EDITORIAL

Sustainable aviation fuel production from *Brassica carinata* in the Southern United States

1 | INTRODUCTION

The latest report of the Intergovernmental Panel on Climate Change categorically mentions that immediate, rapid, and large-scale reductions in greenhouse gas emissions are needed, else limiting global warming to 1.5°C or even 2°C will be beyond reach (Masson-Delmotte et al., 2021). In this context, reducing greenhouse gas emissions of the aviation sector is essential. This is especially true as the aviation sector is currently responsible for 3.5% of overall global warming (Lee et al., 2021). It is projected that the global aviation sector would cumulatively generate an estimated 43 billion metric tons of carbon dioxide emissions through 2050, constituting almost 5% of the global emissions allowable to keep global warming below 1.5°C (Pardee, 2015). This could be attributed to the fact that the total consumption of conventional aviation fuel is expected to increase by almost 2.5 times by the end of 2050 due to the rising demand for aviation worldwide (EERE, 2020).

The United States consumes about 25% of the total conventional aviation fuel worldwide (EERE, 2020). The aviation sector currently emits 181 million metric tons of greenhouse gas emissions, that is, about 5% of the overall greenhouse gas emissions nationwide (USEPA, 2020). Therefore, a critical need exists for reducing carbon emissions of the aviation sector at the national level. Three federal agencies (Department of Energy, Department of Transportation, and Department of Agriculture) have recently signed a memorandum of understanding to launch a government-wide Sustainable Aviation Fuel Grand Challenge to reduce the cost, enhance the sustainability, and expand the production and use of sustainable aviation fuel that achieves a minimum of a 50% reduction in lifecycle greenhouse gas compared to conventional aviation fuel to meet a goal of supplying sufficient sustainable aviation fuel to displace 100% of conventional aviation fuel demand by 2050. This grand challenge supports the national goal of producing 132.5 billion liters of sustainable aviation fuel by 2050 (White House, 2021). This challenge is especially significant for the 13 southern states that together consumed about 35% of the overall conventional aviation fuel nationwide in 2019 (USEIA, 2021).

*Brassica carinata* (henceforth, carinata) provides an opportunity to reduce the aviation sector’s carbon footprint at the regional level. The oil obtained from carinata seeds could be refined using existing conversion technologies to produce sustainable aviation fuel and other valuable bioproducts. Additionally, carinata is a non-food crop, and being a winter crop, it does not compete with other summer crops in the Southern United States. It also potentially provides several other advantages such as water quality improvements, soil protection, weed control, increased soil carbon, and support pollinator health. It is quite likely that the growing carinata would also help farmers in the region by diversifying and augmenting their revenue streams. This is especially true as between 979 and 2045 million liters of carinata-based sustainable aviation fuel could be potentially produced across Georgia, Florida, and Alabama (Alam & Dwivedi, 2019). In this context, over 100 collaborators from 10 public institutions and four industry partners are undertaking research, extension, and education efforts under the aegis of SPARC (Southeast Partnership for Advanced Renewables from Carinata; www.sparc-cap.org) to assess the economic, environmental, and social feasibility of incorporating carinata into current crop rotations in the Southern United States. The focus is also on establishing sustainable supply chains of carinata-based sustainable aviation fuel by developing strategic public-private partnerships. The SPARC is supported by a $15 million CAP (Coordinated Agricultural Project) grant from the United States Department of Agriculture National Institute of Food and Agriculture.

This virtual special issue provides scientific grounding for carinata-based sustainable aviation fuel production in the Southern United States based on the research conducted by SPARC. It is divided into four sections. The first section introduces carinata. The second section focuses on the agronomy of carinata. The third section focuses on this is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

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carinata economics. Finally, the fourth section focuses on the environmental impacts of carinata-based sustainable aviation fuel production in the region.

