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An Assessment of the Interaction between Carbon Dioxide Emissions and Available Nutrients from the Lifecycle of Several Agricultural Crops

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Abstract

Agricultural products cause the emission of certain significant amount of greenhouse gases. Carbon dioxide (CO_2) is one of the most important greenhouse gases and its emissions are increasing day by day as a result of the increase in agricultural productivity. This study aims to pinpoint the most environmentally friendly crops and fruits that are sources of good nutrients and emits less CO_2 throughout their life cycles. Relation between nutrient availability and CO_2 emissions from staple foods namely; wheat, maize, rice, potato, sugarcane, sugar beet, soybean, palm oil, sunflower, rapeseed, banana, apple and grape are investigated in this study. Secondary data was collected from dataset's website. Spearman's rank and diagram interpretation technique are used to find out the correlation between nutrient availability and CO_2 emissions. Among carbohydrate diets, rice emits 4 kg CO_2 kg^{-1} of crops, which is significantly higher than that of wheat, maize and potato. However, the amount of carbohydrates in rice (0.26%) is less than those carbohydrate diets. Similarly, sugarcane emits more CO_2 as 2.6 kg kg^{-1} of crops than sugar beet (1.4 kg kg^{-1} of crops) among sugar crops. Soybean and palm oil emit more CO_2 as 6 kg kg^{-1} and 7.2 kg kg^{-1} of crops, respectively, as compared to other oilseed crops, but every oilseed crop has the same food value. Among fruits, bananas emit less CO_2 (1.1 kg kg^{-1} of crops) and have a higher content of carbohydrates (0.23%) than other selected fruits. Proper crop selection based on nutrient content can lead to lower CO_2 emissions than at present and a consistent balance between environmental and nutritional needs in the future.

Keywords: carbon dioxide emission; climate change; environment; major crops; nutritional value

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INTRODUCTION

One of current issues recently is the rise in ambient temperature which related to people's diverse activities (Hannigan, 2014). The greenhouse effect is a phenomenon that causes global warming (Varma and Linn, 2012). Carbon dioxide (CO_2) is a major source of greenhouse gases where the emission is increasing every year which triggered by human activities (Zheng et al., 2018; Zhou et al., 2019). A review shows that in 2017, the amount of CO_2 emissions were 35.22 billion tons and it increased up to 36.44 billion tons by 2019. On the other hand, as the world's population rises, the agricultural sector faces increasing pressure on food supply, necessitating the cultivation of a wide range of crops (Angon et al., 2021a). Although every plant produces

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and releases CO_2 in the respiration process, many crop species produce a great amount of CO_2 (Wang and Sun, 2012). A little amount of this produced CO_2 is used by plants in the photosynthesis process. Each year, 12,000 megatons of CO_2 are emitted into the atmosphere as a result of crop production, accounting for around 86% of all food-related CO_2 emissions (Gilbert, 2012). For example, rice produces noticeable amount of CO_2 among the cereal crops (Liu et al., 2017; Chandio et al., 2020). In this study, it has been established that there is a relationship between different types of food, their nutritional value and their impact on the environment. Many crops are incapable of meeting the nutritional needs of the human body and they are also harmful to the environment since they emit enormous amounts of CO_2 (Lawlor and Mitchell, 1991).

Agricultural crop production is responsible for one-third of total greenhouse gas emissions. Rice, wheat, maize, barley, coconut, palm oil, soybean, potato, rapeseed and sugarcane are liable for 75% of greenhouse gas emissions (Carlson et al., 2017). The intensity of CO_2 emissions is concentrated in Asia, where 51% of total greenhouse gas emissions occur in China, Indonesia and India (Carlson et al., 2017). Spatially processed cropland greenhouse gas emission data reveals high intensities of emission rates depending on the production intensity of crops across the area (Carlson et al., 2017). The largest source of calories for humans is supplied by cereals (rice, maize and wheat), which provide close to 60% of all human calorie needs. Cereal production requires maintaining a high yield with an annual increase of 1.3% by 2025 to meet the demand of the enlarging population (Linquist et al., 2012). Conducted hypothesis exhibits that the emission rate of CH_4 and N_2O is higher in rice production than that of maize and wheat production. The rate of global warming potential is largely driven by emitted greenhouse gases from several processes of agricultural production (Collins et al., 2022). Therefore, good agricultural practices can lead to a sustainable environment with a low global warming potential rate per unit of land area (Linquist et al., 2012). The analysis compares the quantity of greenhouse gas emitted by several agricultural crop production. The greenhouse gas emission rate for the production of major food crops is much higher in Europe and North America than in India. One of good agricultural practices that could mitigated greenhouse gas emissions are fertilizer management, increasing organic manure and improved water management (Vetter et al., 2017; Walling and Vaneeckhaute, 2020).

