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WATER SCARCITY IN AGRICULTURE: THE GREATEST THREAT TO GLOBAL FOOD SECURITY

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Freshwater is a vital abiotic resource for ecosystem health and human survival on Earth, as it is essential for people's lives, agriculture and manufacturing processes (Bayart et al, 2010; Layani et al., 2021). Freshwater is renewed through the water cycle; however, excessive use can cause shortages in the supply (Motoshita et al., 2011). Freshwater is the natural resource most extracted from the earth, considering the annual withdrawal is over four trillion m3; with such a large quantity due to population growth, rising living standards and expansion of irrigated agriculture (Pfister et al., 2009; Levintal et al., 2023). An increasing global demand for fresh water to produce foods and livestock feeds, and a wide range of other commodities, to support industrial processes, and to sustain urban and rural populations' needs (Hoekstra et al., 2012), is resulting in groundwater overdraft in all regions affected by a scarcity of surface water (Levintal et al., 2023).

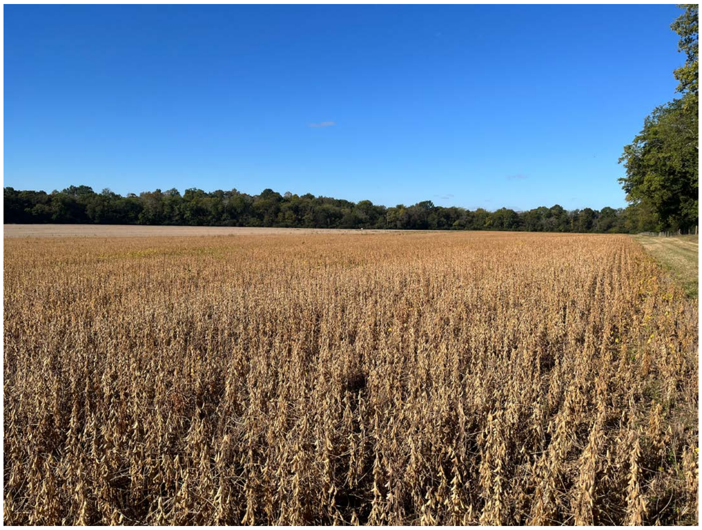

Figure 1. *Soybeans ready to harvest.*

The scarcity of freshwater is increasing rapidly in many regions of the world and has become one of the most critical and frequently debated concerns from societal survival perspectives (Bayart et al., 2010; Hoekstra et al., 2012). Even though it contributes to human health and prosperity, freshwater consumption is one of the main environmental aspects for which agricultural production is responsible, along with land use, fossil fuel consumption and the emission of greenhouse gases (GHGs) (Mekonnen and Gerbens-Leenes, 2020). In many countries around the globe, human health/well-being along with numerous natural ecosystems are being seriously affected by changes in the global water cycle that is resulting from climate change and water-intensive human activities (Pfister et al., 2009).

