has been credited with increased crop output, this has largely had a negative impact on the environment, which has, in turn, led to global arming. Nontheless, palaeoclimatic studies indicate that the earth is not experiencing climate change for the first time in its history. Scientists are now beginning to understand the far-reaching and devastating effects of this phenomenon. A decline in agricultural production, food and nutrition insecurity, loss of livelihoods, and biodiversity; among others are some of the casualties of this phenomenon. The recent outbreak of the Covid-19 pandemic has changed life as we know it conceivably forever. The negative effects of this pandemic on agricultural production and consequently food and nutrition security are imminent. Stephens et al. (2020) identified food and nutrition security, farm labor availability, farm system resilience, and agricultural connectivity as some of the immediate concerns of the pandemic. Elleby et al. (2020) estimated that although the consumption of food during the pandemic remained unaffected, a 7%–8% and 4%–7% decline in meat prices and dairy products respectively was expected. This would be followed by a decline in maize, feedstocks, and oilseed. However, according to the same authors, a carbon emission reduction from agricultural production was estimated at 1% in comparison to the same period in the previous year. Due to the lockdown regulations resulting from the pandemic, reports of the IMF (2020), OECD (2020), and the World Bank (2020) estimated a reduction in global GDP in the range of 3%–7% in the year 2020 and an increase in the range 2.8%–5.8% in 2021. The social distancing measures that are being enforced globally bring a new set of production challenges. However, people still need food on their tables. According to Laborde et al. (2020), the economic downturn of the world is expected to drive the number of people living in extreme poverty to 20% and this translates to 140 million people. Reports indicate that the global population will rise from the current (2021) 7.8 billion to about 8.6 and 9.8 billion by 2030 and 2050, respectively (UN/DESA United Nations, Department of Economic and Social Affairs, Population Division, 2019). According to the same report, a third of this growth is projected at already struggling third world countries and Africa tops this list. This growth is expected to increase food demand from 59% to 98% between 2005 and 2050 meaning that more food will need to be produced to meet this demand (Valin et al., 2013). This is an increase from an earlier FAO (2009) report. Cereal production needs to be increased by 40% within the same period to meet the aforementioned demand (FAO, 2009). A recent study has shown that there is a decrease in the number of new and young farmers. For example, farmers older than 65 outnumber those younger than 45 by a ratio greater than two (Kumar, 2018). This means a threat to the continued production of food in the long run. More young people need to be brought into the farming business to ensure continued food production.

Humans need a source of carbohydrates/energy, protein as well as vitamins and minerals for growth and development. These are provided by the food they consume. The source of energy is mostly referred to as a staple since it dominates a portion of the standard diet and is supplied in large quantities at any given time (Su et al., 2017). The relish is there to supplement the staple with protein and some essential vitamins and minerals. Some important sources of energy are cereal grains, root/tuber crops, and legumes, and these supply approximately 90% of the world's carbohydrate requirements (Bender and Smith, 1997). However, globally, grains alone supply about 70% of calories (Glover and Reganold, 2010). In Southern Africa, about 99% of the population consumes maize, wheat, rice, sorghum, millets, oats, rye, and barley in this decreasing order (Dlamini and Siwela, 2015). Grains, therefore, play a crucial role in the diet and their production is critical in food and nutrition security. Climate change has brought about some changes in seasons which have in turn negatively affected agricultural production. The study of Wei et al. (2019) shows global declines in grain production of between 6% and 5% (RCP 2.6), 7%–10% (RCP 4.5), and 10%–25% (RCP 8.5) between 2050 and 2100. RCP (Representative Pathway Concentration) values are a trajectory of greenhouse gas concentrations, not emissions as adopted by the

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Intergovernmental Panel on Climate Change (IPCC). This shows that under extreme greenhouse gas emission circumstances, which is highly unlikely, a reduction in grain production of 25% would be experienced. However, if changes in greenhouse gas emissions are implanted, reductions in production can be as low as 5%. In the Mediterranean, losses of between 17% (RCP 4.5) and 27% (RCP 27%) are expected between 2050 and 2080 (Yang et al., 2019). Africa, on the other hand reportedly will experience a reduction of 8% in grain production by 2050 due to climate change (Sultan et al., 2019). According to the same report, Australia showed a reduction of wheat production by up to 50% by the year 2050. However, China, the world's largest greenhouse gas emitter is expected to experience a reduction in grains by up to 8% by 2030 if changes are not implanted (Li, 2018). In some regions in the United States, an increase of temperatures by 1% has been shown to lead to reductions in grain production by up to 22% (Kukal and Irmak, 2018). These projected declines in grain production mean that the need for food will continue to rise and more people will be unable to put food on their tables. This manuscript, therefore, focuses on cereal grain crops with a view to exploring their past, current, and future status, and their role in the diet and human physiology. The major grains that feed the world including maize/corn, wheat, rice, sorghum, millets, oats, rye, and barley. We also review the underutilized, climate-smart, and drought pest, and disease-resilient pseudocereals such as Amaranth, buckwheat, chia, Canahua, and quinoa. The potential of pseudocereals needs to be explored. These crops have the potential to replace the major cereals and play a bigger role in food and nutrition-insecure households. A better understanding of these crops that feed the world and their potential role in the diet will help secure their future and ensure food and nutrition security.

2 Brief overview of the grains that feed the world

History indicates that humans started collecting wild grains for food over 105,000 years ago, and plants were first domesticated about 11,500 years ago (Zeder, 2011). Cereals (maize, wheat, rice, sorghum, millets, oats, rye, and barley) and legumes (beans, soybeans, lentils, and peanuts) are the two major groups of grains. These are processed into flour, oil, and/or gas for consumption by humans and/or animals. To secure a future for the grains, there is a need to understand their past and current status.

2.1 Maize

Maize (*Zea mays* L.) is thought to have been domesticated in central Mexico around 1500 BC and spread throughout the Americas and the rest of the world (McCann, 2005). The "Columbian Exchange" introduced maize to Africa around AD 1500 and it spread throughout the continent in 500 years (McCann, 2005). The current maize crop was genetically modified from the Teosinte plant (*Zea luxurians*) that is indigenous to Mexico (Piñeyro-Nelson et al., 2017). However, the Teosinte plant looks nothing like the current maize crop. Selection and cross-breeding is thought to have taken thousands of years to develop a crop with specific traits seen in the current species. Numerous cultivars have been developed the world over to cater to the different biotic and abiotic conditions as well as pests and diseases among others. Based on the endosperm of the kernel, maize is divided into eight groups, viz: dent, flint, pop, flour, sweet, pod, waxy, and baby corn. Today, maize is cultivated on about 100 million hectares of land in 125 countries of the world. The United States, China, and Brazil are the top three current leading producers of maize (Fig. 1). These countries accounted for over 70% of the 1.1 metric million tons of maize produced in the 2018/19 season (Statista, 2020b). In sub-Saharan Africa alone, maize is a major staple that is cultivated on 36 million hectares with over 208 million people relying on it for food and nutrition security as well as economic well-being (Abatem et al., 2017).

2.2 Wheat

Wheat is one of the most important crops in the world today. In fact, it is the most widely cultivated crop in the world, covering over 220 million hectares annually in diverse climatic regions of the world (Shiferaw et al., 2013). The global yield exceeds 650 metric million tons per year. As of 2019, the European Union, India, and China produced 24%, 20%, and 16%, respectively, of the world's total yield of 734.74 million metric tons (Fig. 2). Because almost all the wheat produced is for consumption, it makes the crop important in food and nutrition security. However, the history of this crop indicates that it was first cultivated in the Fertile Crescent of the Middle East more than 10,000 years ago (Wetherell, 2019). The current wheat bread crop was developed from emmer (*Triticum dicoccon* L.) and einkorn (*Triticum monococcum*) grasses (Shiferaw et al., 2013). The crop was then introduced to Greece, Cyprus, and India about 9750 years ago, Egypt 9000 years ago, Germany and Spain 7500 years ago, the British Isles and Scandinavia 6000 years ago, China 3750 years ago, and 90 years ago in Africa (Diamond, 1997; Brace et al., 2019). Currently, wheat has over 30,000 cultivars from 14 species

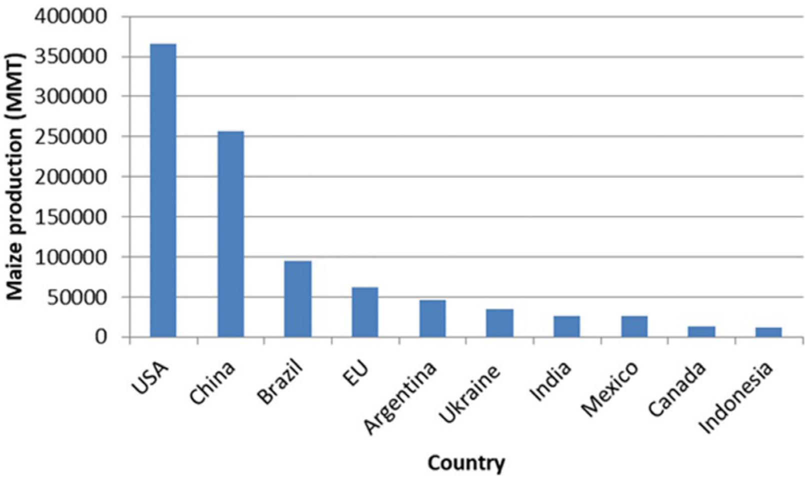

FIG. 1 Top 10 maize-producing countries in the world—2019/20 season (Statista, 2020b).