Agronomic nitrogen use efficiency (N-AE) increases agricultural crop production and improves nutrient management for crops. Using fertilizers and removing crop residues increases the emission rate of greenhouse gases (van Loon et al., 2019). Global warming potential can lead to downward nutrient expert (NE) based fertilizer management. NE based farmers' fertilization practices increase crop yield and reduce fertilizer consumption. NE is a simple, interactive, computer-based decision support tool that may quickly offer nutrient recommendations for a specific farmer field whether or not there are results from soil tests. Greenhouse gas emission rate and crop yield rely on agro-ecology, farmers' current level of fertilization, crop type, crop intensity and soil properties. Increased nutrient use efficiency in agricultural croplands contributes to meet the three times demand for food in 2050 (Sapkota et al., 2021). Variation in human diet composition, amended use of resources and food waste reduction can reduce the greenhouse gas emission rate in the agro-food production system. In Mediterranean agro-systems, the mitigation practices of total greenhouse gas emissions (CH_4 emissions, N_2O and C sequestration) by establishing a proper Mediterranean diet are studied (Sanz-Cobena et al., 2017).

Agricultural crop production is responsible for 10% to 12% of total greenhouse gas emissions and the amount of indirect emission is about 30% to different agricultural practices (Skinner et al., 2019). Several studies have shown that organic farming can contribute more to decreasing greenhouse gas emissions than inorganic farming (Powlson et al., 2016; Haque et al., 2021). Though added nitrogen can increase the crop yield, the biodynamic and bioorganic farming systems provide a sustainable environment for the future (Skinner et al., 2019).

This study will be relevant to how to select the suitable crops and fruit so that people may meet their nutritional demands while not damaging the environment. The aim of this paper is to identify the right environment-friendly crops and fruits, which emit less CO_2 in their life cycles but are rich sources of nutrients. This analysis has been done based on secondary data collected from the https://www.kaggle.com/ website. Despite all this data being sufficient, no such work has been done so far. To find out the correlation between CO_2 and nutrient availability of different types of crops is the nobility of this paper. The nobility of this research is to determine the co-relations between CO_2 and the availability of nutrients in selected crops.

MATERIALS AND METHOD

Data collection

Two topics (available nutrients and CO_2 emission) are the primary emphasis of this article. Information is collected from each crop's most recent years (2014 to 2020). One of the biggest dataset's website is used for data collection (Kaggle, 2022). Microsoft Excel is used to arrange the data. From there, the mean value is computed for analysis. Four times replication data is used for this study. Kg per unit kg has been selected as the unit for the convenience of data processing. Three materials (protein, carbohydrate and lipid) have been emphasized when determining the number of nutrients in foodstuffs. The authors used percent as a unit of nutrient availability (Appendix 1).

Crop items

Data regarding CO_2 emissions is collected from certain agricultural food and crop samples. Thirteen types of crops are selected, which are included within 4 groups (carbohydrate crops, oil crops, sugar crops and fruit) for analysis. Plants must emit CO_2 during their life cycle due to the respiration mechanism (Gifford, 2003). Selected crops and fruits are included wheat (*Triticum aestivum*), maize (*Zea mays*), rice (*Oryza sativa*), potato (*Solanum tuberosum*), sugarcane (*Saccharum officinarum*), sugar beet (*Beta vulgaris*), soybean (*Glycine max*), palm oil (*Elaeis guineensis*), sunflower (*Helianthus annuus*), rapeseed (*Brassica napus*), banana (*Musa acuminata*), apple (*Malus domestica*) and grape (*Vitis vinifera*). The authors selected the crops and fruits which world people consume most. Crops that are taken as carbohydrates are the staple meals of some countries. The main food of the people in Ireland and some other European countries is potato (Valcarcel et al., 2015), while rice and wheat are the main cereal foods of South Asian countries, i.e., Bangladesh, India, Nepal and Sri Lanka (Poudel and Chen, 2012; Gadal et al., 2019). The paper tried its best to find the appropriate crop among each selected division of agricultural crops. Oil-producing crops have nearly identical qualities, yet not all of them have the same environmental impact. Some crops emit more CO_2 and some less (Beyer et al., 2020). Again, all sugar crops do not produce the same amount of sugar and have not the same environmental impact (Firouzi et al., 2022). Fruit provides people with several critical nutrients (Silva et al., 2020).