2 | DEVELOPMENT OF CARINATA

George et al. (2021) introduce carinata as a crop in the Southern United States, highlighting its role as a potential winter crop. Carinata seeds can be crushed to extract the oil, which can be processed with existing conversion technologies for sustainable aviation fuel production along with other commercially valuable co-products (e.g., naphtha, bio-diesel). It is also mentioned that leftover carinata seed at the carinata oil extraction phase could readily be utilized for animal feed due to its high protein content after some basic pre-processing. They have also provided more details about SPARC. A need for building resilience through partnerships across academia, industry, and state and federal agencies is emphasized for ensuring sustainable bio-economy development in the Southern United States.

Seepaul, Kumar, Iboyi, et al. (2021) provide details of the origin, distribution, genomic resources, morphology, phenology, reproduction, and agronomy of carinata based on studies across the world. It was found that carinata is adaptable to diverse growing regions, cropping systems, and management regimes with demonstrated potential to be grown on the continents of Asia, Africa, North America, South America, Europe, and Australia either as a spring or winter crop in double-cropped systems. It further reports that carinata could be potentially produced in a double-crop system in the Southern United States, though it would require continued research to integrate crop biology with agronomy to understand the interaction between crop growth and development with agricultural inputs and management.

3 | AGRONOMY OF CARINATA

Seepaul, Kumar, Boote, et al. (2021) quantified the total aboveground dry matter accumulation (TDM), allocation, growth, nutrient uptake, and seed quality of carinata based on field experiments conducted during 2017–2018 (Year 1) and 2018–2019 (Year 2) in Quincy, Florida. The two carinata cultivars Avanza 641 and AX17012 accumulated 10,826 and 9343 kg TDM/ha in Year 1 and 9655 and 10,642 kg TDM/ha in Year 2, respectively, at harvest maturity. The proportion of DM in the vegetative parts such as leaves and stems decreased, and the DM in reproductive structures such as siliques walls and seeds increased with maturity. Seed yield was similar between cultivars but differed between years with Year 1 (2732 kg/ha), producing 29% greater seed yield than Year 2 (1929 kg/ha).

Bashyal et al. (2021) conducted a nitrogen rate (0, 45, 90, 134, and 179 kg N/ha) study during the winter–spring growing seasons (2017–2018 and 2018–2019) across Florida (one site) and Georgia (three sites, 2018–2019 only) focusing on carinata nutrient uptake, biomass, seed yield, and seed chemical composition. Seed yield showed a linear response up to 134 kg N/ha. Seed protein and glucosinolate concentrations decreased from 0 to 90 kg N/ha, and then increased from 90 to 179 kg N/ha. The seed oil concentration was inversely related to seed protein concentration. Additionally, a two-split N application was found to be more profitable than either a single N application or a three-split N application based on marginal return for the study sites located in Georgia. The authors recommended a two-way split N application (at-plant + pre-bolting) at 134 kg N/ha for optimizing seed yield.

Iboyi et al. (2021) conducted a study to evaluate the effect of tillage system (conventional, no-till, broadcast-disc, and ripper-roller) and seeding rate (1.12, 5.60, 10.09, and 14.57 kg seed/ha) on the performance of carinata. Studies at Headland in AL and Jay and Quincy in FL during the winter–spring growing seasons (2017–2018 and 2018–2019) found that soil penetrometer resistance was significantly affected by the tillage system, with the ripper-roller consistently having the lowest penetration resistance values across all sites and years. Yield response to the tillage system was variable. Among seeding rate treatments, the yield was lowest at 1.12 kg seed/ha and similar among 5.60, 10.09, and 14.57 kg seed/ha on the performance of carinata. Studies at Headland in AL and Jay and Quincy in FL during the winter–spring growing seasons (2017–2018 and 2018–2019) found that soil penetrometer resistance was significantly affected by the tillage system, with the ripper-roller consistently having the lowest penetration resistance values across all sites and years. Yield response to the tillage system was variable. Among seeding rate treatments, the yield was lowest at 1.12 kg seed/ha and similar among 5.60, 10.09, and 14.57 kg seed/ha across all sites and years. There was no tillage by seeding rate interaction for yield. Among the seeding rate treatments, 5.6 kg seed/ha rate was optimal across all sites and years regardless of land preparation method and is thus the recommended seeding rate for commercial carinata production.