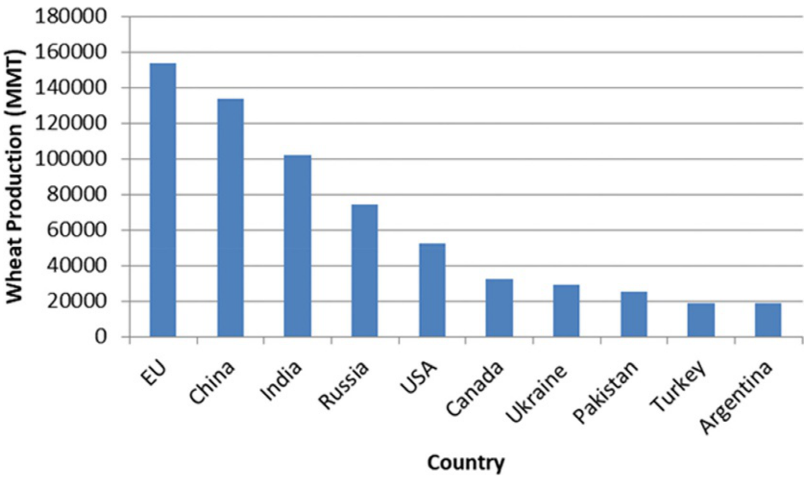

FIG. 2 Top 10 wheat-producing countries in the world—2019/20 season (Statista, 2021).

growing around the world. However, some common wheat classes that are seasonally cultivated in most countries of the world including the United States and the United Kingdom include durum, hard red spring, hard red winter, soft red winter, soft white, and hard white.

2.3 Rice

Oryza sativa (Asian rice) and *Oryza glaberrima* (African rice) are the two main species of rice with over 120,000 cultivars (Khush, 1997). *O. sativa*, the most widely cultivated species was domesticated in the Pearl River region of China between 10,000 and 14,000 years ago from the wild species *Oryza rufipogon* (Choi et al., 2017).

Furthermore, according to the same report, *O. sativa* has five subspecies namely *aromatic rice*, *aus*, *indica*, temperate *japonica*, and tropical *japonica*. Further detailed classifications and distributions are given in the GRiSP (2013). In India and Sri Lanka, rice was already a major crop about 3000 years ago; and over 2300 years ago in Greece around which time the crop spread gradually in Europe and some parts of northern Africa (GRiSP, 2013). According to the previous authors, rice in North America dates back 335 years. Furthermore, although the Chinese rice eventually outcompeted the African rice, cultivation of the African species dates back 3500 years ago from the Niger River delta and extending to Senegal. Rice is very important in food and nutrition security because it provides a fifth of the calories needed in the diet in the world today. Fig 3 shows that in the 2018/19 season, China and India alone contributed 37% and 29% respectively of the 495.9 million metric tons produced globally (Statista, 2020c). In addition, China remains the largest consumer of rice, having consumed 143.79 million metric tons (MMT) in the same season.

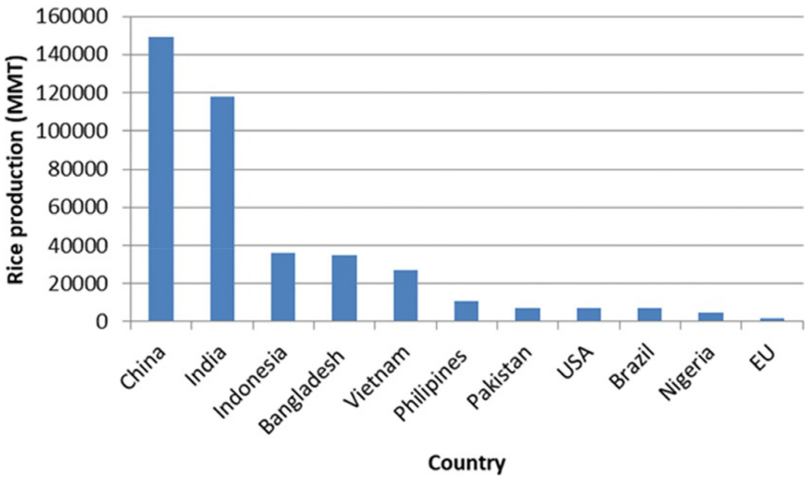

FIG. 3 Top 10 rice-producing countries in the world—2019/20 season (Statista, 2020c).

2.4 Sorghum

Sorghum bicolor (L.) Moench is indigenous to North-East Africa where it was domesticated in Ethiopia, Chad, and the Sudan 4000 to 7000 years ago (Prażak, 2016). Furthermore, the crop is presumed to have been bred from its wild ancestor *Sorghum arundinaceum*. The crop then spread throughout Africa through Ethiopia's highlands and the semi-arid Sahel. In Southern Africa, sorghum arrived over 3000 years ago (CFIA, 2017). In China, the near East, and India, evidence indicates that the crop was already known by the 8th century BC while it arrived in the late 19th century in North America and eventually the South and Australia (Prażak, 2016). The crop not only plays an important food and nutrition security role but is also an important fodder crop the world over. Sorghum is the fifth most-produced grain crop after wheat, rice, maize, and barley. Due to its drought, disease, and pest resilience, sorghum is planted in the most drought-prone areas of the world. Although sorghum is indigenous to Africa, the United States is the leading producer of grain. As shown in Fig. 4, in the 2019/20 season, the USDA (2020a) reported that of the 58.4 MMT globally produced; the United States and Nigeria produced 9 and 6.5 MMT respectively while Ethiopia and Mexico produced 5 MMT separately. According to the same report, global production has declined from 63 to 60.6 to 58.5 MMT in 2016/17, 2017/18, and 2018/19 seasons, respectively.

2.5 Barley

Barley (*Hordeum vulgare*), the fourth most important cereal grain after maize, wheat, and rice is currently cultivated on 52.66 million hectares of land worldwide (USDA, 2020d). This crop was domesticated from its wild ancestor *H*. spontaneum in the Fertile Crescent about 10,000 years ago, making it one of the first crops to be domesticated (Hughes et al., 2019). The crop then spread to India, Persia, Mesopotamia, Syria as well as Egypt Greece, and Italy about

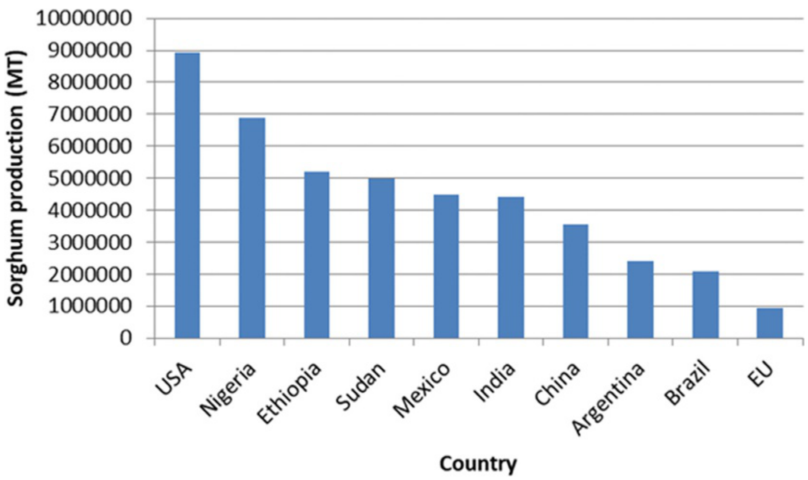

FIG. 4 Top 10 sorghum-producing countries in the world—2019/20 season (USDA, 2020a).

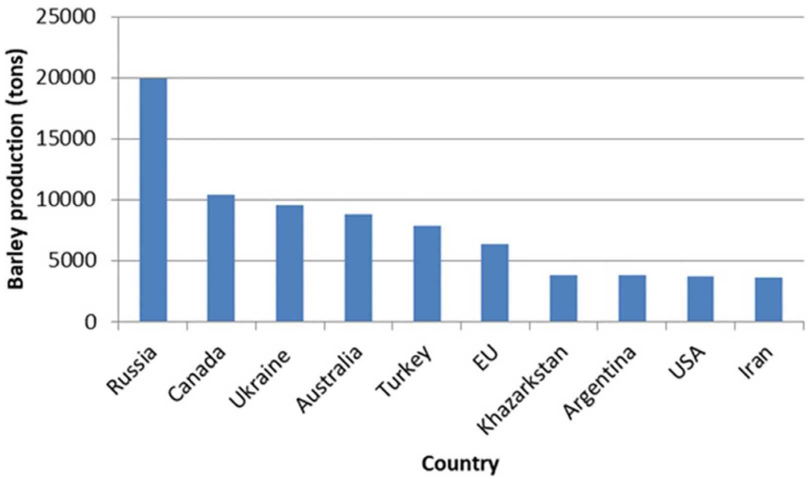

FIG. 5 Top 10 barley-producing countries in the world—2019/20 season (USDA, 2020d).

3300 to 5700 years ago (Stachowski, 2008). This crop was very widely used and important in the ancient world, it once became a currency. About 26 species of barley exist with over 150 cultivars in the United States alone. As shown in Figs. 5, 2019/20 crop yielded 139.30 MMT and it is projected that the 2019/20 season will yield 156.25 MMT (USDA, 2020d). The EU, Russia, Australia, and Canada are the current leading producers with a combined yield of 65% and Russia alone with 11%.