Data processing and analysis

The results have been divided into three main sections namely, analysis of CO_2 emission in different phases of crops and fruit cultivation; nutritional analysis (secondary data from google) of selected crops; and comparison between CO_2 emission and available nutrition (secondary data from google) of selected crops. Fourier-transform infrared spectroscopy (FTIR) used to determine CO_2 emission from plants (Feitz et al., 2018). Diagram interpretation technique was utilized. Where comparative differences are depicted using bar graphs and the relationship is evaluated (Angon et al., 2021b). Through assessment, environmentally friendly crops have been identified. The diagram is constructed by using Microsoft Excel using a data analysis tool. The correlation coefficient (Spearman's rank) is calculated using IBM SPSS Statistics 25 (Angon et al., 2022) between CO_2 emission and available nutrition of chosen crops.

Model and CO_2 gas emission

Carbon dioxide, the major greenhouse gas, is emitted from trees through respiration, which is the established method for years. Aerobic respiration depends on the atmospheric oxygen level, light, CO_2 concentration, increased oxygen level and respirable materials (Figure 1). The method of identity, or kaya identity, encapsulates all the factors related to CO_2 emission and the consequences of these factors over time, which is stated as the index decomposition approach (IDA) also (Tajfel, 1978). Respiration in plants occurs both in daylight and at night, though more experiments have occurred based on night respiration and through this process, energy is produced from sugar burning.

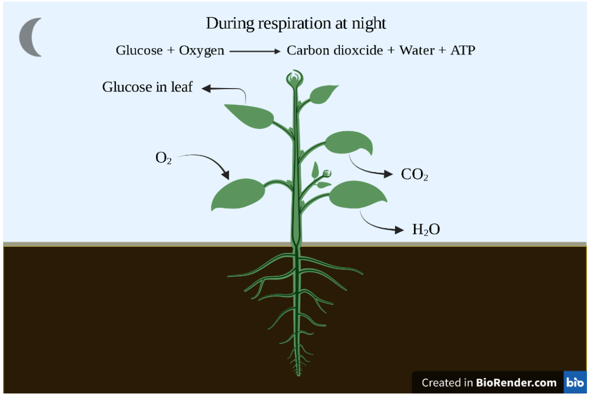

Figure 1. Components of the respiration process produce CO_2

The respiration rate decreases significantly when the CO_2 concentration increases over time, which helps to increase calcium ion concentration and eventually close stomata. When CO_2 rate increases up to 1% to 5% internal breakdown, constraints of plant growth and disruption in physiological condition occurs. Carbon balance is maintained in the ecosystem and also has an impact on the carbon cycle globally through this process.

RESULTS AND DISCUSSION

Analysis of CO_2 emissions in different phases

Wheat, maize, rice and potatoes emit 0.8, 0.5, 3.6 and 0.2 kg CO_2 kg^{-1} of crops during vegetative stage, respectively. Both sugar beet and sugarcane emit 0.5 kg CO_2 kg^{-1} of crops (Figure 2a). Rapeseed emits 2.3 kg CO_2 kg^{-1} of crops, which is higher than that of other oil-based crops. Meanwhile bananas, apples and grapes emit 0.3, 0.2 and 0.7 kg CO_2 kg^{-1} of crops, respectively (Figure 2a). Exorbitant emissions of CO_2 are associated with raw materials collection, processing, packaging, extraction and transportation were included (Nutter et al., 2013). The amount of CO_2 generated during the processing of the selected crops was studied.

Wheat, maize and rice processing emit 0.2, 0.1 and 0.1 kg CO_2 kg^{-1} of crops respectively, while potatoes emit nil CO_2. In between sugar crops, the CO_2 emission rate for sugar beet was 0.2 kg CO_2 kg^{-1} of crops, whereas there was no CO_2 exposure for sugarcane. Regarding the processing of oil crop plants, soybean, palm oil, sunflower and rapeseed emit 0.3, 1.3, 0.2 and 0.2 kg CO_2 kg^{-1} of crops, respectively. Apples and grapes generate no CO_2, whereas only bananas emit 0.1 kg m^{-2} of CO_2 (Figure 2b).

