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An Outlook on Processing Sweet Corn Production from the Last Three Decades (1990s–2010s)

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Abstract. **Sweet corn (*Zea mays* L. var. *rugosa* or *saccharate*), consumed both fresh and processed (primarily canned or frozen), is a popular vegetable crop in the United States. Recent nationwide data have reported declining trends in sweet corn production, which poses serious challenges for the US processing sweet corn producers. Here, we evaluated a processing sweet corn dataset that represents nearly 3 decades (1992–2018) of commercial production in the Upper Midwest and the Pacific Northwest regions in an attempt to understand national trends in US processing sweet corn. The objectives of this study were to (a) quantify trends in processing sweet corn production (harvest area and total green ear mass production); (b) understand trends in planting date, plant population density, and hybrid lifespan; and (c) estimate interannual yield deviations in green ear mass yield. Our results reveal declining trends in sweet corn hectares, particularly in rainfed production systems of the Upper Midwest. For the past 3 decades of commercial sweet corn production, plant population density and planting dates used by vegetable processors have remained unchanged. Our analysis revealed a large range (1 to 20 years) in hybrid lifespan, which can be attributed to wide differences in hybrid yield stability across the diverse production environments in the United States. Rainfed production systems are becoming scarcer because sweet corn yields under rainfed conditions are particularly susceptible to severe weather, including heat and drought stress events. Future research is needed to understand sweet corn yields as a function of climatic and nonclimatic variables to stabilize the industry, particularly given predictions of a future with more frequent weather extremes.**

The United States is the largest producer, consumer, and exporter of sweet corn (*Zea mays* L. var. *rugosa* or *saccharate*), globally (Food and Agriculture Organization of the United Nations 2021). Sweet corn in the United States is grown for both fresh market and processing. Processing sweet corn is grown under a contract, wherein vegetable processors make decisions on major aspects of crop production including hybrid selection, plant density, and planting date. Recent National Agricultural Statistics Service (NASS) findings reveal downward trends in processing sweet corn production. For instance, total area planted of processing sweet corn and green ear mass production has decreased by 33% and 24%, respectively, over the past 2 decades [US Department of Agriculture (USDA)–NASS 2021]. Such trends suggest the US processing sweet corn industry is facing some serious challenges.

Sweet corn for processing is concentrated in the Upper Midwest (Illinois, Minnesota, and Wisconsin) and Pacific Northwest (Oregon and Washington). The Upper Midwest region uses a combination of rainfed and irrigated production systems, whereas the Pacific Northwest is entirely irrigated. Agronomic decision-making in the vegetable processing industry is delineated by production area, which is defined as a collection of fields within a limited geographic area (usually several counties) often located near a processing facility. Historically, each production area has its own field advising team, comprised of agronomists, research technicians and field supervisors. Such recommendation domains for US sweet corn production have economic merit for the industry, as evidenced by recent research on optimizing plant population density (Dhaliwal and Williams 2020).

Field-level observational data can provide valuable insights into production dynamics at scales finer than state-level data to better understand national trends (Assefa et al. 2017; Edreira et al. 2020; Lobell et al. 2014). The objectives of this report were to conduct an exploratory analysis to (a) quantify trends in processing sweet corn production (harvest area and total green ear mass production); (b) understand trends in planting date, plant population density, and hybrid lifespan; and (c) estimate interannual yield deviations in green ear mass yield.

Methods

Historical processing sweet corn dataset. A long-term processing sweet corn yield dataset (hereafter called "US sweet corn data") was procured by the authors from multiple US vegetable processors. This dataset represents 27 years (1992–2018) of field-level commercial sweet corn production for processing with contract growers in the Pacific Northwest and Upper Midwest regions. Processing sweet corn production (harvest area and green ear yield) records from more than 20,000 contract growers' fields were in the dataset. The Pacific Northwest region is characterized by semiarid climate with hot, dry growing conditions, and ample water supply is ensured by center pivot irrigation. Growing conditions in the Upper Midwest region generally are hot and humid. Typically, fine-textured soils in the Midwest are rainfed and coarse-textured soils are irrigated. Contract growers followed crop management guidelines (e.g., nutrient management, pest and weed control) that reflected commercial sweet corn production standards at the time. Sweet corn for processing was harvested at the R3 growth stage and green ear mass yield was recorded by the processor. The Materials Transfer Agreement governing use of these datasets dictates strict confidentiality, including names of the processors, contract growers, and hybrids. Nonetheless, the dataset represents a significant portion of US sweet corn production, accounting for ∼15% of the USDA processing sweet corn acreage data (USDA-NASS 2021). Because other vegetable processors are growing sweet corn in the same production areas, often using the same or similar hybrids, yield trends observed in the dataset are believed to be representative of the US industry as a whole.