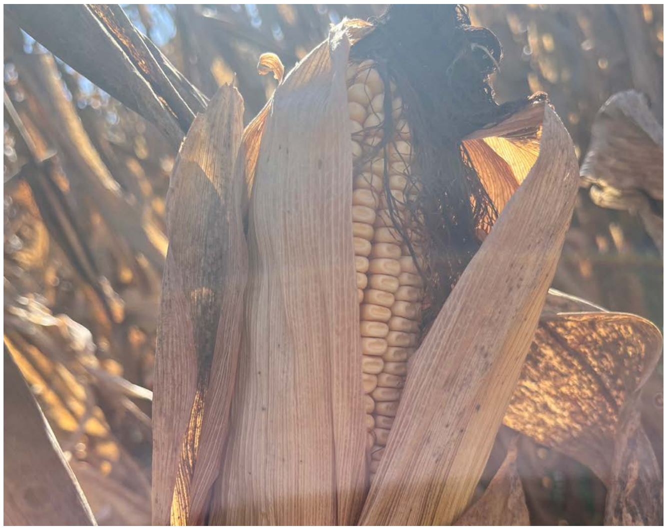

Figure 2. *Corn ready to harvest.*

The hard truth is that, without water, there is no food. And without food, there would soon be no people….it is that simple. Fresh water supplies are facing increasing pressure globally from climate change and growing populations (Immerseel et al., 2020; Milly and Dunne, 2020). Water is a neglected, and often ignored, dependency whose scarcity threatens our ability to feed an ever-increasing global population. Many areas of the world currently face water scarcity (Alcamo et al., 1997; Liu et al., 2017) and the projected increase in global population suggests that increased food demand is expected in the future, with a direct effect on agricultural water usage (Mancosu et al., 2015). Furthermore, because of increased water insecurity and drought due to climate change, water use for irrigation is expected to increase, leading to potential conflicts and competition between agriculture and other sectors of the economy.

Global **food security depends on a resilient agricultural system**, which, in turn, depends on a consistent freshwater supply, whether from rainfall or irrigation.

Globally, agriculture is the largest consumer of water, accounting for approximately 70 percent of total water withdrawals (Johnson et al., 2001; FAO, 2011a). The poultry industry, like others, must act to use water wisely and as efficiently as possible. Live production of poultry on a global scale requires huge amounts of water, particularly in relation to production of feed grains like soybeans (Figure 1) and corn (Figure 2) which make up the majority of commercial poultry feeds. In addition, an average size poultry processing plant processing over 250,000 birds per day may use **3.8 to 7.6 M liters of water daily** (Tabler et al., 2023). Ensuring that sufficient water is available in the future will become increasingly challenging as various sectors of the economy compete for what freshwater is available. The use of water markets can increase water use efficiency in agriculture and is pivotal to ensuring water and food security (Matchaya et al., 2019; Nwokediegwu et al., 2024).

Agricultural production is responsible for over 70 percent of global freshwater water withdrawal volume, while the industrial and domestic sectors are responsible for approximately 22 percent and 8 percent, respectively (Aivazidou et al., 2016). The increase in water demand and the degradation of freshwater due to urbanization, agricultural intensification, and climate change have become major concerns, particularly in regions already under water stress conditions (Saraiva et al., 2020a; Saraiva et al., 2020b). More than 25 percent of the world's population and over 40 percent of global agricultural production heavily rely upon unsustainable groundwater extraction (Levintal et al., 2023). This highlights the need for transitioning to more sustainable agricultural practices (Ingrao et al., 2023).

With a rapidly increasing population and climate change altering precipitation patterns, pressures on food production systems are expected to increase in the coming decades. Although management intensification has led to more productive systems, some of these gains are at the expense of the environment, including GHG emissions, and the net benefits of some of these strategies are based on environments that are not resource limited, particularly with regards to the availability of water (Fitton et al., 2019). Livestock production, which depends heavily on production and yields of row crops (such as corn and soybeans), which in turn depend heavily on adequate water supply and availability, could be restrained from expansion, or perhaps hindered from maintaining current production levels by increased detrimental changes in water scarcity.

WATER SCARCITY

Water scarcity is one of the most pressing development challenges of our time. Today, 2.4 billion people live in water-stressed countries (Li, 2023). Many of these individuals are smallholder farmers who are already struggling to meet their daily needs for drinking water, nutritious food, and basic services such as hygiene and sanitation. Most at risk are women, indigenous peoples, migrants and refugees (Li, 2023). Competition for water is increasing around the globe, as water scarcity increasingly becomes a source of conflict. Freshwater resources per person have dropped 20 percent over the past two decades, while water availability and quality are deteriorating quickly due to decades of misuse, lack of coordinated management, over-extraction of groundwater, pollution and climate change (Li, 2023). Extreme weather events such as droughts and floods cause additional stress on ecosystems with serious consequences for global food production.

In the United States, drought and water scarcity are of a serious concern to the agriculture community. The agricultural sector contributes mightily to the US economy in many ways, from promoting food and energy security to providing jobs for millions of people in rural communities. In 2015, farms contributed $136.7 billion to the US economy and accounted for 2.6 billion jobs, with approximately half of farm revenue coming from livestock production. However, sustained drought and water shortages have considerable negative effects on crops and livestock, including reduced production, destruction of property, and livestock deaths and sell-offs. Drought ranks third among environmental phenomena associated with billion-dollar weather disasters since 1980, behind only tropical cyclones and severe storms (Drought.gov, 2024).