Regarding the carbohydrate crops, wheat, maize, rice and potatoes emit 0.1 kg CO_2 kg^{-1} of crops separately. Transportation of sugarcane contributes to greater emissions than any other agricultural crop. Among the sugar crops, sugarcane generates 0.8 kg CO_2 kg^{-1} of crops and sugar beet generates 0.6 kg CO_2 kg^{-1} of crops. Among the oil-based crops, soybean emits 0.3 kg CO_2 kg^{-1} of crops and palm oil, sunflower and rapeseed emit 0.2 kg CO_2 kg^{-1} of crops separately. Bananas, apples and grapes emit 0.3, 0.1 and 0.2 kg CO_2 kg^{-1} of crops, respectively (Figure 2c). During packaging, wheat, maize, rice, sugarcane, sugar beet and banana generate 0.1 kg CO_2 kg^{-1} of crops separately. Oil-based crops exhibit a higher CO_2 emission rate comparatively, where palm oil and sunflower emit 0.9 kg CO_2 kg^{-1} of crops and soybean and rapeseed emit 0.8 kg CO_2 kg^{-1} of crops. Grapes emit 0.2 kg CO_2 kg^{-1} of crops. No significant CO_2 is reported during the packaging of potatoes and apples (Figure 2d). The main driver of the rise in agricultural CO_2 emissions was the economic factor (Xiong et al., 2016; Huong et al., 2022). People are producing more crops by damaging the environment to rise their economic status. Labor factor also has a role in rising agricultural CO_2 emissions (Xiong et al., 2016). Different agricultural industries emission a lot amount of CO_2 due to the use of fossil fuels.

Comparison between CO_2 emission and available nutrition of selected crops

Wheat, maize, rice and potatoes provide carbohydrates at 76%, 72%, 28% and 17%, respectively. Among them, rice emits 0.40% and potatoes emit 0.03% (the least amount) of CO_2. The human body acquires 1% of protein from wheat and maize, but only 0.2% and 0.27% of protein from potatoes and rice, respectively. Among sugar crops, sugarcane contains only 4% carbohydrate, whereas sugar beet contains 1.60% protein, 8% carbohydrate and 9.66% lipid. On the other hand, 0.26% and 0.14% CO_2 emissions are reported for sugarcane and sugar beet, respectively. Sugar beet provides more nutritional and environmental benefits than sugarcane.