Data analysis. Unless otherwise stated, all analyses were conducted at the production area level. Aforementioned sweet corn production regions—the Pacific Northwest and Upper Midwest were split into five distinct production areas, Illinois-Irrigated, Illinois-Rainfed, Minnesota-Rainfed, Washington-Irrigated, and Wisconsin-Irrigated.

Harvest area and green ear mass production trends. Linear regression models (R Core Team 2021) were fit to hectares of sweet corn harvested and green ear mass production (Mt) as a function of time (i.e., years). Slope coefficients were used to quantify changes in harvested area and green ear mass production over time.

Exploratory analysis. Data visualization techniques (Wickham 2016) were used to reveal any patterns in plant population density and planting dates over time (years). Hybrid lifespan—the total number of years a hybrid was grown—was evaluated using a biplot.

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Interannual green ear mass yield deviations. Long-term expected mean yield values were obtained using regression smoothing spline models for each production area. Regression splines were fit with green ear yield as dependent variable and year as independent variable using splines package in RStudio (R Core Team 2021). For each production area, the best model with the lowest Akaike's information criterion was used to extract the expected mean green ear yield values (predictions) corresponding to each year. Then, yield deviations from the expected mean yield (yield residual) for each year was calculated as $(\boldsymbol{Y_t} - \boldsymbol{T_t})/\boldsymbol{T_t} \times 100$, where Y is the observed mean yield and T is the expected mean yield for year t. In other words, percent change in yield relative to the expected mean yield was compared each year, separately for production areas.

Results and Discussion

Trends in processing sweet corn production: Harvest area and green ear mass production. US processing sweet corn showed sharp decline in total production starting in the early 2000s (Fig. 1). Similarly, sweet corn production for processing showed a declining trend in harvest area across all the five production areas (Fig. 2A). Moreover, production areas under rainfed systems show greater loss in harvest area compared with irrigated systems. Among irrigated production areas, Illinois-Irrigated and Wisconsin-Irrigated showed minimal decline in harvest area from 1992 to 2018.

Green ear mass production over years varied by production area (Fig. 2B). For instance, WI-Irrigated showed an increasing trend in green ear mass production despite previously discussed harvest area decline. However, green ear mass production in Illinois-Rainfed plummeted in recent years, with an annual decrease of more than 1000 Mt since 1992 (Fig. 2B). Illinois-Irrigated and Minnesota-Rainfed reveal nearly stable green ear mass (Mt) over a quarter-century of commercial sweet corn production for processing.

These results agree with national trends in processing sweet corn production, which report up to 65,000 ha decline in harvest area the past 2 decades (USDA-NASS 2021). Similarly, total green ear mass production has decreased by 696,000 Mt for processing sweet corn since 1998 (USDA-NASS 2021). Recent decline in processing sweet corn production can be attributed to lower per capita consumption of sweet corn, which has declined by 1 kg from 2000 to 2018 (Lucier and Broderick 2020). A declining green ear mass production captures, in part, changing consumer preferences, which have shifted from canned foods toward fresh or whole foods (Román et al. 2017). One exception to national trends was green ear mass in the Wisconsin-Irrigated production area. The upward trend in green ear mass production in Wisconsin-Irrigated was the result of yield gains sufficient to overcome the decline in sweet corn hectares. Therefore, the Wisconsin-Irrigated