2.6 Millets

Millets are one of the oldest known grain crops to be consumed by humans. In general, millets are classified into pearl (*Pennisetum glaucum, Pennisetum typhoides, Pennisetum tyhpideum, Pennisetum americanum*), and minor millets. Finger (*Eleusine coracana*), proso/common (*Panicum miliaceum*), foxtail (*Setaria italica*), barnyard (*Echinochloa crusgalli, E. colona*), little (*Panicum sumatrense*), and kodo (*Paspalum scrobiculatum*) millets constitute the minor millets due to their smaller grains. Although their origin is debatable, many scholars agree that their domestication occurred separately in many parts of the world including East and West Africa as well as East and South Asia. Different species seem to be indigenous to different parts of the world. In Asia, for example, domestication appears to have predated that of rice. The Chinese are thought to have domesticated proso and foxtail millet about 10,000 years ago (Lu et al., 2009). In addition, the previous authors present archeological evidence of the use of millets in the preparation of noodles about 4000 years ago. Kodo and little millets were domesticated 3700 to 5000 years ago in South Asia and about 3200 years ago in India (Pokharia et al., 2014). Pearl millet was domesticated in West Africa between 3500 and 8000 years ago while in Mali of the Sahel Region, evidence shows cultivation about 4500 years ago (D'Andrea and Casey, 2002; Manning et al., 2011). Finger millet on the other hand is indigenous to the highlands of East Africa where its domestication was in the third millennium BC (Engels et al., 2002). Although millet is one of the oldest known grain crops, its cultivation is minimal, ranking it the sixth most-produced crop in the world. As shown in Fig. 6, India, Niger, China and Nigeria were the leading producers of millets in the 2019/20 season with 11, 3.8, 2.3, and 2 million tons respectively from a global estimate of 27.8 million tons (USDA, 2020b). Africa however remains the largest consumer of millets by over 40%.

2.7 Oats

The oat is the seventh most important and produced cereal crop in the world; accounting for only 1% of total cereal production and currently globally cultivated on 9.99 million hectares of land (USDA, 2020d). The common oat (*Avena sativa* L.) which is current widely cultivated was bred from its closely related wild ancestor *Avena sterillis* in the Fertile Crescent of the Near East (Zhou et al., 1999). About 12 species were initially identified by Stanton in 1953, including the Ethiopian oat (*Avena abyssinica* Hochst.), bristle oat (*Avena strigosa* Schreb.), the red oat (*Avena byzantina* C. Koch.), common wild oat (*Avena fatua* L.) and *Avena nuda* L. the naked oat (Arendt and Zannin, 2013). The crop was domesticated 4000 years ago and almost independently in Europe, China, and other areas of the world (Tosh and Miller, 2016). Although the oat was consumed or known as a usable weed, its domestication was late in comparison to that of wheat and barley. This domestication was outside the center of its origin. However, only 10% of oats produced are used for human consumption. The rest

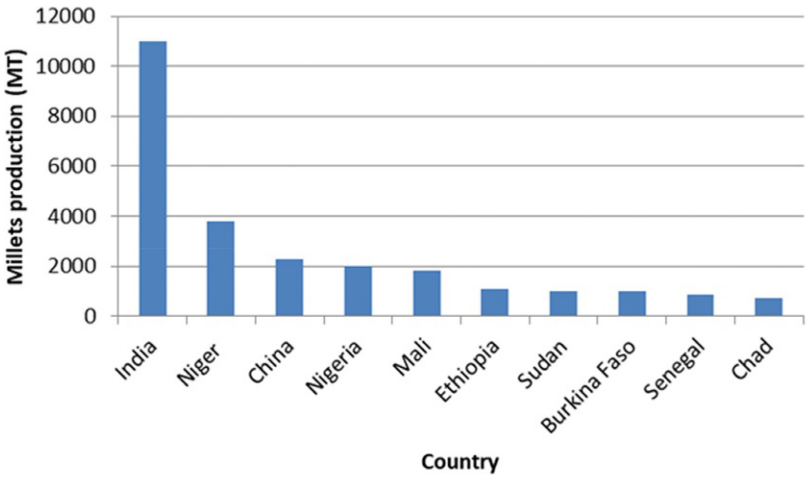

FIG. 6 Top 10 millets producing countries in the world—2019/20 season (USDA, 2020b).

are for feed and industrial applications. Production for food is considered not profitable due to its light weight and massive volumes it occupies during transportation. In the 2019/20 season, world production of oats was 22.24 MMT, a decrease from 23.7 MMT from the previous season (Statista, 2020d). However, an increase to 24.44 MMT in the 2019/20 season is projected (USDA, 2020c). According to the same report, the European Union, Russia, and Canada will contribute about 71% of the total production (Fig. 7). Russia alone will contribute about 20%.

2.8 Rye

Despite a lack of clarity on the history of rye (*Secale cereale*), L. Synonyms. Secale fragile M. Bieb. Rye (*Secale cereale*) many of the researchers/experts agree that the crop may have originated from Asia Minor (Turkey) where its close wild relative (*S. cereale* ssp. *segetale* or *S. vavilovii*) is located (Hirst, 2019). In addition, the same author argues that domestication may have occurred as early as 10,000 years ago, making it one of the early crops to be consumed by humans including barley and wheat. Due to its obscurity and close resemblance to wheat, it is thought that the crop may have first spread to Europe around 4000 BC by Vavilovian mimicry and then the rest of the world (McElroy, 2014). Rye ranks eighth among the cereals and is currently cultivated on 3.85 million hectares with a total annual yield of 10.01 MMT in the 2018/19 season and projections of 12.06 MMT for the 2019/20 season (USDA, 2020d). Furthermore, according to the same report, the EU, Russia, and Turkey respectively produced 6.22, 1.91, and 0.50 MMT in the 2018/19 season (Fig. 8). Turkey interestingly also has one of the highest yields per hectare despite its low total yield.

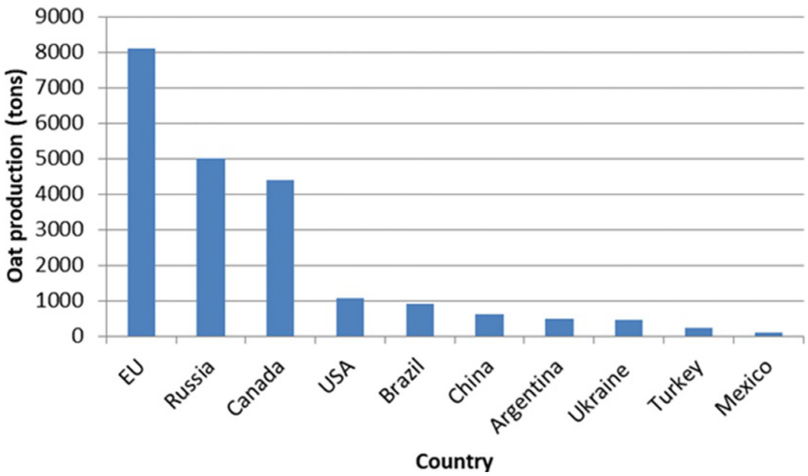

FIG. 7 Top 10 oat-producing countries in the world—2019/20 season (Statista, 2020d).

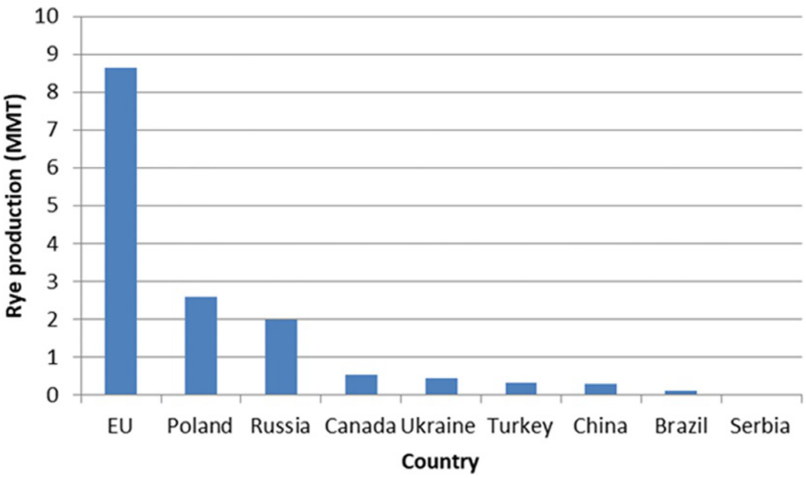

FIG. 8 Top 10 rye producing countries in the world—2019/20 season (USDA, 2020d).

3 Pseudocereals

Pseudocereals are so named because of the close resemblance of their grains and seeds to those of true cereals. Non-the-less, although pseudocereals are non-grasses, their texture, cooking method, palatability as well as starch compositions are the same as those of true cereals (Morales et al., 2020). Although underexplored and underutilized, numerous cultures around the world still use pseudocereals as their main source of starch in the diet. Most of these cereals played a pivotal role in pre-civilization cultures and/or diets such as in the Aztec, Mia, and Inca empires (Petrova and Petrov, 2020). However, these cereals are potentially the cereals of the future due to their stress resilience, nutritional and polyphenolic compositions, and their requirements for minimal cultivation. In this chapter, we explore Amaranth, buckwheat, chia, Canahua, and quinoa. These are the most common and globally known pseudocereals that play a significant role in the diet of various cultures.