The CROPGRO model is a mechanistic crop simulation of daily crop growth and development as a function of daily weather, soil properties, crop management, and species parameters (Boote et al., 2018). Using data published in the above studies (Bashyal et al., 2021; Iboyi et al., 2021; Seepaul, Kumar, Boote, et al., 2021), Boote et al. (2021) adapted the CROPGRO model to simulate carinata growth over time. A case study was also developed to simulate the response of carinata relative to sowing dates at eight sites. Simulated yields were higher for the earlier sowing dates. The October 16 date gave the highest yield for five of the eight sites, although the November 6 date was the highest yielding at three sites. For the more northerly locations (Tifton and Midville in GA; Plains, Shorter, and Brewton in AL), it was recommended to sow between October 16 and November 6, both to achieve high yield, and to avoid late harvest that could interfere with...
summer crops. For the southerly sites closer to the Gulf (Quincy, Jay, and Fairhope in FL), the sowing date range for high yield and reasonable maturity is broader, and stretches from October 16 to November 27. Overall, the adapted model provided good simulations of the growth dynamics of carinata during different seasons.

Tiwari et al. (2021) conducted field experiments over 2 years (May 2018–September 2019; May 2019–August 2020) at Jay, FL, for ascertaining the role of carinata on weed management strategies at the rotational level for the following summer crops. Using a randomized complete block design arranged as a split plot with seven and eight replications in the 2018–2019 and 2019–2020 seasons, the authors reported that carinata reduced the emergence of common weeds by more than 25% compared to winter fallow without using herbicides. The authors concluded that carinata could reduce herbicide use and contribute to an integrated weed management scheme in the long term as it is effective in weed control during and after the winter season.

Baldwin et al. (2021) documented the occurrence of arthropod pest species associated with carinata during different phenological stages by performing field trials over 2 years (2017–2018 and 2018–2019) at Jay, FL. The authors also determined the possible source of host plant resistance by non-preference in the carinata germplasm and the impact of defoliation on seed yield. It was reported that several insect species utilized carinata as a host. It was also found that several such pests were defoliators. Carinata was tolerant of low levels of defoliation (<50%) during the vegetative and flowering stages.

4 | CARINATA CO-PRODUCTS AND ECONOMICS

Although carinata meal is an important co-product obtained after the oil extraction phase of protein for animal nutrition, several other commercially available value-added co-products can also be derived across the whole supply chain. Ammar et al. (2021) investigated the biochemical conversion of carinata biomass to propionic acid by first pretreating the carinata meal with concentrated phosphoric acid to remove hemicellulose and gain access to the cellulose constituent of the meal. Then, they subjected the pretreated meal to enzymatic hydrolysis with cellulase enzyme to depolymerize cellulose to glucose. Finally, the recovered glucose was successfully fermented primarily to propionic acid using the bacterium Propionibacterium freudenreichii with a yield of 0.57 g of produced propionic acid/gram of consumed cellulosic glucose. Such bio-based propionic acid and other co-produced organic acids can serve as renewable building blocks for manufacturing industrial chemicals and food preservatives replacing fossil-derived organic acids.

Zhao et al. (2021) assessed the impact of conventional aviation fuel price volatility on the return on investment in a carinata biorefinery employing a real options analysis (ROA). The key advantage of ROA over traditional net present value (NPV) analysis is that it simultaneously assesses the optimal timing for investments and the impact of conventional aviation fuel price dynamics on the likelihood of positive economic returns from investments in processing plants. Considering the volatility of conventional aviation fuel prices, the ROA price threshold for a profitable investment was 45% greater than the NPV threshold. The ROA model identifies the necessary market conditions for a profitable investment and highlights the importance of considering market price dynamics before making substantial capital investments in a carinata biorefinery.