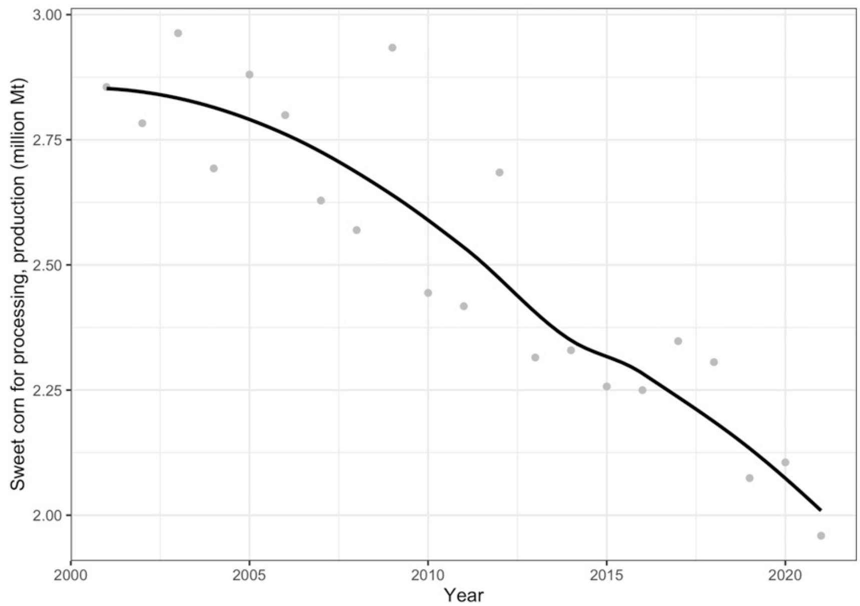

Fig. 1. Trend in the US processing sweet corn production (Mt) for years 2001–21 using publicly available US Department of Agriculture–Economic Research Service data.

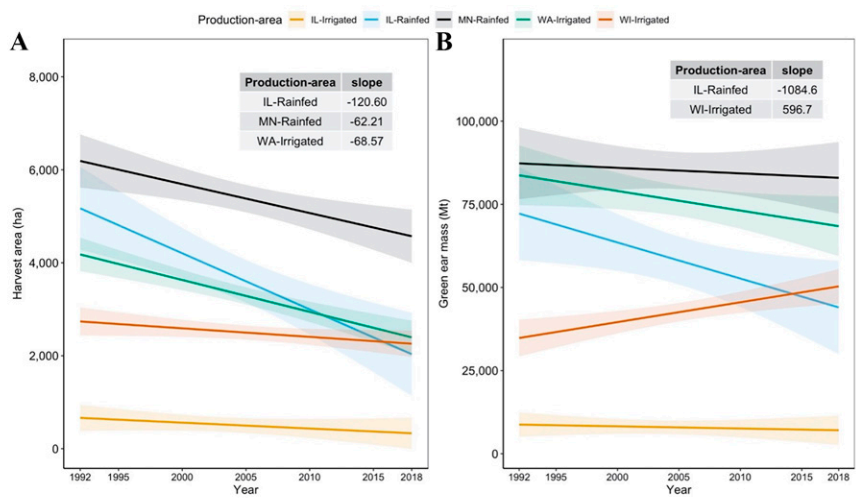

Fig. 2. Trends in (**A**) total processing sweet corn harvest area (hectares) and (**B**) total processing sweet corn production (green ear mass, Mt) over years 1992 through 2018 across different production areas. Simple linear regression models described the relationships. Ninety-five percent confidence intervals are shown by the shaded regions around the line of best fit. Slope estimates significant at alpha level 0.05 are shown.

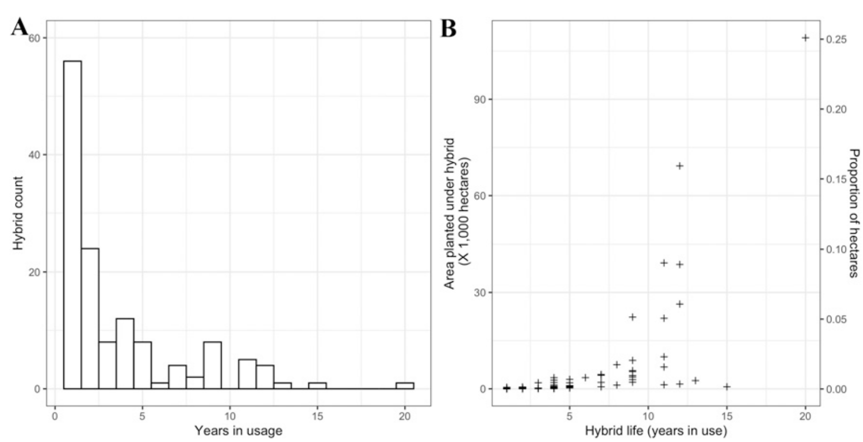

Fig. 3. Processing sweet corn hybrid lifespan analysis. (**A**) Frequency distribution of hybrid count by years of use in commercial production. (**B**) Scatterplot for total area and proportion of area (in hectares) planted under a hybrid and hybrid life (years in use) of sweet corn hybrids.