Water scarcity and food security are closely intertwined. Food security is defined in terms of food availability, access, utilization and stability, such that all people, at all times, have physical and economic access to sufficient quantities of safe and nutritious food that meets their dietary needs and food preferences. Water scarcity, however, affects not only the quantity, but also the quality, variety and seasonal availability of foods that can be produced and consumed (Michel, 2023). Therefore, on a global scale, water scarcity (e.g., droughts in grain-producing nations) may contribute to grain shortages that increase food insecurity for hundreds of millions of people in numerous countries. At the local household level, scarce or polluted water can prevent a family from growing a backyard garden, raising livestock, or preparing available foods and shifting their diets to less water-intensive but perhaps less nutritious foods.

Several major river systems throughout the world — including the Colorado, Ganges, Indus, Nile, Tigris-Euphrates and Yellow Rivers — currently have yearly water withdrawals nearly equal to or even exceeding long-term flow balances and ecosystems needs (Michel, 2023). In addition, underground aquifers currently supply one-third of all water use, providing half of all irrigation needs. However, withdrawals in many major aquifers surpass natural rates of replenishment, thereby lowering water tables and exhausting groundwater reserves. Examples include depletion of the Ogallala Aquifer beneath the Great Plains in the United States and the Mississippi River Valley Alluvial Aquifer in Mississippi.

Water scarcity has been a concern in developing countries for decades. However, water scarcity is rapidly becoming a major global issue (Beekman, 1998; Casani et al., 2005; Hoekstra, 2014; Liu et al., 2017) in both developed and developing countries. Shiklomanov (1998) estimated that the agricultural sector accounted for two-thirds of the total global water withdrawals and almost 90 percent of total global water consumption. Numerous factors, including climate change, population growth, increasing dietary shifts toward animal protein as developing nations become more affluent, irrigated agriculture, seawater intrusion and greater competition and demands for domestic and industrial water, all contribute to this worsening issue (Meneses et al., 2017).

Poultry's universal acceptability, high nutritional value and recognized health benefits have propelled it to the top position of animal protein in the world, accounting for 35 percent of global animal protein production according to FAO (2022). The continuing growth in global population and the recent African Swine Fever outbreak across various Asian and African countries has put additional pressure on the poultry industry to increase its capacity and output.

Water scarcity resulting from physical, economic or institutional constraints is currently a problem for one-third of the world's population (Molden et al., 2007). About 1.2 billion people suffer physical water scarcity, meaning they lack enough water to satisfy demand. Symptoms of physical water scarcity include severe environmental degradation, pollution, declining groundwater supplies and water allocations in which some groups win at the expense of others (International Water Management Institute (IWMI), 2007). Another 1.5 billion people are affected by economic water scarcity, where human and/or financial resources are likely insufficient to develop local water systems, even though the supply might be adequate if it could be exploited (Molden et al., 2007). Symptoms of economic water scarcity include scant infrastructure development, meaning there is little to no distribution system (supply lines, piping or canals) to get water to the people and where infrastructure does exist, the distribution of water may be inequitable.

Sub-Saharan Africa is one of many regions around the world facing water scarcity issues where the problem is particularly severe. This region is characterized by economic water scarcity and water development in the region could greatly assist in poverty reduction (IWMI, 2007; Matchaya et al., 2019). However, most governments fail to invest adequately in the maintenance of irrigation and drainage systems. Inadequate management and operation, along with failure to sufficiently maintain systems, results in the systems' declining performance and subsequent need for rehabilitation (World Bank, 2022). Institutional water scarcity can often be traced back to ill-adapted or poorly functioning institutions even in the presence of adequate water supplies. In this case, laws, rules and a more supportive organizational framework are key to mitigating water problems (Molden et al., 2007).