3.1 Amaranth

Amaranth is one of the most common pseudocereals in the world, comprising over 50 genera and close to 1000 species (Sauer, 1993). According to Anubhuti (2017), Amaranth is further classified into two main culinary groups according to vegetable (*A. cruentus*, *A. dubius*, and *A. tricolor*) or grain (*A. cruentus*, *A. caudatus,* and *A. hypochondriacus*) usage. But the history of Amaranth dates back 8000–6000 years where its seed was discovered in archeological sites in Argentina (Stetter et al., 2017). *A. cruentus*, the supposed original cultivar is thought to have been domesticated 6000 years ago as shown by archeological finds in the Tehuacán Pebla caves of Mexico (OWGC, 2020). Tehuacán Pebla is an early agricultural site that is about 6000 years old. According to Joshi et al. (2018), Amaranth was a major cereal among the Aztecs in the 15th and 16th centuries where it was mainly used for religious purposes. But the crop is also found in archeological sites that date back 3000 years in China and South East Asia, although a general consensus places the origins of this crop in the New World or what is now known as the Western Hemisphere/Americas (Joshi et al., 2018). The cultivation and use of Amaranth have been spreading from Central America, South East Asia, and Africa in the past two centuries with the cereal being introduced to America by George Mateljan in the 1970s (DAFF, 2010). Global and country production data of Amaranth is scanty; however, reports indicate that China and Russia once had 300,000 and 100,000 ha, respectively, under cultivation while the global yield was between 2 and 5.5 t/ha (Taylor and Emmambux, 2008). However, some statistics (Statista, 2020a) indicate that Mexico produced 4000, 5000, 7000, 9000, 6000 and 5000 metric tons in 2012, 2013, 2014, 2015, 2016 and 2017, respectively. In spite of that, the current global market share of the seed follow the decreasing order: China (24.2%) > Canada (7.1%) > Netherlands (6.5%) > Paraguay (5.9%) Austria (4.7%) > Benin (4.2%) > Germany (3.3%) > Ghana (3.2%) Mexico (2.45) > Ukraine (2.4%); with export values ranging between 229.46 and 22.45 million USD (TRIDGE, 2020a).

3.2 Quinoa

Quinoa (*Chenopodium quinoa* Willd.) is a herbaceous tetraploid with halophytic, frost, and drought-resilient properties from the Chenopodiaceae family (Martinez et al., 2015). Quinoa's closest ancestor is thought to be the North American species *Chenopodium berlandieri* var. nuttalliae or the southern Hemisphere complex of species including *Chenopodium* *carnasolum* Moq., *Chenopodium petiolare* Kunth., *Chenopodium berlandieri* var. nuttalliae., *Chenopodium pallidicaule* Aellen. (Kañahua), *Chenopodium quinoa* var. melanospermum., and *Chenopodium hircinum* Schard (Angeli et al., 2020). These South American Andean origins conceivably led to this crop's domestication and cultivation about 8000 years ago (Martinez et al., 2015). Furthermore, its history of usage by the Inca in sacred religious ceremonies and its banning by the Spanish invaders in the 1530s is similar to that of Amaranth among the Aztecs. This is why the crop disappeared from history but not completely, only to resurface in the 1970s when it was introduced to the modern world and is now cultivated in Bolivia, Canada, India, Italy, Peru, Sweden, and the United States (Petruzzello, 2020). But statistics show that out of the 158.92 thousand metric tons produced in the 2017/18 season; Peru, Bolivia, and Ecuador produced 86.01, 70.76, and 2.15 thousand metric tons of quinoa respectively (TRIDGE, 2020b). According to the same report, Peru is the top producer and exporter while the United States is the top importer.

3.3 Chia seeds

Chia seeds are a pseudocereal that is harvested from *Salvia hispanica* L., a herbaceous plant of the Lamiaceae or mint family. This plant is of Andean origin (Northern Guatemala and Central Mexico) and was domesticated and cultivated in the same region by the Aztecs about 5500 years ago (Sosa, 2016). However, because of the Spanish conquest of the Mesoamericans, the plant was banned from cultivation and use between 1550 and 1810 (Knez Hrnčič et al., 2019). This was due to its use in sacred religious ceremonies which beliefs clashed with those of the Spanish invaders. However, even though cultivation laws were relaxed after independence, this did not lead to the plant's revitalization, cultivation, and increased usage. It is reported that during the pick of the Aztec empire, the annual production and consumption of chia seeds was up to 15,000 tons per year, making the seeds a major grain of the period (Sosa, 2016). Cultivation has since then spread throughout the world to Australia, Argentina, Bolivia, Columbia, Europe, Peru, Ghana, and South Africa in Africa, and the United States. Global production statistics are scanty, but reports indicate that Germany is the world's topmost consumer at 5551.6 metric tons in 2018 with Bolivia, and Mexico being this country's major suppliers (Market Reports World, 2020). Another report indicates that the market size of this pseudocereal which was at 1.14 billion USD in 2018 will increase by 22.5% between 2019 and 2025 (Market Analysis Report, 2019). This increase has been attributed to global changes in dietary preferences and/or needs; for example, about 10% of Germany's population is now vegan. The Covid-19 pandemic is also forcing lifestyle changes globally and previously neglected foods are now becoming new favorites to many people because of their perceived health benefits. These changes are expected to increase and push the demand for these foods up.

3.4 Buckwheat

The term buckwheat refers to three of the 15-member genus Fagopyrum (*Fagopyrum esculentum* Moench. [common buckwheat], *Fagopyrum dibotrys* (D. Don) Hara. [perennial buckwheat], and *Fagopyrum tataricum* (L.) Gaertn. [tartary buckwheat]) of the Polygonaceae family (Jing et al., 2016). Buckwheat is not related to the common wheat crop since it's not grass but a herbaceous plant that produces grains that are physiologically similar to the common grain. Another genus, Eriogonum is collectively known as wild buckwheats (*E. fasciculatum*, *E. alpinum*, *E. flavum*, *E. maculatum*, *E. gracillimum*, *E. nidularium* and *E. strictum*) are widespread in North America. Non-the-less, domestication of the common buckwheat is thought to have occurred in western Yunnan, southeast Asia, about 8000 years ago although the earliest known archeological finds date 3400 years back (New World Encyclopedia, 2020). But in the Balkans in Europe, Tibet, and Japan, pollen grains dating 6000 years back have been documented. The crop was introduced to Russia in the 14th century, spreading to Belgium, Poland, France, and Germany and becoming established in Spain by the 17th century. Europeans are thought to have introduced the common buckwheat to North America, but the global presence of this crop had been registered by the year 2006. Recent statistics indicate that of the 2.9 million metric tons produced in the 2017/18 season, China and Russia were the major producers with 39.1% and 32.1% respectively (TRIDGE, 2020c). But the current global market for this crop is 1.2 billion USD and is expected to reach 1.4 billion USD by the year 2027 (Report Linker, 2020).

3.5 Cañahua

Cañahua (*Chenopodium pallidicaule* Aellen) is a semi-domesticated herbaceous, drought-resilient, halophytic perennial plant that is recognized for its edible seeds. This food plant that is known by many names (cañigua, cañahua, cañawa, cañihua, and kañiwa) according to various native languages is a close relative of quinoa (*Chenopodium quinoa* Willd.) belonging to the Amaranthaceae family. This crop is thought to have been domesticated and cultivated in the Andean region particularly in the west to central South America about 7000 years ago (Mangelson et al., 2019). However, like quinoa, the Spanish invasion ceased its cultivation and use due to its use in religious ceremonies which were viewed as ungodly by the Spanish. Therefore, this led to cañahua's near disappearance from history, until recently. The crop is currently cultivated at high altitudes across the Andean Altiplano's region of Bolivia and Peru as well as in Chile at about 3500–4200 m above sea level. Although over 200 cultivars are known in Bolivia alone, about 20 are still in use and over 85% of the farmers only cultivate one cultivar (Bioversity International, 2013). However, although the crop has been under cultivation for a while after the Spanish laws were reversed, the crop has been introduced and is slowly gaining popularity in Europe, the United States and slowly spreading to the rest of the world (Rodríguez et al., 2017). Data on production is currently not available although Bolivia and Peru are the current major producers of the crop.

4 Nutritional and polyphenol composition

4.1 Nutritional components

Since the late 1960s to early 1970s, when food scares relating to pesticides were reported in the United States, consumer interest in the chemical and nutritional compositions of the food they eat has not stopped rising. This is a push to produce and table food that is nutritionally healthy and free of toxic elements, some of which have been linked to chronic ailments and lifestyle diseases and/or conditions such as hypertension, obesity, diabetes, and others. About 38 million people were reported to be infected with HIV globally in 2019 and 690,000 died from AIDS-related illnesses during the same period (UNAIDS, 2020). The number of deaths has decreased by 37% since 2010. This large decrease since 1981's first reported case has been attributed to many global interventions including an improvement of the diet which has been found to positively improve the lives of the infected. It is therefore not surprising that people no longer regard HIV/AIDS as a major issue anymore in comparison to cancer. Be that as it may be, a strong correlation between AIDS-related mortalities and a poor diet has long been established. The world has therefore been pushing for improved food and nutrition security to ameliorate against some avoidable mortalities. It is therefore important to know and monitor the nutritional compositions of the cereals that feed the world since they play a major role in food and nutrition security. Cereals are staples and therefore meant to supply the much-needed carbohydrates/energy while other macro and micronutrients, as well as vitamins, are meant to be supplied by the relish mainly consisting of meat and vegetables. The essential nutrients and vitamins contained in the cereal grains are shown in Tables 1 and 2.