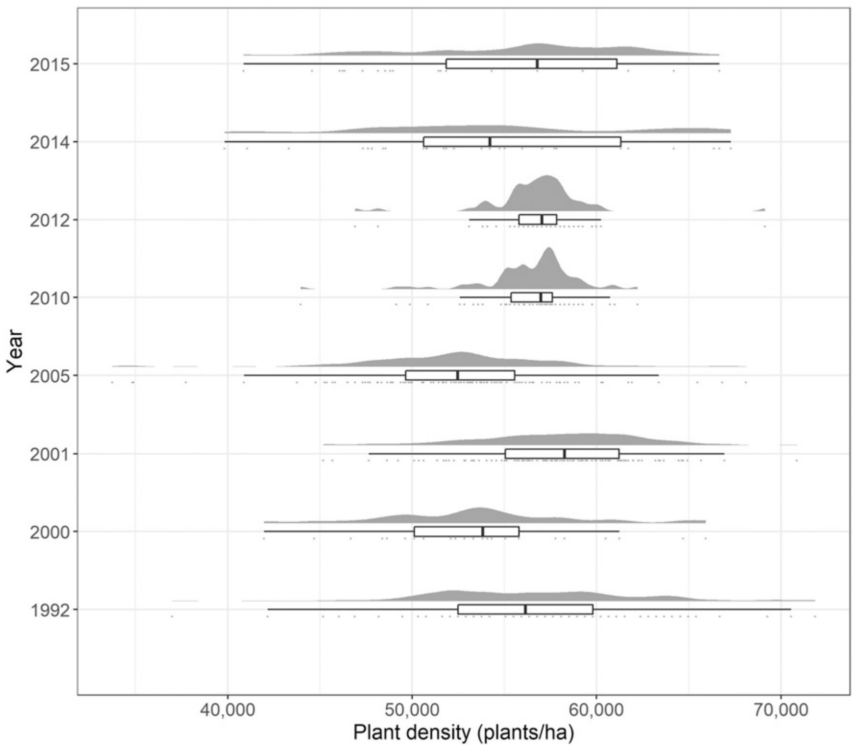

Fig. 4. Trends in plant population density of processing sweet corn hybrids grown for commercial scale production. Probability distributions for plant population density (plants/ha) from years with at least 10 data points are shown.