The rapid rise in global meat production is putting increased pressure on water resources. Livestock production is a very water-intensive agricultural operation, with about one-third of the total water that is utilized in global agricultural production assigned to animal production (El Sabry, 2023). In addition, from 1998 to 2008, water use in the food industry increased by approximately 40 percent and has continued to grow (Klemes et al., 2008; Meneses et al., 2017). For example, in conventional poultry processing systems, access to water is particularly critical for the cleaning, maintenance and disinfection of the processing areas, as well as in processing operations such as scalding, chilling and carcass washing (Micciche et al., 2018).

Water requirements have become limiting factors for economic growth in China and India (Klemes et al., 2008). Furthermore, in 2010, the United States alone used 1.1 trillion liters (L) of potable fresh water each day, or 3,000 L per capita each day (Maupin et al., 2014). While the water used for producing poultry is decreasing, the industry still consumes approximately 113 L of water for every kg of poultry (live weight) produced (Putman et al., 2017). The water footprint is a water metric measurement that has been used to accurately calculate water use in relation to final product output. It includes blue (surface and groundwater), green (rainwater), and gray (freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards) water sectors. According to Mekonnen and Hoekstra (2010; 2012), animal products have a larger water footprint per kg of product than crop products (Table 1). Much of this water footprint for animal products is related to growing rainfed and irrigated crops to produce food for the livestock.

Table 1. Water footprint of selected food products from vegetable and animal origin.

Water footprint (liters/kg) of product)

Food Item	Green	Blue	Grey	Total
Sugar crops	130	52	15	197
Vegetables	194	43	85	322
Starchy roots	327	16	43	387
Fruits	726	147	89	962
Cereals	1,232	228	184	1,644
Oil crops	2,023	220	121	2,364
Pulses	3,180	141	734	4,055
Nuts	7,016	1,367	680	9,063
Milk	863	86	72	1,020
Eggs	2,592	244	429	3,265
Chicken	3,545	313	467	4,325
Butter	4,695	465	393	5,553
Pork	4,907	459	622	5,988
Sheep/goat meat	8,253	457	53	8,763
Beef	14,414	550	451	15,415

Adapted from Mekonnen and Hoekstra (2012).

More than **80 percent of global agricultural land is rainfed**, thus only green water (rainfall) is consumed (IWMI, 2007). In addition, approximately 20 percent of the total cultivated land is irrigated with blue water and contributes 40 percent of the total food produced worldwide (World Bank, 2022). Irrigated agriculture is, on average, at least **twice as productive per unit of land as rainfed agriculture**, thereby allowing for more production intensification and crop diversification (World Bank, 2022). However, future demand for water by all sectors will require as much as **25 to 40 percent of water be reallocated** from lower to higher productivity activities, particularly in water stressed regions. In most cases, this **reallocation is expected to come from (and at the expense of) agriculture** due to its high share of water use (World Bank, 2022).

CLIMATE CHANGE AND WATER MANAGEMENT

Climate change is projected to **reduce average yields** over the next century for major US field crops — corn, soybeans, rice, sorghum, cotton, oats and silage — under both irrigated and dryland production systems (Marshall et al., 2015). While irrigation is widely viewed as an important adaptation to climate change, USDA Economic Research Service (ERS) simulation analysis projects that field crop acreage will decline because of climate change (rising temperatures, shifting rainfall patterns, etc.) throughout the current century (Marshall and Aillery, 2015) (Table 2).

Table 2. Percent changes in total U.S. production (average percent change)

	2040	2060	2080
Barley (bushels)	-.06	-3.5	**1.0**
Corn (bushels)	-8.7	-13.8	-16.2
Cotton (bales)	-6.1	-5.6	-5.9
Hay (dry tons)	-0.6	**2.7**	**4.2**
Oats (bushels)	-10.7	-16.1	-20.8
Rice (cwt)	-2.5	-4.2	-6.8
Silage (dry ton)	-9.5	-13.1	-14.4
Sorghum (bushels)	-5.4	-14.0	-17.0
Soybeans (bushels)	-8.8	-11.9	-14.3
Wheat (bushels)	**1.3**	**5.6**	**11.6**

Note: Percent changes in total US production include irrigated and dryland production, when averaged over future climate change scenarios and compared to reference production levels that assume no climate change. Source: Adapted from USDA, Economic Research Service.