In human physiology, carbohydrates (glucose, fructose, sucrose, and sorbitol) provide energy to the body when they are broken down and absorbed into the bloodstream. High fiber diets have been linked with improved gastrointestinal functions such as the easing of bowel movements; and a reduction in cardiovascular diseases. The role of proteins as transport carriers, hormones, in membranes, and as enzymes is well known. However, although plant-based proteins have the ability to supply these proteins, some essential amino acids can only be supplied by animal sources. Lipids are broadly grouped as phospholipids, waxes, sphingomyelins, sterols, and fats. Their role in the diet is to enhance food taste and acceptability, and they are also the richest source of metabolic energy. Amino acids are the building blocks of polypeptides and proteins; hence in human physiology, their functions are directly linked to that of proteins.

This data indicates that white, sweet, and raw maize is only able to supply the least amount of the Recommended Daily Intakes (RDIs) of carbohydrates (25%), energy (3%), fiber (4%), and protein (6%) in the diet. Rice is able to supply the highest amounts of carbohydrates (107%); rice, millets, and oats can supply the highest amount of energy (15%); oats the highest amounts of protein (26%) and lipids (8%) and barley the highest amounts of the RDI of fiber (58%).

In a similar fashion, the data indicate that maize is able to supply the least Ca (200%), Cu (6%), Fe (7%), and Mn (7%) RDI while oats are able to supply the highest Ca (5200%) and Fe (53%). Wheat, sorghum, and rye have the potential to supply the least (133%) Na RDI and maize has the highest potential supply amounting to 1000%. Millet and wheat can potentially supply 83% and 173% respectively of the RDI of Cu and Mn.

These grains are not richly endowed with the essential vitamins. For example, Vitamin A, D, C, and B12 are either absent or below the limit of detection in all cereals. However, Vitamin C is 6.8 mg in maize while Vitamin A is only 1 mg in rye. But wheat can supply 0.3% of the RDI while millet has the highest potential at 4.5%. Rice has the lowest potential supply of thiamin and riboflavin at 5% and 3% respectively. Oats and barley/wheat have the lowest (6%) and highest (26%) potential of niacin RDI values respectively, while barley and rye can potentially supply 4% and 21% RDI of pantothenic acid. Wheat and sorghum can potentially supply 2% and 22% of the RDI of Vitamin B6. Rice can supply the least RDI of Vit. K (0.1%) and folate (2%) while rye can potentially supply the highest RDI of Vitamin K (5.9%) and millets the highest amount of folate (21%). Although these minerals and vitamins can be supplied by these grains, supplements are needed, and these are normally supplied by the relish or meat and lentils. But production of superior

TABLE 1 The essential nutrients and minerals in raw cereal grains (USDA, 2019).

	Macronutrients (%)					Micronutrients (mg/100 g)					
	Energy (KJ)	Carbs	Fiber	Total lipid	Protein	Ca	Cu	Fe	Mg	Mn	Na
Maize[a]	0.36	19.02	2.70	1.18	3.22	2.00	0.05	0.52	37.00	0.16	15.00
Rice[b]	1.53	79.95	1.30	0.66	7.10	28.00	0.22	0.80	25.00	1.09	5.00
Wheat[c]	1.37	71.00	12.2	1.54	12.60	29.00	0.43	3.19	126.00	3.99	2.00
Barley[d]	1.48	73.48	17.3	2.30	12.48	33.00	0.50	3.60	133.00	1.94	12.00
Sorghum[e]	1.38	72.09	6.70	3.46	10.62	13.00	0.28	3.36	1.65	1.61	2.00
Millets	1.58	72.85	8.50	4.22	11.02	8.00	0.75	3.01	114.00	1.63	5.00
Oats	1.59	67.70	10.10	6.52	13.15	52.00	0.39	4.25	138.00	–	6.00
Rye[f]	1.41	75.86	15.10	1.63	10.34	24.00	0.37	2.63	110.00	2.58	2.00
RDI	8.37–10.46	75.00	30.00	44.00–77.00	50.00	1.00	0.90	8.00	400.00	2.30	1.50

[a]*Corn, sweet, white, raw.*
[b]*Rice, white, long-grain, regular, raw, unenriched.*
[c]*Wheat flour, white, all-purpose, unenriched.*
[d]*Barley, hulled.*
[e]*Sorghum grain.*
[f]*Rye grain.*

quality grains is the current trend in research. This work aims to improve the nutritional compositions of these crops, while their products such as bread are often fortified to meet the RDI of the essential nutrients and vitamins.

4.2 Polyphenolic components

Several studies have revealed the rich polyphenolic components of the various cereal grains. Polyphenolic compounds are plant secondary metabolites that act as antioxidants and defend against oxidative stress in human tissues. Among others, their role in plants is to act as a defense mechanism against biotic and abiotic stress (Bvenura et al., 2018). Polyphenolic compounds are divided into carotenoids, alkaloids, phenolics, organo-sulfurs, and nitrogen-containing compounds. Phenolic acids, flavonoids, coumarins, tannins, stilbenes are the major phenolic compounds. The role of phenolic compounds is in physiology and cellular metabolism (Bvenura et al., 2018).

They determine plant aroma, taste, astringency, and color; and also play a pivotal role in germination, reproduction, growth, development, and pollination as well as help the plant guard against predators (Bvenura et al., 2018). Due to their strong antioxidant nature, phenolic acids (hydroxy-benzoic acids and hydroxy-cinnamic acids) play a protective role in degenerative diseases including diabetes, inflammation, cancer, and cardiovascular conditions (Kumar and Goel, 2019). Among others, by scavenging superoxide radical anion, peroxynitrite and singlet oxygen, hydroxyl radicals, peroxyl radical, and several organic radicals, phenolic acids exert this antioxidant activity (Chandrasekara, 2019). Also, they are responsible for the change in cell signaling pathways. Flavonoids (flavonols, flavones, flavanols, flavanones, anthocyanidins, and isoflavonoids) are the most widely studied phenolics. They are hydroxylated phenolic compounds which the plants produce in response to microbial infection (Kumar and Pandey, 2013). They provide a secondary antioxidant defense in biotic and abiotic stress-exposed plants. Flavonoids play a pivotal role in drought resistance, a functional role in plant freezing tolerance as well plant heat acclimatization (Panche et al., 2016). In human physiology, the anti-carcinogenic, anti-inflammatory and anti-mutagenic properties of flavonoids have been reported. Specifically, flavonoids were found to bind and inhibit the activities of the 2009 H1N1 influenza virus; reduce the harmful effects of diabetes, lower the risk of cardiovascular diseases, and many others (Bondonno et al., 2019; Zakaryan et al., 2017).

However, Table 3 shows that total phenolic acids decrease in the order: millets > rice > barley > oats > sorghum > wheat > rye. Again, as shown in Table 3, Total flavonoids decrease in the order: rice > millet > sorghum > barley > wheat > maize > rye. The role of these grains in health is thus important due to their polyphenolic contents. Red and brown colored grains including fruits and vegetables are generally high in phenolics. This data indicates this. However, white rice appears to be higher in these compounds. This data is consistent with that reported by Shen et al. (2009), who reported that white

TABLE 2 Essential vitamins in cereal grains (USDA, 2019).

	Vit E (mg/100 g)	Vit K (μg/100 g)	Thiamin (mg/100 g)	Riboflavin (mg/100 g)	Niacin (mg/100 g)	Pantothenic acid (mg/100 g)	B_6 (mg/100 g)	Totalfolate (μg/100 g)	TSF (%)	TMF (%g)	TPF (%)
Maize[a]	0.07	0.30	0.20	0.06	1.70	0.76	0.06	46	0.18	0.35	0.56
Rice[b]	0.11	0.10	0.07	0.05	1.60	1.01	0.16	8	0.18	0.21	0.18
Wheat[c]	0.06	0.30	0.12	0.04	1.25	0.44	0.04	26	0.16	0.09	0.41
Barley[d]	0.57	2.20	0.65	0.29	4.60	0.28	0.32	19	0.48	0.30	0.12
Sorghum[e]	0.50	–	0.33	0.10	3.69	0.37	0.44	20	0.61	1.13	1.56
Millets	0.05	0.90	0.42	0.29	4.72	0.85	0.38	85	0.72	0.77	2.13
Oats	0.42	2.00	0.46	0.16	1.13	–	0.10	32	1.11	2.00	2.30
Rye[f]	0.85	5.90	0.32	0.25	4.27	1.46	0.30	38	0.20	0.21	0.77
RDI	4–19 mg/D	2–120 μg/D	0.2–1.4 mg/D	0.3–1.6 mg/D	2–18 mg/D	1.7–7 mg/D	0.1–2.0 mg/D	400 μg/D			

TSF, total saturated fatty acids; *TMF*, total monounsaturated fatty acids; *TPF*, total polyunsaturated fatty acids.
[a]*Corn, sweet, white, raw.*
[b]*Rice, white, long-grain, regular, raw, unenriched.*
[c]*Wheat flour, white, all-purpose, unenriched.*
[d]*Barley, hulled.*
[e]*Sorghum grain.*
[f]*Rye grain.*

TABLE 3 Polyphenols in raw cereal grains.

	Total phenolics(μmol GAE/100 g)	Total flavonoids(μmol CE/100 g)	References
Maize	380.00–720.00	40.89–70.34	Dewanto et al. (2002) and Zhang et al. (2017)
Rice	1160–1890	400–1860	Chutipaijit and Sutjaritvorakul (2018)
Wheat	709–1099	106–142	Adom et al. (2003)
Barley	604–1346	62–300	Idehen et al. (2017)
Sorghum	1090–1170	460–550	Afify et al. (2012)
Millets	400–2700	100–1300	Ofosu et al. (2020) and Kumari et al. (2017)
Oats	758–1225	–	Mikulajová et al. (2007)
Rye	98–337	0–13	Kulichová et al. (2019)

rice had higher total phenolic acids and flavonoids in comparison with red rice. Data indicates that millets are high in both phenolics and flavonoids while maize, rye, and oats struggle in both. However, it is interesting to note that individual cereal grains that have high polyphenolic contents can be used to boost those with a lower output as shown by the work of Kim et al. (2018). These authors improved the polyphenolic compounds in rice by mixing them with sorghum. This presents important information especially in food fortification studies where multi-grain foods rich in polyphenolic compounds can be formulated without the use of synthetics or extracts. The creation of multi-grain beverages today, therefore, comes as no surprise and is understandably on the rise. These beverages are often fermented with probiotics in order to boost their health and functional properties.