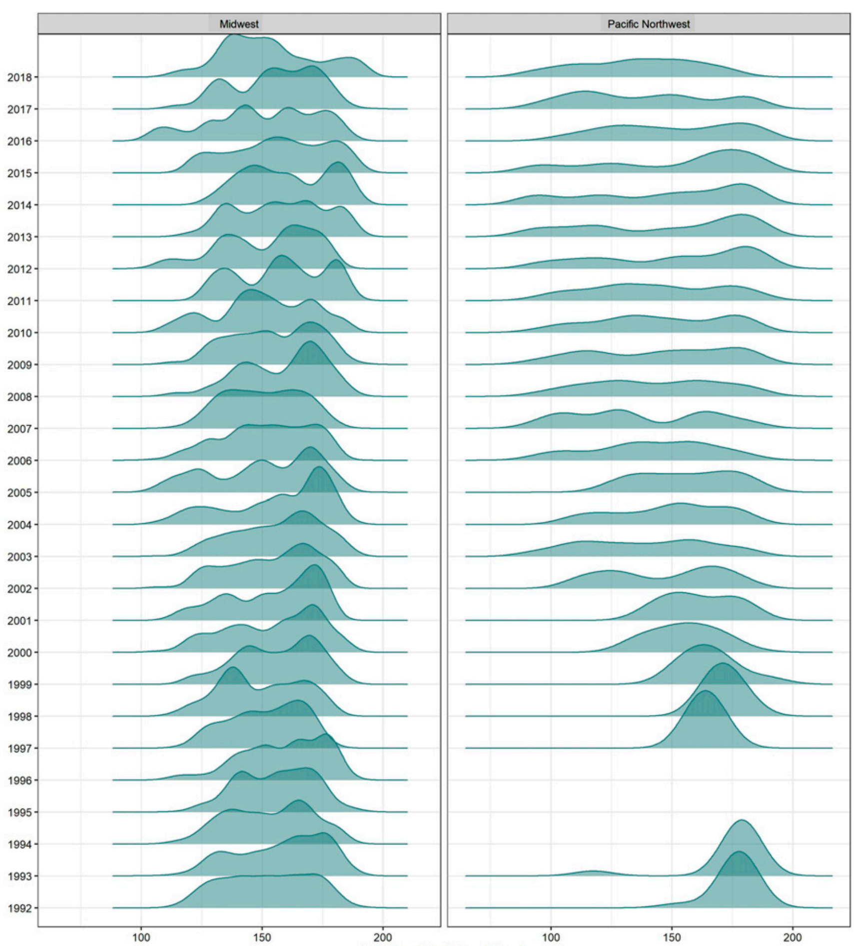

Fig. 5. Probability distribution plots for trends in planting date (day of year) over time (1992–2018) for processing sweet corn in the United States. Data for production areas in the Midwest and the Pacific Northwest are visualized separately.

production area is unique in that it is producing more processing sweet corn on fewer acres over the last quarter century.

Processing sweet corn is declining in rainfed areas. Trends with negative slope coefficients for harvest area and green ear mass production are greatest in rainfed production areas. The trajectory for declining sweet corn production in rainfed areas extends beyond this dataset. Following the 2019 growing season, Del Monte Foods closed processing plants in Illinois and Minnesota. Rainfed production areas are more likely to be a high-risk enterprise, impeding crop yield potential, especially under changing climate patterns (Kukal and Irmak 2019; Li and Troy 2018).

Consumer demand and consumption trends. Consumers in the United States ate less sweet corn per person in 2021 compared with any point in the past 5 decades [USDA Economic Research Service (ERS) 2022]. A major reason for this is a shift from canned fruit and vegetables to fresh or frozen options, but both fresh and processed sweet corn have experienced a significant drop in consumption from 2017 to 2021. However, there are also indications that domestic supply pressures may be contributing to these decreases.

Domestic sweet corn production is mainly concentrated in California and New York for fresh markets, whereas Minnesota, Wisconsin, and Washington state are the most common regions for processing markets. Domestic production accounts for ∼85% of US fresh and processing sweet corn consumption. From 1987 to 2016, the amount of fresh sweet corn consumed per person in the United States increased from 2.7 kg/person to 3.6 kg/person. However, since 2017, fresh sweet corn consumption has decreased from 3.2 kg/person to 1.8 kg/person in 2021. From 1987 to 2021, per capita consumption of processing sweet corn has decreased from 8.6 kg/person to 5 kg/person, with the greatest proportion of that drop coming from sweet corn for canning (USDA-ERS 2022).

Hybrid lifespan. Out of 135 processing-type hybrids grown by certain US sweet corn growers during 1992–2018, the majority (∼60 hybrids) were grown only for a single year (Fig. 3A). A group of 27 hybrids was employed for more than 5 years in grower fields; 10 of them were employed for more than a decade. The top-ranked sweet corn hybrid contributed to one-quarter of total hectares of sweet corn planted for processing from 1992 to 2018 (Fig. 3B). A similar analysis reported hybrid field corn lifespan averages ∼3 years, and some elite hybrids last 5 to 6 years before being replaced by better genetics (Rizzo et al. 2022). The longer lifespans in processing sweet corn may be attributed in part to yield stability, which is a hybrid's performance over a range of environmental conditions. For instance, stable production of sweet corn product (i.e., cases of kernels) across diverse environments is a more important trait to hybrid adoption than the ability of a hybrid to produce record yields under favorable environments (Williams 2017). Processing