The increasing global temperatures and more variable rainfall associated with climate change would also impact production as well as flock health and animal welfare (El Sabry et al., 2021; Abbas et al., 2022; Morgado et al., 2022). Heat alters birds' behavioral and physiological responses leading to decreases in production (Lara and Rostango, 2013), with implications for bird health and welfare both during growth and transport. Numerous factors affect the daily water requirement for poultry including age (Xin et al., 1994), housing conditions (temperature, lighting program, etc.), performance level and feed related factors (El Sabry et al., 2023). Water can also be used to provide evaporative cooling thus decreasing temperature within housing and increasing production (Tao and Xin, 2003).

Although several factors contribute to water scarcity, including global population growth, urbanization, water pollution and/or poor management of water resources, **climate change is the main threat to the sustainability of freshwater resources** (Arnell et al., 2011; UNICEF, 2021; Leal Filho et al., 2022). Water scarcity occurs when freshwater demand exceeds the available supply (Kummu et al., 2016). A small **3 percent of the world's water is freshwater**, but only 0.5 percent is useable. The remaining 2.5 percent is unavailable because it is locked up in the atmosphere and soil, polar ice caps and glaciers, or is highly polluted or lies too far beneath the earth's surface to be extracted at a reasonable cost. According to the FAO (2020), water scarcity primarily affects people in rural areas, with around 3.2 billion people currently living in water-stressed agricultural areas.

Water scarcity eventually leads to food insecurity because crops and livestock require water to survive and grow. The USDA ERS indicates that the number of food insecure people in 2022 was estimated at 1.3 billion, an increase of 118.7 million people from the ERS' 2021 estimate (Zereyesus and Cardell, 2022). Sub-Saharan Africa had the highest share of people who are food insecure at 51 percent, reflecting the effects of food price inflation for low-income populations across the region (Zereyesus and Cardell, 2022). Some countries have advanced faster than others in the progress made in the management of water in agriculture. Other countries facing water scarcity challenges may not have an incentive to act in a timely manner or lack the expertise and infrastructure to do so. However, failure to act in response to climate change will prove problematic in the future. Flexibility is going to be increasingly important for the future of agriculture. In addition, the ability of food systems to address food insecurity in the face of water scarcity presents a triple challenge of 1) ensuring food security and nutrition for a growing global population, 2) supporting the livelihoods of millions of people working in the food supply chain arena around the world, and 3) doing so in an environmentally sustainable manner that limits habitat loss and reduces anthropogenic GHG emissions (OECD, 2021). This challenge is made more daunting because, unfortunately, **water is rarely on the agenda** when food insecurity is discussed, despite its importance to food systems and its susceptibility to climate change.

FOOD WASTE AND WATER SCARCITY

We cannot expect to achieve sustainable food production if water resources are not properly managed. As increasing numbers of nations become more affluent and shift towards more nutritious and healthier diets, the effects on water usage will increase. Food items like meat, fruits and vegetables, either directly or indirectly, come with a large water footprint that must be considered and taken into account. In addition, something rarely discussed in the same context with water scarcity and climate change is food waste, but this issue must receive additional attention in the future. Globally, 30 to 50 percent of food is lost to waste (Gustavsson et al., 2011; Godfray et al., 2010). Food waste is also the waste of other resources, including the water that it took to produce that food. The FAO (2011b) reported that, globally, the water used to produce discarded food constituted 24 percent of the total water volume used for production. The causes of waste differ between high- and low-income countries. Most food waste in low-income countries occurs on-farm and in transporting and processing food. In high-income countries, most of the food waste occurs at the consumer level, such as retail stores, food services and at home (Rethinking Food Waste through Economics and Data, 2021), and very little is lost on-farm or in transportation or processing. Unfortunately, food waste at the consumer level in high-income countries is primarily associated with discarding usable food and the failure to consume food within the “best if used by” date, then disposing of the item once it passes the “use by” date, regardless of the food’s continued quality and edibility past that date.