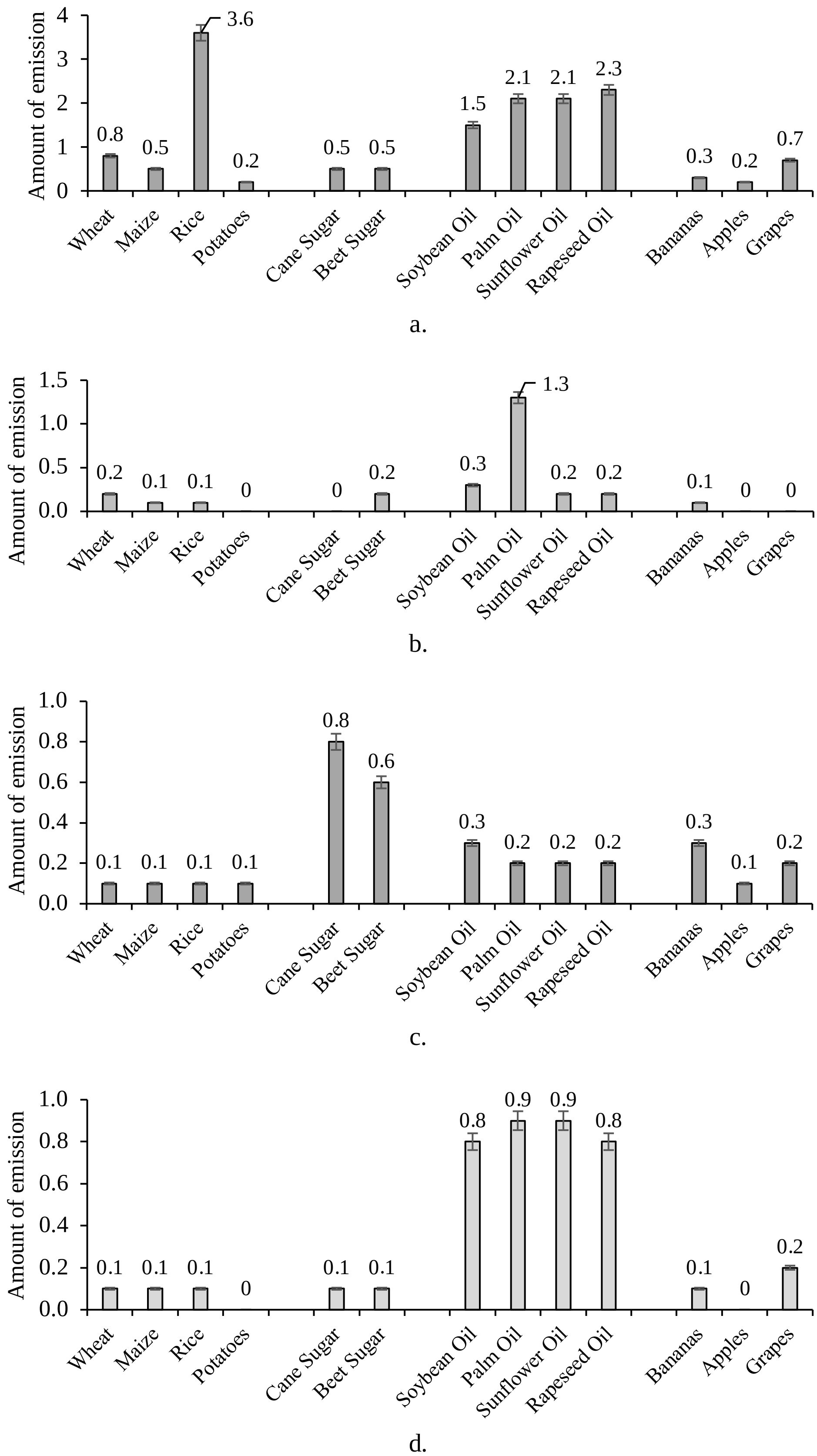

Figure 2. Carbon dioxide emission rate (a) during farming, (b) during processing, (c) during transport, (d) during packaging. Here unit is kg per unit of 1 kg crops (Source: https://www.kaggle.com/)

Oilseed crops are reported to generate the most CO_2 compared to agricultural crops. The most prominent characteristic is that they are entirely composed of lipid or fat, with no carbohydrates or protein. The corresponding CO_2 emissions for soybean, palm, sunflower and rapeseed are 0.60%, 0.76%, 0.35% and 0.37%. Fruits contain an adequate amount of carbohydrates. In particular, apples, berries and grapes provide 0.23%, 0.14% and 0.14% of carbohydrates, respectively. In comparison to other crops, fruits contain significantly lower protein and lipid content. Bananas, apples, berries and grapes contain 1.1%, 0.3% and 0.7% of protein, respectively. Considering lipid content, 0.3%, 0.2% and 0.3% of lipid are available for bananas, apples, berries and grapes. Among them, bananas, apples and grapes generate 0.08%, 0.03% and 0.11% of CO_2 in their lifetime. Out of all of these crops, apples and potatoes emit the least quantity of CO_2. On the other hand, palm oil is reported to generate the highest amount of CO_2 emissions during its lifetime (Figure 3).

The greenhouse gas emissions from the agricultural sector are 8.5% of total emissions, of which CO_2 emissions are mainly observed from various agricultural crops (Yamanoshita, 2019). Technology, distribution and population effects in the modern world were typically unable to reduce agricultural CO_2 emissions (Chen et al., 2018). Our study deals with nutrition requirements in the human body from certain crop species along with the emission of CO_2 in the environment. CO_2 emission in various stages of processing and obtained nutrient content analysis are from factual datasets which are representative of resolving nutrient content in the human body. Low yield producing crops emit comparatively more CO_2 on the basis of production per kg parameter than high yielding crops. Thus, evading the cultivation of low-yielding crops will be economically beneficial as well. Some determinant variables have a significant impact on CO_2 gas emissions from on farm activities and processing. As all crops are grown under the same condition and treatment, the difference is identified predominantly during the fertilizer treatment and field management during genesis, which results in the emission of CO_2 (Riya et al., 2014; Naskar et al., 2015; Yan et al., 2015).