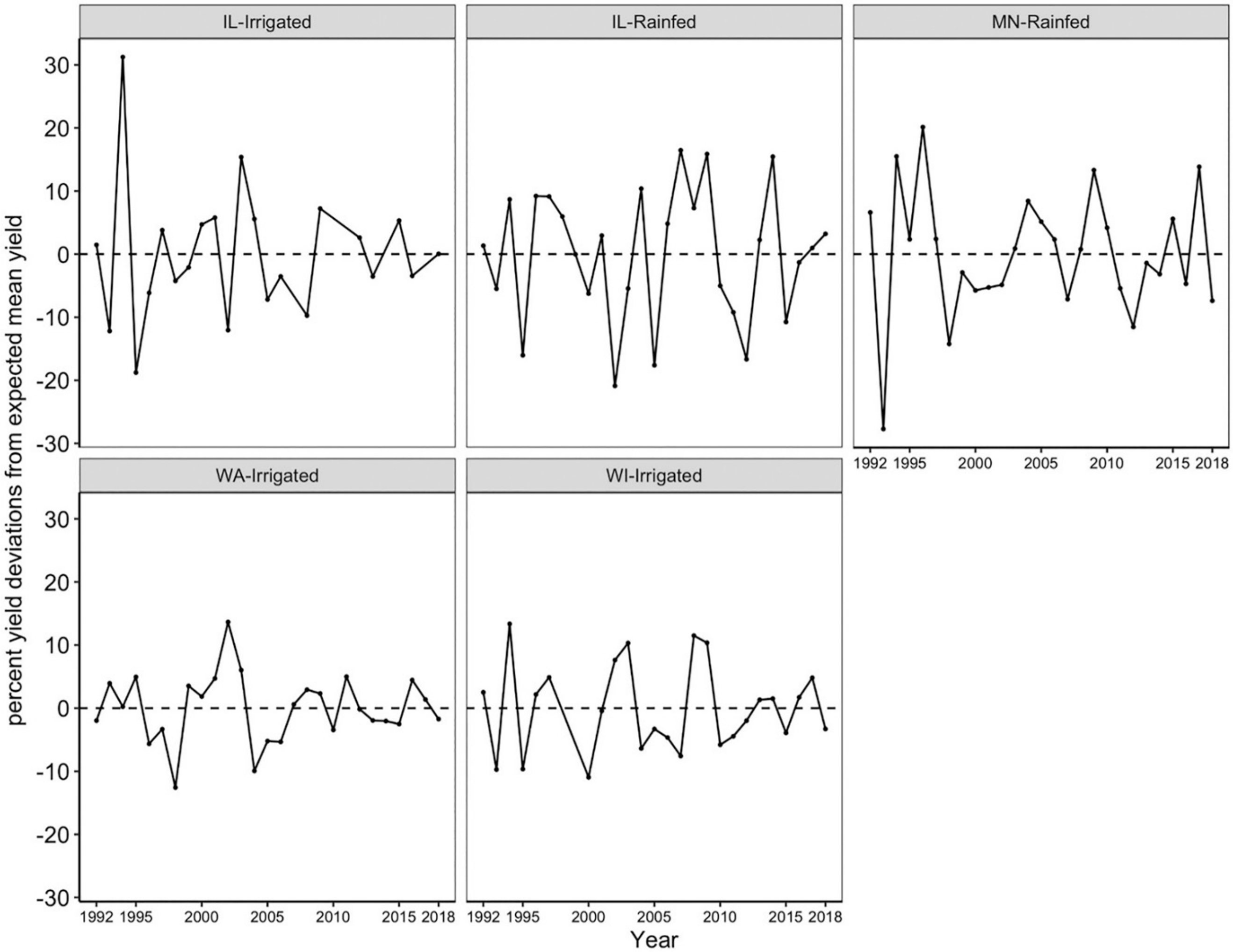

Fig. 6. Processing sweet corn green ear mass yield deviations (%) for 27 years (1992–2018) across different production areas. Yield deviations measure the difference between the long-term expected mean yield and mean observed yield. Negative yield deviations (%) indicate observed yields were less than expected yields for a particular year.

facilities are limited on how much green ear mass they can process daily, so it is reasonable that the sweet corn industry aims for a stable level of crop production in the face of environmental variability.