In addition, Parfitt et al. (2010) indicated three global trends positioned to influence the rates of food waste. Urbanization and the contraction of the agricultural sector is the first trend. Approximately 55 percent of the world’s population now lives in urban areas, and that number is expected to grow to 68 percent by 2050 (United Nations, 2018). This will lengthen food supply chains and place food at an increased risk of waste due to added exposure during transportation, processing and at-home consumption. The second trend is the diet transition mentioned earlier. As incomes rise in many low-income countries, these higher incomes are often accompanied by increased consumption of meat, dairy, fish, and fresh fruits and vegetables. These foods tend to have shorter shelf lives than grains and starchy alternatives and are more prone to increased waste. The final trend is an increase in international trade. Global trade results in increased imports that can undercut domestic equivalents in many low-income countries (Brown et al., 2015). Imports are then marketed in supermarkets that dispose of large quantities of edible food simply for reasons of appearance, despite its continued quality and edibility. Increasing food production must be a high priority going forward to feed an increasing global population. However, efforts to save the 30 to 50 percent of food that is currently wasted must also be a high priority. Decreasing food waste is critical to maintaining an affordable and sustainable food supply, not to mention improving water management programs and addressing global water scarcity.

CAN THE POULTRY INDUSTRY PLAY A ROLE?

Yes, and work is underway to do that on multiple fronts from divergent selection (genetic selection of birds that naturally drink less water than their counterparts) (Hiltz, 2021) to new methods of cooling birds that use 60-70 percent less cooling water than current cool cell systems. Williams and colleagues (2013) characterized water consumption of flocks grown in 1991, 2000-2001 and 2010-2011. These researchers utilized large-scale inline flow meters to measure water intake in commercial style housing and observed differences between all growth periods with respect to water intake (liters) per 1,000 birds. During the 1991, 2000-2001 and 2010-2011 timeframes, water intake per 1,000 birds were as follows: 140.33 liters/1,000 birds, 160.54 liters/1,000 birds, and 190.48 liters/1,000 birds respectively. Water-to-feed ratios were calculated as 1.90, 1.98 and 2.02, respectively (Williams et al., 2013). In recent years, multiple researchers have reported impressive cooling water savings using a sprinkler cooling system (Figures 3 and 4) for cooling broilers in hot weather with equal or enhanced bird performance compared to using a cool cell system (Liang et al., 2020; Dunlop and McAuley, 2021; Moon et al., 2023). Water is used to 1) grow crops (mainly corn and soybeans) for chicken feed, 2) for birds to drink on the farm, 3) to cool birds during warmer temperatures, and 4) to process birds and clean and sanitize equipment at the processing plant. Efforts to improve efficiency and reduce water usage in all these areas are currently underway.