5 | ENVIRONMENTAL AND ECONOMIC TRADEOFFS

About 88% of the total population across Southern Unites States depend upon freshwater withdrawal (surface water withdrawal is about 58% of the total freshwater withdrawal) for meeting their daily domestic needs (Dieter et al., 2018). Hoghooghi et al. (2021) used the Soil and Water Assessment Tool to assess the potential influence of carinata on water balance components, nutrients, and sediment loads under plausible future scenarios of land-use change in the upper Suwannee River Basin in the Atlantic Coastal Plain Physiographic Region near Tifton in South-Central Georgia. Three future scenarios were considered: winter carinata-fallow-fallow, winter wheat-fallow-fallow, and winter carinata-winter wheat-winter wheat over the same simulation period. They reported that under all three scenarios, surface runoff, sediment, phosphorus, and nitrogen loadings decrease at watershed and local scales, with higher average monthly reductions in the carinata scenario relative to the winter wheat scenario. When carinata and winter wheat were planted over 36% of the total watershed area, reduction in total sediment, mineral phosphorus, and nitrate loads ranged between 11.5% and 50.0%. Authors suggested that the extent of carinata planting is crucial in assessing its hydrologic and water quality benefits.

Alam et al. (2021) combined the information generated from studies (Bashyal et al., 2021; Boote et al., 2021; Iboyi et al., 2021; Seepaul, Kumar, Boote, et al., 2021) for determining the unit cost and carbon intensity of carinata-based sustainable aviation fuel using a similar system boundary and common assumptions. They reported that without...
co-product credit or other subsidies such as Renewable Identification Number (RIN) credit, carinata-based sustainable aviation fuel price was $0.85/L to $1.28/L higher than conventional aviation fuel ($0.50/L). With co-product credit only, the break-even price ranged between $0.34/L and $0.89/L. With both co-product and RIN credits, the price ranged between −$0.12/L and −$0.66/L. The total carbon emission of the carinata-based sustainable aviation fuel was 918.67 g CO₂e/L without accounting for carbon sequestered in soils. This estimate provided a 65% relative carbon savings compared with conventional aviation fuel (2618 g CO₂e/L) at the airport.

6 | SUMMARY

The use of carinata-based sustainable aviation fuel provides an immense opportunity to reduce the aviation sector’s carbon footprint by up to 65% in the United States. The studies presented in this special issue indicate that carinata can be grown in the Southern United States in the winter months while providing several ecological (e.g., water quality, soil erosion, etc.) and economic (e.g., added revenue stream, reduced cost for weed control) benefits. The studies also indicate that carinata can be rotated with common summer crops in the region, subject to timely planting. Furthermore, these studies indicate that the cost of carinata-based sustainable aviation fuel is higher than conventional aviation fuel under current circumstances. Policy initiatives are needed for ensuring investment in the supply chain of the carinata-based sustainable aviation fuel, especially those initiatives that could potentially reduce the volatility of conventional aviation fuel price for a potential bio-refinery. For example, long-term contracts and price guarantees could provide an impetus for carinata-based sustainable aviation fuel production. Additionally, incentivizing the use of valuable co-products obtained from carinata for lowering the overall cost of carinata-based sustainable aviation fuel production would also support the establishment of carinata-based sustainable aviation fuel production in the southern region.

Future research should investigate the supply chain costs and related carbon emissions after including carbon sequestered in soils to get an accurate production potential for carinata-based sustainable aviation fuel in the region. With new knowledge and technology, there is always room for improvement in integrating cost- and emissions-effective agronomic practices in carinata production. Developing and evaluating improved crop genetics for increased adaptability and input use efficiency in the context of weather variability and sustainability frameworks are other research areas of relevance in the near term. Research also needs to continue to understand the barriers and opportunities that influence the decisions of farmers and the adoption of an emerging feedstock like carinata (Christ et al., 2020). A more concerted effort among various stakeholder groups, for example, academics, industry, non-profits, state agencies, federal agencies, international partners, and investors, will be central to the successful establishment of the supply chain of carinata-based sustainable aviation fuel in the Southern United States. We hope that this special issue will jump-start the bioeconomy development in the Southern United States for increasing the flow of ecosystem services, rejuvenating rural economies, and most importantly, reducing the carbon footprint of the aviation sector in the region and beyond for mitigating global climate change.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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