The bioavailability of polyphenolic compounds

Bioavailable compounds are those that reach systemic circulation unaltered after oral administration. Ideally, solutes must overcome the luminal and vascular barrier membranes in the intestinal epithelial cells thereby ensure the selective exchange and uptake between the body and the environment (Koziolek et al., 2019). Therefore, the polyphenolic values shown in the raw grains are different from those that become bioavailable. The real values that become available to the human system may be lower than those in the raw grains. But, other factors such as processing also play a large role between raw grain values and the bioavailability. Nevertheless, it has also been reported that compounds decline as they pass through the gastrointestinal tract. For example, Akhlaghi and Foshati (2017) reported that less than 1% of flavonoids administered are absorbed and bioavailable. Earlier on, the rule-of-five model had predicted that compounds whose relative molecular mass is greater than 500 and are prone to form hydrogen bond interactions are not able to cross membranes by passive diffusion (Yang and Hinner, 2015). Unfortunately, flavonoids are found within this zone and therefore may not be able to be passively absorbed in the intestines. The majority of influx membrane transporters responsible for nutrient absorption are unfortunately not able to do the same for flavonoids, while those responsible for expelling drugs and xenobiotics (multi-specific efflux transporters) are able to recognize flavonoids and this leads to their extrusion and excretion (Koziolek et al., 2019). However, as reported by Williamson et al. (2018), the organic anion transporter families (OAT) which include the organic anion transporting peptide (OATP) and the multi-drug resistance-associated protein (MRP) families are responsible for the absorption, distribution as well as the excretion of flavonoids in the body. The trans-epithelial movement of organic anions in the brain, liver, and kidneys is monitored by these families of transporters. It is important to note the specificity of these transporters in the absorption, bioavailability, transport, and excretion of flavonoids. On the other hand but in a near similar fashion, phenolic acid bioavailability is thought to start when the glycosidase enzymes of bacteria in the saliva combine with food during the chewing process in the mouth (Hussain et al., 2019). On reaching the stomach, it has been shown that various phenolic acids may need to undergo structural modifications before they can be absorbed in the epithelial membranes (Kawabata et al., 2019). Phenolic acids such as gallic acid are also thought to be of very low molecular weight and are easily absorbed in the gastrointestinal tract (GIT) (Kawabata et al., 2019).

Therefore, although the polyphenolic data shows that the cereals are rich in total phenolic acids and flavonoids; the real test of their quality is proven by the ability of the GIT to digest and absorb them so that they become available to the chemical processes happening in the body.

The effects of processing on nutritional and polyphenolic compounds

Research has shown high polyphenolic compositions in grains, although these are mainly located on the outer shell of the grains (Tian et al., 2019). Polyphenolic compounds are important in the food that we eat since they increase antioxidant activities. An increase in antioxidant activities has been linked with increased protection of the cells against free radicals. All grains need to be processed before consumption. Cooking or the introduction of heat and fermentation are the most common methods used. Subjecting these grains to various processing methods has however been shown to affect their phytochemical compositions. We, therefore, explore heat and fermentation treatments due to their global popularity and wide usage. We hope to increase our understanding of these relationships and therefore use them to our advantage.

Heat

A reduction in polyphenolic compounds has been reported due to heat treatment. For example, Carcea et al. (2017) found the total phenolic compounds to decrease in couscous by up to 14% after cooking. However, although the total phenolic compounds declined, the results of their work showed that the free total phenolic compounds slightly decreased while the bound total phenolic compounds slightly increased. These authors were able to further show that the polyphenols are diluted by the water that they absorb during cooking.

In a different study, Chmiel et al. (2017) showed that although heat treatment significantly reduced polyphenols in rice, the source and mode of the heat were insignificant. However, the rice cooker caused the highest (29%–31%) reduction, followed by the microwave (18%–33%) and boiling had the least reducing effect (18%–28%). Furthermore, these authors were also able to show that reheating the cooked rice further reduced the polyphenolic compounds.

Fermentation

The metabolic process by which chemical compositions of inorganic substrates change through the action of enzymes is known as fermentation. Fermentation has been used for centuries in many cultures of the world as a food preservation technique; to improve flavor, aroma, and taste and to detoxify some toxic compounds. Fermentation also improves the health components of food by the introduction of some beneficial bacteria such as the Lactobacillus species. The majority of cereal grains are fermented for various purposes prior to cooking or after cooking. This process often introduces some beneficial bacteria by spontaneous or natural occurrences, controlled fermentation (inoculation), or back slopping (reintroduction of successful previously fermented batches). Some of the products of fermentation of grains include sourdough bread, sour porridge, fermented oats, and probiotic cereal beverages among others. It is therefore important to understand the effects of this process on the polyphenolic components of the grains.

During fermentation, large molecules such as proteins and carbohydrates are consumed while small molecules with physiological activities are produced (Tian et al., 2019). A cohort of studies has shown that fermentation can either increase or decrease polyphenolic compounds in cereals. A comprehensive review of the response of phenolic acids to fermentation is given by Adebo and Gabriela Medina-Meza (2020). Furthermore, a study of the mechanisms of the response of grains to fermentation shows that fermentation increases the: release of bound phenolics to their free forms; synthesis of new compounds; the breakdown of cereal cell walls; bioavailability of phenolic compounds such as such exopolysaccharides and vitamins; decarboxylases, hydrolases, reductases, esterases, β-glucosidase enzyme activities and metabolic activities of fermenting microorganisms (Adebo and Gabriela Medina-Meza, 2020; Gan et al., 2016; Verni et al., 2019). However, according to the same authors, the adverse effects of fermentation include reducing phenolic acid extractability; a reduction in the hydrolysis of some bioactive compounds, the degradation of phenolic acids by some microbial enzymes, and a decrease in binding of phenolic acids with other constituents. Although these effects appear to be dependent on many factors including the grain and fermentation organisms among others, it is clear that the health benefits of this process by far outweigh the negative effects and as such, has survived for centuries in many cultures.

5 Pests and diseases in cereal grains

The use of synthetic fertilizers has increased in agriculture over the years to increase yield to meet growing population demand. Also, due to persistent pest and disease resistance, there has been an increase in the use of synthetic pesticides and herbicides. These chemicals that are constantly being introduced negatively impact the environment and climate.

Ecosystems are constantly being changed the world over resulting in high biodiversity losses. The continued usage of synthetic chemicals has also led to elevated contamination of soils and crops by heavy metals and these eventually end up in the food chain. In fact, it is reported that agricultural fertilizers entering coastal ecosystems have played a large role in the production of more than 400 ocean dead zones (UN/SDG, 2019). According to the same report, more than a million fauna and flora species are threatened with extinction mainly due to human activities and pollution is one of the major culprits. It is, therefore, no surprise that numerous studies are increasingly focusing on alternative, less aggressive, and environmentally friendly methods of dealing with pests and diseases. As global temperatures continue to increase, notorious pests find the conditions extremely suitable for breeding and therefore their proliferation. When pests increase, the domino effect is an increase in pesticide use especially on commercial farms where farmers are more concerned about turning a profit. The current global loss of crops to pests is at 45% and this costs economies billions of USD around the world in losses (Sharma et al., 2019). The most severe losses are felt by the middle to low-income countries. The global pesticide usage is currently 3.5 million tons with China, followed by the United States and Argentina being the major users (Delcour et al., 2015). Fungicides account for 18% of the total pesticides globally used today (Sharma et al., 2019). In Africa, South Africa is a major user of pesticides, with over 3000 pesticides registered for use and having imported over $170 million worth of pesticides in 2006 alone, a figure which is now far beyond this (Dabrowski, 2015; Quinn et al., 2011). This is because the South African agricultural sector contributes about 12% to the GDP and employs 8% of the formal workforce. The annual loss of close to 13 million hectares of forests for monoculture further increases pests and destroys indigenous ecosystems (UNDP, 2021). The extensive use of synthetic pesticides leads to water, soil, and air pollution and ultimately causes ecosystem damage due to their biomagnification and persistent nature (Sharma et al., 2019). This has led to the European Union banning up to 50% of crop protection chemical groups because of environmental and health concerns (EU, 2021). Pests and diseases are economically important since they determine the yield and therefore play a large food and nutrition security role. Hundreds of crop pests and diseases have been recorded, however, not all of them are of economic significance. Table 4 shows some pests and diseases of economic importance. Pests can be defoliators, such as grasshoppers and locusts,

TABLE 4 Some common pests and diseases-affecting cereal grains.