Plant population density and planting date. Both plant population density and planting date showed no obvious trends over time (Figs. 4 and 5). Processing sweet corn continued to be planted at average plant population density of 55,000 plants/ha (Fig. 4), which agrees with on-farm surveys conducted in Midwest production areas (Dhaliwal and Williams 2019; Williams 2012). A recent study reported historic plant density tolerance in sweet corn has improved since inception of hybrid sweet corn (Dhaliwal et al. 2021). The present data, showing no change in plant densities over time, suggest that plant density tolerance was not widely exploited from 1992 to 2018. In on-farm research throughout the Midwest, Dhaliwal and Williams (2019) showed the use of modern sweet corn hybrids with improved density tolerance can be planted up to 79,300 plants/ha to increase profits for both vegetable processors and growers.

Planting dates for processing sweet corn have not shown any deviations since 1992, with the planting window ranging from late April to early July (Fig. 5). Vegetable processors strategically schedule planting dates to meet market demands and make more efficient use of labor and equipment at processing facilities. Recent climate change reports indicate an increase in the length of frost-free growing season in the Midwest (Reidmiller et al. 2018); however, the projections and evidence of precipitation in winter and spring are likely to create complications for maintaining the wide range in planting window (USDA-NASS 2021). A survey of Iowa sweet corn growers reported weather uncertainty, unpredictable spring frost, and matching supply to demand were among top concerns for future sweet corn production (Morton et al. 2017).

Interannual green ear mass yield deviations. Generally, rainfed production areas showed more deviations in yield over years. Yield deviations were visibly higher in certain years than others (Fig. 6). Further investigations revealed years with relatively higher yield deviations had an extreme weather event(s) during the growing season. For instance, both production areas in Illinois show evidence of yield loss from the heat wave of 1995 (Fig. 6). Similarly, Upper Midwest production areas showed yield losses from the floods of 1993 and the drought of 2012 (Fig. 6).

Previous studies have reported sweet corn yield loss from extreme weather events such as floods (Hatfield 2010) and anomalies in growing season air temperature (Lucier et al. 1993). Our results show sharp deviations from expected yields in years with adverse growing season weather. For instance, an intense heat wave in Jul 1995 raised daily maximum temperatures to 40 °C, which was detrimental to sweet corn yields in Illinois. Each growing degree day above 30 °C results in field corn grain yield loss by 1% in rainfed systems and nearly 2% in drought conditions (Lobell et al. 2011). Our results serve as evidence for yield losses in sweet corn from adverse weather conditions, particularly in rainfed production areas. The severity and spatial heterogeneity of sweet corn yield losses from extreme weather events is unknown.

Conclusion

The goal of this study was to better understand national trends in sweet corn grown for processing. Using field-level, long-term commercial production data, the research used a scale much finer than the national or state level to gain new insight into processing sweet corn production in the United States, including hybrid lifespan and trends in yield, plant population density, and planting date.

In agreement with national trends, harvest area has been declining. Additionally, these data reveal downward trends in green ear mass production for all but the Wisconsin-Irrigated production area. Sweet corn grown under rainfed production systems is declining the greatest because the crop is susceptible to yield losses exacerbated by adverse weather. For the past 3 decades of processing sweet corn production, plant population density and planting dates have remained unchanged. Additional research to understand causal relationships between sweet corn yield and underlying climatic and nonclimatic variables to stabilize the processing sweet corn industry, particularly in a future with more frequent extreme weather events.

References Cited

Assefa Y, Prasad PV, Carter P, Hinds M, Bhalla G, Schon R, Jeschke M, Paszkiewicz S, Ciampitti IA. 2017. A new insight into corn yield: Trends from 1987 through 2015. Crop Sci. 57(5):2799–2811. https://doi.org/10.2135/cropsci2017.01.0066.

Dhaliwal DS, Williams MMII. 2019. Optimum plant density for crowding stress tolerant processing sweet corn. PLoS One. 14(9):e0223107. https://doi.org/10.1371/journal.pone.0223107.

Dhaliwal DS, Williams MMII. 2020. Understanding variability in optimum plant density and recommendation domains for crowding stress tolerant processing sweet corn. PLoS One. 15(2):e0228809. https://doi.org/10.1371/journal.pone.0228809.

Dhaliwal DS, Ainsworth EA, Williams MMII. 2021. Historical trends in sweet corn plant density tolerance using era hybrids (1930–2010s). Front Plant Sci. 12:707852. https://doi.org/10.3389/fpls.2021.707852.