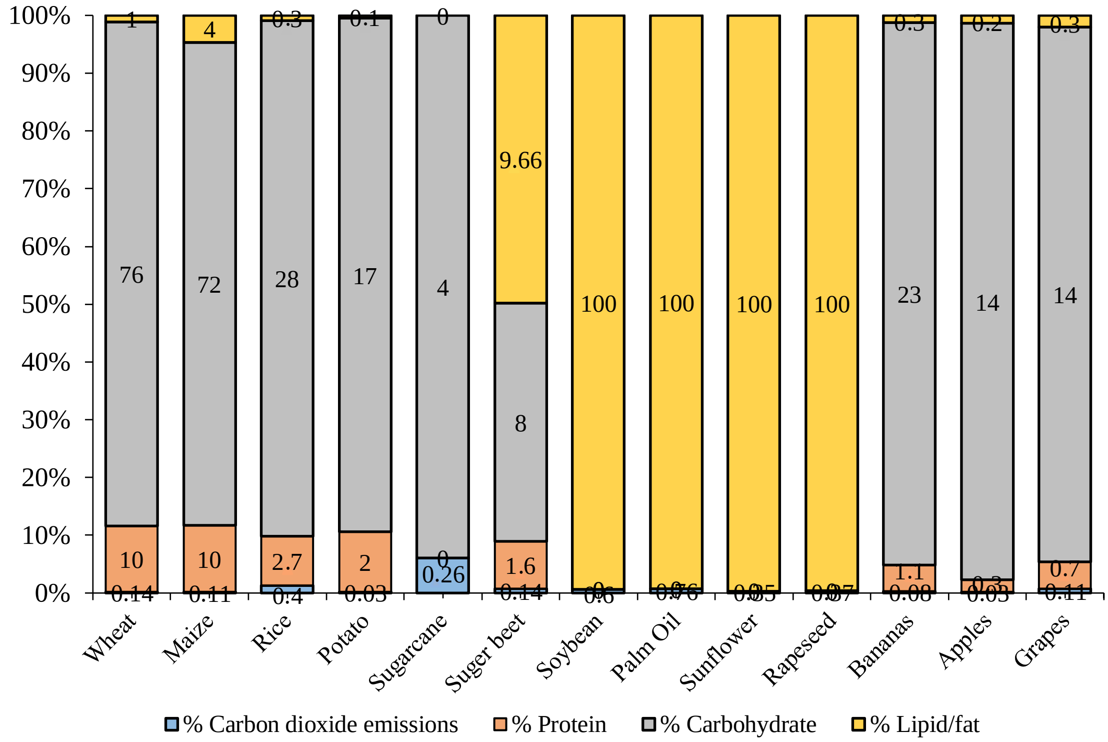

Figure 3. Comparison between CO_2 emissions and available nutrition of carbohydrates, sugar, oil crops and fruits (Source: https://www.kaggle.com/). Conventional cultivation method and six planting seasons were taken

Table 1. Correlations between CO_2 emissions and available nutrition

			CO_2 emissions	Protein	Carbohydrate	Lipid
Spearman's Rho	CO_2 emissions	Correlation coefficient	1.000	-.480*	-.560*	.658*
		Sig. (2-tailed)	.	.097	.046	.014
		N	13	13	13	13
	Protein	Correlation coefficient	-.480	1.000	.937*	-.343
		Sig. (2-tailed)	.097	.	.000	.251
		N	13	13	13	13
	Carbohydrate	Correlation coefficient	-.560*	.937*	1.000	-.529
		Sig. (2-tailed)	.046	.000	.	.063
		N	13	13	13	13
	Lipid	Correlation coefficient	.658*	-.343	-.529	1.000
		Sig. (2-tailed)	.014	.251	.063	.
		N	13	13	13	13

Note: *Correlation is significant at the 0.05 level

Evaluation and selection of suitable crops and fruits

Environment sustainable crop cultivation patterns and post-processing criteria could be developed from the output of the result. Amid different stages of emission, fruit production in vegetative stage, processing, packaging and entire CO_2 ejection are more sustainable for the atmosphere and carbohydrate crops also produce less CO_2 in the processing of crops. Counting the nutritional content of the carbohydrate (wheat and maize) as well as fruits put into the superfluous amounts for the human body. Table 1 shows that CO_2 emission has a strong negative correlation with protein and carbohydrate availability in crops (Ulfat et al., 2021). On the other hand, lipids and CO_2 have a very strong and positive correlation (Arumugham et al., 2021). In many studies, it was shown that a higher concentration of CO_2 reduces the in-grain protein, carbohydrates and nutrients (Smith, 2015). As a result, it may be extrapolated that crops that emit more CO_2 have fewer carbohydrates and proteins.