Pests		Diseases	
Biological name	**Common name**	**Pathogen**	**Common disease name**
Maize[a,b]			
Agrotis spp.	Cutworms	*Aspergillus, Diplodia, Colletotrichum, Pythium, Fusarium* spp.	Stalk and ear rots
Arachnodima spp.	Click beetle	*Aureobasidium* spp.	Eyespot, brown spot
Atherigona spp.	Rice seedling fly	*Harpophora* spp.	Late wilt of maize
Belonolaimus spp.	Sting nematodes	*Helminthosporium* spp.	Leaf blight
Buphonella spp.	Maize rootworms	*Puccinia* spp.	Maize rust
Busseola, Zeadiatraea, Diatraea, Elasmopalpus, Chilo, Sesamia, Ostrinia, Eldana, Nezara spp.	Maize stock borer	*Sclerospora, Sclerophthora, Peronosclerospora* spp.	Downy mildews
Cicadulina spp.	Leaf hoppers	*Setosphaeria* spp.	Northern leaf blight
Conogethes spp.-*Larvae*	Yellow peach moth	*Ustilago* spp.	Common smut, boil smut, blister smut
Forficula auricularia	Black earwig		
Frankliniella spp.	Maize thrips		
Gonocephalum spp.	Ground beetles		
Helicoverpa spp.	Bollworm		
Heteronychus spp.	White grubs		

TABLE 4 Some common pests and diseases-affecting cereal grains—cont'd

Pests		Diseases	
Biological name	**Common name**	**Pathogen**	**Common disease name**
Lotris spp.	Spittle bugs		
Macrotermes spp.	Termites		
Meloidogyne spp.	Root knot nematodes		
Mussidia spp.	Ear borer		
Odontotermes spp.	Termites		
Orthoptera, Oxya spp.	Locusts and grasshoppers		
Paratrichodorus spp.	Stubby root nematodes		
Poophilus spp.	Spittle bugs		
Pratylenchus spp.	Root-lesion nematodes		
Prostephanus truncates	Larger grain borer		
Rhopalosiphum maidis	Maize aphid		
Schizaphis graminum	Wheat aphid		
Sitophilus spp.	Weevils		
Spodoptera spp.	Army worms		
Tenebrionidae spp.	Darkling beetle		
Thaumatotibia spp.-*Larvae*	False codling moth		
Wheat[c,d]			
Anguina tritici	Seed gall nematode	*Alrernaria, Cladosporium, Stemphylium, Epicoccum* spp.	Black molds (sooty molds)
Cephus cinctus	Sawfly	*Alternaria triticina*	Alternaria leaf blight
Oulema melanopa	Cereal leaf beetle	*Alternaria, Helminthosporium,* and *Fusarium* spp.	Black point
Diuraphis spp.	Russian wheat aphid	*Calonectria nivalis*	Fusarium leaf blotch
Heterodera avenae	Cereal cyst nematode	*Claviceps purpurea*	Ergot
Mayetiola destructor	Hessian fly	*Cochliobolus sativus*	Helminthosporium leaf blotch
Meloidogyne spp.	Root knot nematode	*Corticum rolfsii*	Sclerotium wilt (southern blight)
Meromyza americana	Wheat stem maggot	*Corynebacterium tritici*	Bacterial spike blight (yellow ear rot)
Metopolophium spp.	Rose-grain aphid	*Erysiphe grarninis*	Powdery mildew

Continued

TABLE 4 Some common pests and diseases-affecting cereal grains—cont'd

Pests		Diseases	
Biological name	**Common name**	**Pathogen**	**Common disease name**
Rhopalosiphum spp.	Bird cherry-oat aphid	*Fusarium* spp.	Scab (head blight)
Schizaphis spp.	Bugs	*Gaeumannomyces graminis*	Take-all
		Helminthosporium, Fusarium, and *Pythiurn* spp.	Common root rot, foot rot, and crown rot
Sitobion spp.	English grain aphid	*Pseudocercosporella herpotrichoides*	Eyespot (straw breaker)
Somaticus, Gonocephalum spp.	Wireworms	*Pseudomonas syringae*	Basal glume rot and bacterial leaf blight
		Puccinia spp.	Rusts
Spodoptera spp.	Armyworms, cutworms	*Pyrenophora trichostorna*	Tan spot
Gryllotalpa spp.	Crickets	*Rhizoctonia solani*	Sharp eyespot and rhizoctonia root rot
Scirpophaga spp.	Borers	*Sclerophthora rnacrospora*	Downy mildew
		Septoria spp.	Septoria diseases
		Tilletia spp.	Bunts
		Urocystis, Ustilago spp.	Smuts
		Xanthornonas spp.	Bacterial black chaff and bacterial stripe
Rice[e,f]			
Brevennia rehi	Rice mealy bugs	*Cercospora oryzae*	Narrow leaf spot (Cercospora leaf spot)
Gryllotalpa orientalis	Mole cricket	*Cochliobolus miyabeanus*	Brown spot
Leptocorisa oratorius F. and *Leptocorisa acuta Thunberg*	Rice bug	*Fusarium moniliforme*	Bakanae
Nephotettix spp., *Recilia dorsalis, Nilaparvata lugens, Laodelphax striatellus, Sogatella furcifera*	Leafhoppers & plant hoppers	*Magnaporthe grisea, Pyricularia grisea*	Rice blast
Orseolia oryzae	Rice gall midge	*Magnaporthe salvinii*	Stem rot
Paraponyx stagnalis Stagnalis (Lepidoptera: *Pyralidae) Nymphula depunctalis (Guenee)*	Rice case worm	*Microdochium oryzae*	Leaf scald
Scirpophaga incertulas, Chilo suppressalis, Scirpophaga innotata	Stem borers	*Rhizoctonia solani*	Sheath blight
	Rats	Rice grassy stunt virus (RGSV)	Grassy stunt
	Snails	Rice tungro bacilliform virus (RTBV)	Tungro
		Ustilaginoidea virens	False smut
		Xanthomonas oryzae	Bacterial leaf streak
		X. oryzae pv. *oryzae*	Rice Bacterial blight

TABLE 4 Some common pests and diseases-affecting cereal grains—cont'd

Pests		Diseases	
Biological name	**Common name**	**Pathogen**	**Common disease name**
Sorghum[g,h]			
Agrostis spp.	Cutworms	*Ascochyta sorghi*	Rough spot
Blissus leucopterus	Chinch bug	*Bipolaris sorgicola*	Target leaf spot
Conogethes punctiferalis	Yellow peach moth	*Cercospora sorghi*	Gray leaf spot
Cryptoblabes adoceta	Sorghum head caterpillar	*Colletotrichum graminicola*	Anthracnose
Gonocephalum spp.	Wireworms	*Fusarium, Curvularia, Alternaria, Aspergillus, Phoma* spp.	Head mold/grain mold/head blight
Helicoverpa armigera	Bollworm	*Gloeocercospora sorghi*	Zonate leaf spot
Helicoverpa zea,	Corn earworm	*Macrophomina phaseolina*	Charcoal rot
Nala lividipes	Black field earwigs	*Peronosclerospora sorghi*	Downy mildew
Nola sorghiella	Sorghum webworm	*Pseudomonas syringae* pv. *syringae*	Bacterial leaf spot
Nysius vinitor	Rutherglen bug (RGB)	*Puccinia purpurea*	Rust
Phyllophaga spp.	White grub	*Ramulispora sorghi*	Sooty stripe
Rhophalosiphum maidis	Corn aphid	*Sclerophthora macrospora*	Crazy top
Spodoptera frugiperda	Fall armyworm	*Sphacelia sorghi*	Ergot or sugary disease
Stenodiplosis sorghicola, Contarinia sorghicola	Sorghum midge	*Sphacelotheca, Sporisorium* spp., *Tolyposporium* spp.	Smuts
Oats[i]			
Aeolus spp.	Wireworms	Barley yellow dwarf virus (BYDV)	Barley yellow dwarf
Agrotis spp.	Cutworm	*Colletotrichum graminicola*	Anthracnose
Balaustium spp.	Balaustium mite	*Erysiphe graminis*	Powdery mildew
Desiantha spp.	Desiantha weevil	*Fusarium* spp.	Scab
Euschistus spp.	Stinkbugs	*Pseudomonas coronafaciens*	Halo blight
Melolontha spp.	Cockchafer	*Puccinia coronata*	Crown rust
Mythimna unipunctata, Spodoptera praefica	Armyworms	*Puccinia graminis*	Stem rust
Orthoptera	Locusts	*Pyrenophora chaetomioides*	Pyrenophora leaf blotch
Rhopalosuphum, Diuraphis, Sitobion spp.	Aphids	*Septoria avenae*	Septoria blotch
Sminthurus viridis	Lucerne flea	*Ustilago avenae*	Loose smut
Rye[j,k]			
Aeolus, Anchastus, Melanotus, Limonius spp.	Wireworms	Barley yellow dwarf virus (BYDV)	Yellow dwarf virus