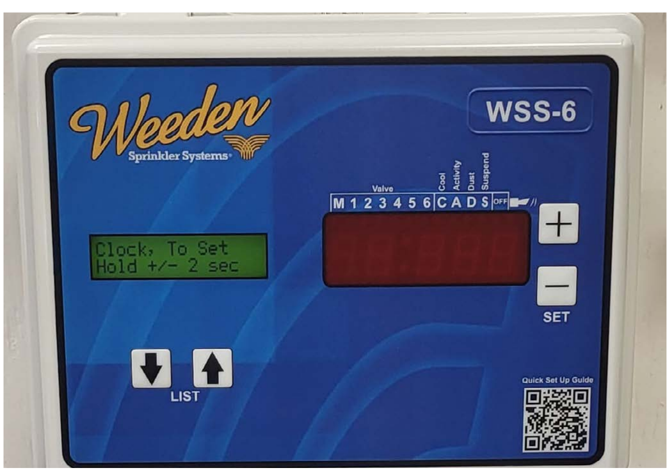

Figure 3. *Sprinkler Cooling Controller.*

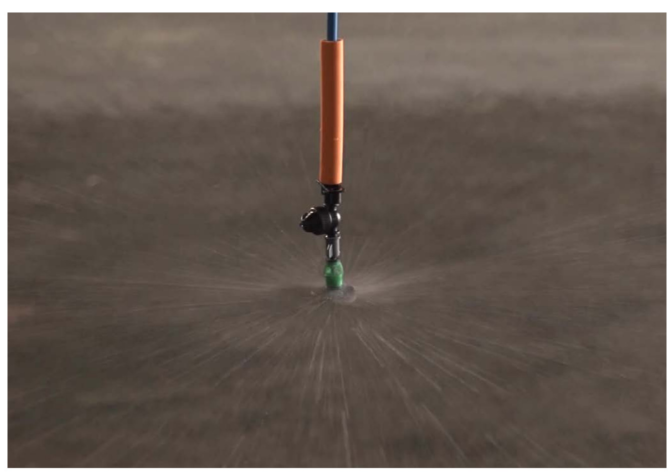

Figure 4. *Activated sprinkler in operation.*

To support the future population growth, expected to reach approximately 10 billion by 2050, it is projected that the current food supply must increase by 60 percent (Alexandratos and Bruinsma, 2012). This increase in food supply will ultimately result in a concurrent increase in freshwater demand. Total water consumption is expected to increase 20 to 30 percent by 2050 (Boretti and Rosa, 2019). Cereal grains for animal feed/production account for most of the water use in agriculture followed by drinking water for livestock. Of the livestock species characterized by Mekonnen and Hoekstra (2016), poultry is the most efficient followed by pork then beef. Over the past several decades, poultry has proven to be one of the most efficient and versatile edible protein sources in both water secure and water stressed environments. Broilers have the lowest water footprint of any animal meat protein and eggs are one of the most nutritious and efficient animal products available (Mekonnen and Hoekstra, 2012). Poultry is currently raised by 80 percent of households in developing countries (FAO, 2017) and considering the efficiencies of both the broiler and table egg industries, this number is only expected to grow in the future. In fact, since 1960 the global per capita consumption of eggs has doubled, while poultry meat consumption has increased fivefold (FAO, 2017), suggesting that poultry products will continue to play a substantial role in the global protein supply for years to come. With the anticipated population growth, this will likely be especially true in developing countries, most of which are currently either completely or partly water stressed (Hiltz, 2021).

Poultry processing practices also offer water conservation opportunities. A change in stunning method from water stunning to gas or dry stunning techniques has potential to considerably reduce water use. The scalding and plucking stages at the processing plant represent half of the total water consumption used during the processing process (Amorim et al., 2007). Reducing the size of the scalding tank while respecting the time/temperature requirement or switching from water immersion in hot water to spraying hot water and steam may offer water savings potential (Bailone et al., 2022). The chilling stage, where the carcasses are usually immersed in cold water to rapidly bring the carcass temperature down to 7 degrees C (44 degrees F) is another water saving potential. Air chilling, where the birds go through a tunnel for air refrigeration, with or without water spraying, is becoming a more common alternative to water chilling. In addition, water used during scalding and chilling can be re-purposed in most poultry processing plants and used during cleanup to flush items such as offal and feathers (Valta et al., 2016).

SUMMARY

Water scarcity has a huge impact on global food production. Global food security depends on a consistent freshwater supply. Agricultural production is responsible for over 70 percent of global freshwater water withdrawal volume. This highlights the important role of agriculture in water conservation efforts. The poultry industry is a major player in the agriculture sector, requiring huge amounts of water, particularly in relation to production of corn and soybeans which make up the majority of commercial poultry feeds. In addition, an average size poultry processing plant may use 3.8 to 7.6 M liters of water daily for processing and cleaning operations. Food waste is another serious concern, with 30 to 50 percent of the food produced on a global scale lost to waste, and the water used to produce this discarded food making up 24 percent of the total water volume used for production. Food waste and the squandered water associated with it is especially troubling given the fact that this waste occurs amidst ongoing food shortages and devastating famines around the world. We are often too short-sighted in how we address complicated issues and seek the easy way out, and water scarcity is a complicated issue. It will require a long-term, sustainable, systematic approach, not a short-term quick fix, involving all stakeholders in the food chain, from farmers to the end consumers, to address the water scarcity issue we face. Poultry production can play a huge role in addressing water scarcity, especially in developing countries.

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