Edreira JI, Mourtzinis S, Azzari G, Andrade JF, Conley SP, Specht JE, Grassini P. 2020. Combining field-level data and remote sensing to understand impact of management practices on producer yields. Field Crops Res. 257:107932. https://doi.org/10.1016/j.fcr.2020.107932.

Food and Agriculture Organization of the United Nations. 2021. FAOSTAT statistical database. Publisher: FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. https://www.fao.org/faostat/en/#data. [accessed 5 Apr 2022].

Hatfield JL. 2010. Climate impacts on agriculture in the United States: The value of past observations, p 239–253. In: Hillel D, Rosenzweig C (eds). Handbook of climate change and agroecosystems: Impact, adaptation and mitigation. Imperial College Press, London UK. http://www.usda.gov/oce/climate_change/effects.htm. [accessed 5 Apr 2022].

Kukal MS, Irmak S. 2019. Irrigation-limited yield gaps: Trends and variability in the United States post-1950. Environ Res Commun. 1(6):061005. https://doi.org/10.1088/2515-7620/ab2aee.

Li X, Troy TJ. 2018. Changes in rainfed and irrigated crop yield response to climate in the western US. Environ Res Lett. 13(6):064031. https://doi.org/10.1088/1748-9326/aac4b1.

Lobell DB, Bänziger M, Magorokosho C, Vivek B. 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nat Clim Chang. 1(1):42. https://doi.org/10.1038/nclimate1043.

Lobell DB, Roberts MJ, Schlenker W, Braun N, Little BB, Rejesus RM, Hammer GL. 2014. Greater sensitivity to drought accompanies maize yield increase in the US Midwest. Science. 344(6183):516–519. https://doi.org/10.1126/science.1251423.

Lucier G, Broderick P. 2020. Vegetable and pulses outlook. Economic Research Service, US Department of Agriculture. https://www.ers.usda.gov/publications/pub-details/?pubid=98294.

Lucier G, Lin BH, Allhouse J. 1993. Vegetables and specialties situation and outlook report. Commodities Economic Research Service, US Department of Agriculture, TVS-261.

Morton LW, Nair A, Gleason M. 2017. Climate, weather, and sweet corn. Sociology Technical Report 1048. Department of Sociology, Iowa State University, Ames, IA. https://www.climatehubs.usda.gov/sites/default/files/Clmiate%20Weather%20and%20Sweet%20Corn.pdf. [accessed 5 Apr 2022].

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. [accessed 5 Apr 2022].

Rizzo G, Monzon JP, Tenorio FA, Howard R, Cassman KG, Grassini P. 2022. Climate and agronomy, not genetics, underpin recent maize yield gains in favorable environments. Proc Natl Acad Sci USA. 119(4). https://doi.org/10.1073/pnas.2113629119.

Roman S, Sanchez-Siles L, Siegrist M. 2017. The importance of food naturalness for consumers: results of a systematic review. Trends in Food Sci Technol. 67:44–57. https://doi.org/10.1016/j.tifs.2017.06.010.

US Department of Agriculture–Economic Research Service. 2022. Commodity highlights: Vegetables and pulses. https://www.ers.usda.gov/topics/crops/vegetables-and-pulses/commodity-highlights/. [accessed 5 Apr 2022].

US Department of Agriculture–National Agricultural Statistics Service. 2021. NASS—Quick Stats. https://data.nal.usda.gov/dataset/nass-quick-stats. [accessed 5 Apr 2022].

US Global Change Research Program. 2018. Impacts, risks, and adaptation in the United States: Fourth national climate assessment. Volume II. US Global Change Research Program (USGCRP), Washington, DC, USA. https://doi.org/10.7930/NCA4.2018.

Wickham H. 2016. Ggplot2: Elegant graphics for data analysis. Springer-Verlag, New York, NY, USA. https://ggplot2.tidyverse.org. [accessed 5 Apr 2022].

Williams MM II. 2012. Agronomics and economics of plant population density on processing sweet corn. Field Crops Res. 128:55–61. https://doi.org/10.1016/j.fcr.2011.12.007.

Williams MM II. 2017. Genotype adoption in processing sweet corn relates to stability in case production. HortScience. 52(12):1748–1754. https://doi.org/10.21273/HORTSCI12595-17.