Continued

TABLE 4 Some common pests and diseases-affecting cereal grains—cont'd

Pests		Diseases	
Biological name	**Common name**	**Pathogen**	**Common disease name**
Blumeria graminis	Powdery mildew	*Claviceps purpurea*	Ergot
Mythimna, Spodoptera spp.	Armyworms	*Colletotrichum graminicola*	Anthracnose
Rhopalosuphum, Diuraphis, Sitobion spp.	Aphids	*Drechslera teres*	Net blotch
		Erysiphe graminis	Powdery mildew
		Fusarium spp.	Crown rot and Fusarium head blight
		Puccinia spp.	Rust
		Pyrenophora tritici-repentis	Yellow spot
		Rhizoctonia solani	Rhizoctonia root rot
		Rhynchosporium secalis	Scald
		Ustilago, Tilletia spp.	Smuts
		Xanthomonas translucens	Bacterial blight
Barley[l,m]			
Aeolus, Anchastus, Melanotus, Limonius spp.	Wireworms	Barley yellow dwarf virus (BYDV)	Barley yellow dwarf
Agrotis spp.	Cutworms	*Bipolaris, Cochliobolus, Fusarium* spp.	Common root rot
Chlaraps spp.	Gout fly	*Claviceps purpurea*	Ergot
Euschistus spp.	Stinkbugs	*Fusarium graminearum*	Fusarium head blight (FHB or scab)
Mythimna, Spodoptera spp.	Armyworms	*Pseodocercosporella herpotrichoides*	Eyespot (foot rot)
Orthoptera, Oxya spp.	Locusts and grasshoppers	*Pseudomonas syringae*	Basal glume rot
Rhopalosuphum, Diuraphis, Sitobion spp.	Aphids	*Pyrenophora graminea*	Barley stripe
Rhynchosporium secalis	Leaf scald	*Pyrenophora teres*	Net blotch
Tipula species	Leather-jackets	*Sclerophthora, Blumeria* spp.	Mildews
Trionymus haancheni	Barley mealybug (Haanchen mealybug)	*Stagonospora avenae*	Stagonospora leaf blotch
–	Slugs	*Ustilago* spp.	Smuts
		Xanthomonas spp.	Bacterial blight
Millets[n]			
Acigona ignefusalis	Millet stem borer	*Claviceps* spp.	Ergot
Atherigona spp.	Flies	*Colletotrichum graminicola*	Anthracnose
Blissus leucopterus	Chinch bug	*Drechslera nodulosum, Cochliobolus setariae, Cercospora* spp.	Helminthosporium leaf spot
Geromyia penniseti	Grain midge	*Ephelis oryzae*	Udbatta

TABLE 4 Some common pests and diseases-affecting cereal grains—cont'd

Pests		Diseases	
Biological name	Common name	Pathogen	Common disease name
Heiliocheilus albipunctella	Head miner	*Fusarium* spp., *Curvularia lunata, Alternaria alternate, Phoma sorghina, Bipolaris* spp., *Aspergillus* spp.	Grain mold
Holotrichia consanguinea	White grub	*Helminthosporium nodulosum*	Seedling and leaf blight
Orthoptera, Oxya spp.	Locusts and grasshoppers	*Puccinia substriata*	Rust
Psalydolytta spp.	Beetles	*Pyricularia grisea*	Blast
Schizaphis graminum	Green bug	*Sarocladium oryzae*	Sheath rot
Sesamia inferens	Pink stem borer	*Sclerospora graminicola*	Downy mildew
		Sclerospora, Peronosclerospora, Sclerospora spp.	Mildews
		Sporisorium, Tolyposporium, Melanopsichium, Ustilago spp.	Smuts

[a] *Rahmawati et al. (2020).*
[b] *Plant Village (2021a).*
[c] *Plant Village (2021b).*
[d] *CIMMYT (n.d.).*
[e] *Plant Village (2021c).*
[f] *Iqbal (2020).*
[g] *Plant Village (2021d).*
[h] *Spurlock et al. (2018).*
[i] *Plant Village (2021e).*
[j] *Plant Village (2021f).*
[k] *GRDC (2018a).*
[l] *Plant Village (2021g).*
[m] *GRDC (2018b).*
[n] *Gahukar and Reddy (2019).*

sap-sucking such as aphids, and borers such as the stem borers which are normally larvae. Nematodes on the other hand attack below-ground plant parts and sometimes stem and leaves leading to massive yield losses. Diseases are normally caused by bacteria, fungi, and viruses although some genetic deformities may lead to losses in yield. However, some grain crops are more resilient to some pests and diseases in comparison to others and this is normally true for crops that are indigenous to particular regions (Bvenura et al., 2019). These crops would have acquired resistance over time before their eventual domestication millennia ago.

6 Technology application and agriculture

The Covid-19 pandemic that left the whole world at a near standstill for a while has changed our lives forever. Various countries imposed a state of emergencies and instituted lockdowns as well as social distancing protocols. Agricultural exports and imports were severely affected due to restrictions and some commercial farmers incurred major losses as they had to destroy their crops. The world was not prepared for this catastrophe. As various countries ease lockdowns and social distancing measures, the agricultural sector is also slowly recovering. The decline in the number of young people taking up farming as a profession and unexpected events such as pandemics should now drive the world into re-thinking farming practices and agriculture as a whole. Besides food and nutrition security, agriculture plays significant role in economies across the world. For example, Statista (2020b) indicate that in South Africa, agriculture accounts for 27.8% of the GDP; 0.61% in the United Kingdom; 1.18% in the United States, and 15% in India. China has the largest agricultural economy in the world but this sector contributes only 10% to its GDP. Agriculture is therefore very important in both agriculture and non-agriculture-based economies. It is documented that an upsurge in the second industrial revolution rendered many jobs obsolete and therefore pushed unemployment up. The current fourth revolution will also bring its own casualties, but new opportunities will be opened as well. Non-the-less, agricultural production must not cease. The fourth industrial revolution which grips the world is finding applications everywhere including in agriculture. Sectors that do not adapt may not be able to survive. One of the facets of this revolution is the widespread adoption and use of artificial intelligence (AI). This term was coined in 1956 and numerous definitions and applications are available. In this chapter, we define AI as the ability of a machine to perform human-like tasks, its ability to learn as well as adjust to new inputs/commands (IBM, 2020). Although this intelligence has been in use since the development of the digital computer in the 1940s, its popularity is gaining momentum in the agriculture sector. The applications of this technology are enormous and never-ending for both field and controlled environment agriculture. AI maximizes or improves efficiency, uses predictive models to solve current and/or future problems and challenges, and in some cases saves as a replacement for labor. In summary, AI applications have found their way into agricultural robots, crop and soil health monitoring, and predictive analytics (Talaviya et al., 2020). Robots perform some essential tasks such as planting, irrigation, fumigation, weeding, or harvesting; and are more efficient and faster than humans. Crop and soil health monitoring is concerned with the use of some specific algorithms and the use of drone (Unmanned Ethereal Frameworks (UAS) or Unmanned aeronautical vehicles (UAVs)) technology; data capturing to identify weeds, pests, and diseases among others (Mogili and Deepak, 2018). Predictive analytics use some predictive models to compute and analyze changes in climate or the environment on crop quality and yield. Companies such as Bosch have developed some real-time diagnostic tools for glasshouse crop cultivation. The technology that is called Greenhouse Guardian can predict the risk of disease infection using ambient temperatures and humidity, which it computes and processes and alerts the farmer in real-time. This technology has improved yields by up to 15%. However, grain crops are normally cultivated in the field and this technology would then need to be modified to suit field conditions.

Reports indicate that over 250 weeds have become resistant to herbicides and this costs the United States over $43 billion in maize and soybean production alone (WSSA, 2020). However, Blue River Technology reportedly uses drones in the precision application of herbicides on individual weeds on the field. Precision spraying means less herbicide application and reduced resistance of weeds to herbicides. The environmental impacts are enormous under the backdrop that the United States alone uses over four billion kilograms of herbicides per year. This technology has the potential to be modified to target fungi and pests as well.

But, in Berlin a company called PEAT has developed technology that uses algorithms; data analytics, and smart phone camera technology to identify soil nutrient deficiencies and potential defects. This data is then used to link the leaf matter images with potential pests, diseases, and soil defects after which the users are provided with possible solutions to the potential or existing threat. All these companies are using this technology to improve efficiency and therefore improve on quality and yield of crops. Data input can be modified to fit particular crops. The use of this technology in the production of the grains that feed the world could drastically improve grain quality and yield and therefore improve food and nutrition security.

The substitution of human labor with intelligent machines has for long been a subject of contention especially considering a continued rise in unemployment. However, in some countries such as Japan that are faced with aging populations, intelligent machines may be the answer to labor shortages. The pros and cons are often debatable, and yet it is certain that the third industrial revolution will not stop. Countries of the world will need to eventually adapt.

7 Conclusion, opportunities and future challenges

The future of the world's population that continues to grow depends on the increased quality and yield of the grains that feed the cereal grains. These crops feed the world. Plant breeders, therefore, need to continue their work of developing short-season, drought, pest, and disease-resilient crops. Less use of herbicides, fungicides, and pesticides will contribute immensely to a better environment and biodiversity conservation. Also, attention needs to be shifted to small grains such as sorghum and millet as they better adapt to adverse conditions. New cultivars well adapted to saline water need to be developed so that sea water can be used as an irrigation option. The nutritional and polyphenolic contents of these crops are more elevated in the neglected and underutilized small grains such as sorghum, millets, and rye. These crops are drought, pest, and disease-resilient, especially in regions that are prone to adverse weather conditions. Their revitalization and reintroduction into the diet could help alleviate some food and nutrition security concerns the world is facing. Governments need to intervene and work with extension workers to foster and implement the idea of cultivating these crops as well as their consumption. The fourth industrial revolution that puts technology at the center of the development is slowly gaining momentum in the agricultural sector as well. This is through the adoption and use of artificial intelligence. Numerous strides have been made in precision farming, the use of drones, computer programs, smart phones, and cameras to aid farming. The future of farming clearly lies in the use of these technologies. The decline in new young farmers and this new revolution is perhaps what this sector needs? Aging societies may not be able to cope with labor-intensive farming practices but may do well with technology-based solutions that require minimal labor and supervision but with high-quality crops and yields. Young societies will need to adapt and find new employment opportunities in AI-based agriculture. This new technology could see more young people take up farming because it makes it attractive and easier to manage. Future grain crops will be of better quality and higher yield and will clearly be produced using artificial intelligence mechanisms.

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