Utilizing renewable energy sources can replace fossil fuels, lowering both on- and off-farm greenhouse gas emissions. The following renewable energy sources are appropriate for use on farms: geothermal, solar energy systems, anaerobic digestion, wind turbines, soil conservation, solar panels, carbon sequestration and reducing greenhouse gas emissions (Meier et al., 2020). Ecosystems supporting agriculture store a significant amount of carbon, which reduces the emission of CO_2. The following agricultural methods aid in carbon sequestration: improve nitrogen management through nutrient management planning, reduce tillage, lessen bare fallow, return crop wastes to the soil, increased cover cropping, put in place agroforestry systems, rotational grazing, energy conservation and fuel switching are all good examples.

Among carbohydrate crops, the authors suggest cultivating more wheat and maize because they have more carbohydrates and emit moderate CO_2. Potatoes emit less CO_2 but give fewer carbohydrates than wheat and maize. This paper concludes that sugar beet is more suitable for cultivation than sugarcane because sugar beet has more nutritional value and emits less CO_2 than sugarcane among sugar crops. Sunflower and rapeseed oils emit less CO_2 than other oil crops, so the recommendation for cultivating them in greater quantities, given the fact that all oil crops have the same nutritional value. The authors came to a decision through the study that it will be needed to cultivate more bananas because of their higher protein and carbohydrate content and moderate emission of CO_2 than the other selected fruits. Apples are also suitable for cultivation because they emit less CO_2 than bananas and grapes but give a lower amount of carbohydrates and proteins. Dietary habit change can also contribute to the reduction of CO_2 emissions along with health development (Smith, 2015; Aleksandrowicz et al., 2016).

CONCLUSIONS

CO_2 emission has a strong negative correlation with proteins and carbohydrates availability in crops and fruits. People will be able to understand the nutritional content of the food they consume as well as the environmental impact. People must choose the authors selected environmentally friendly crops and fruits for less emission of CO_2. The authors recommendation is to cultivate wheat, maize, potato, sugar beet, sunflower and rapeseed among crops and bananas among fruits. Farmers will realize which crops they should produce more and which cultivation process is important more when other factors (land suitability, nutrient availability) remain unchanged.

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Appendix 1. Data analyzing table with the most significant dataset

Food product	Stage of CO_2 emission (kg kg^{-1} of crops)					Total emissions	Protein	Carbohydrate	Lipid/fat
	Farm	Processing	Transport	Packaging	Others	(kg kg^{-1} of crops)	(%)	(%)	(%)
Wheat	0.8	0.2	0.1	0.1	0.2	1.4	10.0	76	1.0
Maize	0.5	0.1	0.1	0.1	0.3	1.1	10.0	72	4.0
Rice	3.6	0.1	0.1	0.1	0.1	4.0	2.7	28	0.3
Potatoes	0.2	0.0	0.1	0.0	0.0	0.3	2.0	17	0.1
Cane sugar	0.5	0.0	0.8	0.1	1.2	2.6	0.0	4	0.0
Beet sugar	0.5	0.2	0.6	0.1	0.0	1.4	1.6	8	9.7
Soybean oil	1.5	0.3	0.3	0.8	3.1	6.0	0.0	0	100.0
Palm oil	2.1	1.3	0.2	0.9	3.1	7.6	0.0	0	100.0
Sunflower oil	2.1	0.2	0.2	0.9	0.1	3.5	0.0	0	100.0
Rapeseed oil	2.3	0.2	0.2	0.8	0.2	3.7	0.0	0	100.0
Bananas	0.3	0.1	0.3	0.1	0.0	0.8	1.1	23	0.3
Apples	0.2	0.0	0.1	0.0	0.0	0.3	0.3	14	0.2
Grapes	0.7	0.0	0.2	0.2	0.0	1.1	0.7	14	0.3